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Different response of two Hemiptera species groups to sown wildflower strips: True bugs and leafhoppers

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ABSTRACT

Sown wildflower strips should promote the species diversity of several insect groups in order to be an effective tool for the compensation of biodiversity loss in agricultural environments. We studied the responses of two herbivorous insect groups, Heteroptera (true bugs) and Auchenorrhyncha (leafhoppers), to the properties of wildflower strips in a three-year (2008–2010) study in southern Finland. The experiment was replicated in six reed canary grass fields. The insect groups showed opposite responses; the abundance of Auchenorrhyncha was lower while the abundance and species richness of Heteroptera was higher in wildflower than control strips. During succession, both species richness and abundance of Auchenorrhyncha increased unlike Heteroptera. This difference could largely be explained by dietary differences. Auchenorrhyncha, including several grass feeders, could not take advantage of the increasing dicot species richness like Heteroptera species. This was also a likely reason for the unexpected finding that only Heteroptera species richness depended on the placement of the strip, being higher near field margins than in mid-field. We conclude that the optimal planning and implementation of wildflower strips call for the definition of clear goals, the knowledge of the requirements of target species as well as considering the cropping system involved.

1. Introduction

Intensification of agricultural production has led into a decline in the area of semi-natural grasslands and other non-crop habitats which are regarded as key habitats for supporting agro-biodiversity (Stoate et al., 2009). In Europe, the loss of these habitats is compensated by introducing short-term habitats into agricultural environments. Sown wildflower strips appear to be one of the most promising tools for such compensation (e.g., Haaland et al., 2011). More information on the benefits of wildflower strips for the species diversity is needed, especially of herbivorous insects playing a vital role in the food webs of agricultural environments (van Veen et al., 2006).

Wildflower strips are aimed at enhancing the species diversity of insects by providing habitat and increasing food resources at the field scale (Haaland et al., 2011). The ability of wildflower strips to enhance the species diversity of herbivorous insects depends on the seed mixture used in the establishment (Jacot et al., 2007; Marshall, 2007; Pywell et al., 2007; Woodcock et al., 2005). For many grass-feeding insects, such as leafhoppers, the benefits of increased richness of broad-leaved plant species in wildflower strips may be limited (Huusela-Veistola and Vasarainen, 2000). Vegetation structure has also an important role for some species groups, such as leafhoppers (Frank and Künzle, 2006; Zurbrükk and Frank, 2006) and bugs (Kruess and Tscharntke, 2002; Kőrösi et al., 2012). For them, the vegetation succession of wildflower and grass strips plays an important role since species richness has been shown to increase in the course of time (Huusela-Veistola and Vasarainen, 2000; Luka et al., 2006).

Wildflower strips are often planned to promote primarily one target such as pollination or conserving the biological control of agricultural pests (Haaland et al., 2011). The requirements for the optimum management of single targets are well established, e.g., sowing nectar plants for pollinators (Korpela et al., 2013), while the multi-target benefits for biodiversity are less studied (Haaland et al., 2011). In order to benefit agro-biodiversity in general, wildflower strips should support a wide array of insects. Hemiptera is among three major phytophagous insect orders with

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Lepidoptera and Coleoptera (Chapman, 2009) but the less mobile herbivores belonging to this or comparable orders may gain limited benefits of wildflower strips planned to support pollination. Even though colonisation is a key issue in the success of wildflower strips for biodiversity, the importance of the placement of the strips has rarely been studied experimentally (Korpela et al., 2013). Wildflower strips are usually placed near field margins in order to ease management (Pfiffner and Wyss, 2004; Kinross et al., 2004) but sometimes they are placed mid-field for ecological compensation areas (Boller et al., 2004).

In the present study, we aimed at exploring the benefits of wildflower strips sown with seed mixtures originally planned for pollinators (see Korpela et al., 2013) for the species diversity of two herbivorous insect groups, true bugs (Heteroptera) and leafhoppers (Auchenorrhyncha). Both of these groups are common, abundant and species rich in farmland habitats. Auchenorrhyncha is known to be sensitive to habitat change (Biedermann et al., 2005) and Heteroptera to correlate positively with total arthropod species richness (Duelli and Obrist, 1998). The insect groups belong to the same order but differ in terms of species richness and diet breadth. Auchenorrhyncha group is composed solely of herbivores, the majority of them being monocot feeders in the field layer (Söderman, 2007), whereas the more species rich Heteroptera group includes both herbivores with a wider selection of host plants and predators (Rintala and Rinne, 2010).

In addition to the effects of seed mixture, we studied experimentally the effect of the placement of the strips. The placement can be assumed to affect the colonization and species turnover of the wildflower strips. We hypothesized the species richness of both groups to benefit on wildflower strips but the response in species richness to be stronger and the change in species assemblage over years to be greater in Heteroptera than in Auchenorrhyncha due to differences in their biology (Söderman, 2007; Rintala and Rinne, 2010). Further, we hypothesized that the wildflower strips placed near field margins will be colonised more effectively than those in the mid-field resulting in higher species richness and differing species assemblage (Holland et al., 2012; Korpela et al., 2013). The experiment was carried out in reed canary grass bioenergy fields representing a species poor cropping system (Vepsäläinen, 2010).

2. Methods

2.1. Experimental design

A field experiment was established in Jokioinen, south-western Finland (60°85′N; 23°46′E) in May 2007. The experiment consisted of six reed canary grass (*Phalaris arundinacea* L.) field blocks separated by forest (minimum distance between field blocks was 380 m). Reed canary grass was sown on two field blocks (V and VI) in 2006 and on others in 2007. In each field block, replicates of six wildflower strip (T1–T6) and three reed canary grass control treatments (C1, C3 and C5) were established (Fig. 1). The minimum distance between the treatments within a field block was 25 m. Five of the wildflower strips (T1–T5) were sown using a seed mixture of *Centaurea jacea* L. (10 seeds m^{-2}), *C. phrygia* L. (5 seeds m^{-2}), *Leucanthemum vulgare* Lam. (10 seeds m^{-2}), *Trifolium repens* L. (0.5 kg seeds ha^{-1}) and *Agrostis capillaris* L. (1 kg seeds ha^{-1}), and one (T6) with *C. jacea* (50 seeds m^{-2}). Wildflower strips were sown on 29th and 30th May, 2007.

The wildflower strips differed from each other in terms of shape and placement within a field block (Fig. 1). As regards to shape, one (T4) was 10 m × 25 m whereas the other wildflower strips were 5 m × 50 m in dimension. As regards to placement, one wildflower strip (T2) was directed toward the center of the field from the field margin, whereas the other strips were placed at the edge of the field either parallel to field margin between agricultural fields (T1 and T4) or next to forest (T5), or in the middle of the field block (T3 and T6). Control treatments (C1, C3 and C5) were delimited reed canary grass areas (5 m × 50 m) placed in a similar way than wildflower strips T1, T3 and T5. C1 was lacking in study field parcels III and IV, as there were no suitable field edges where transects could have been placed. The experimental fields were fertilized and their vegetation was cut for bioenergy each year in April or May. Herbicides or insecticides were not used.

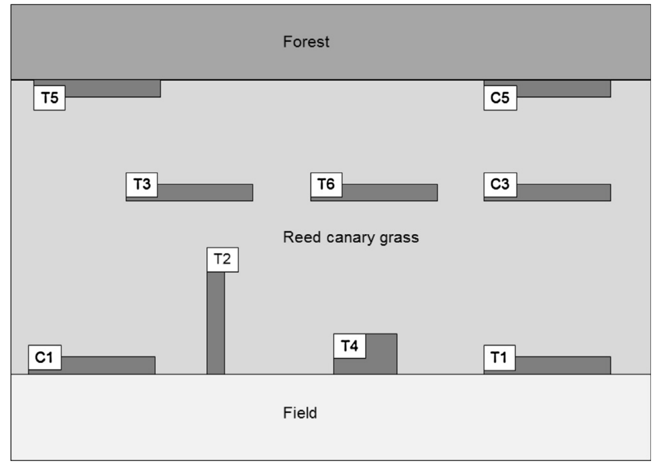

Fig. 1. A schematic illustration of the study design (not to scale) within the study field parcels ($n = 6$). T1–T6 represent the wildflower strip treatments sown with meadow plants and C1–C5 reed canary grass controls. The dimensions of each strip were 5 m × 50 m except T4 which was 10 m × 25 m. The minimum distance between the strips within a parcel was 25 m.

2.2. Sampling

The sampling of Hemiptera was conducted in each experimental plot three times during the growing season between late May and August in 2008–2010. The samples were collected with sweep net (diameter 30 cm), each sample consisting of 60 sweeps. The insects were dried and identified to species. Nomenclature of Auchenorrhyncha follows that of Söderman (2007) and Heteroptera Rintala and Rinne (2010). Some Heteroptera juveniles could not be identified to species and therefore all juveniles were excluded from the data. In addition, altogether 6Heteroptera samples (5 samples in 2008 and 1 sample in 2010) and 14 Auchenorrhyncha samples (5, 7 and 2 samples in 2008, 2009 and 2010, respectively) were excluded due to contamination by fungus or were lost during the study. Plant species were identified and coverage was estimated by species using a scale of 9 classes (1:<0.125%, 2:0.125–0.5%, 3:0.6–2%, 4:2.1–4%, 5:4.1–8%, 6:8.1–16%, 7:16.1–32%, 8:32.1–64% and 9:>64%) in each experimental plot in August each year.

2.3. Data analyses

Two sets of data analyses were conducted. Firstly, the impact of wildflower strip treatment was studied by comparing wildflower strips (T1, T3 and T5) with equally placed reed canary grass control treatments (C1, C3 and C5). Secondly, wildflower strips (T1–T6) were compared among each other. In both sets of analyses, species diversity and species composition were analyzed. Since the data in the two set of analyses were partly overlapping, the results of the latter analyses are reported in detail in appendices.

Species diversity was analyzed by comparing differences in the abundance, species richness and Shannon diversity index values of Heteroptera and Auchenorrhyncha as well as cover and species richness of plants (grasses and dicots separated) among treatments and their placement in the field using a linear mixed model for randomized complete block design with random field block effect. Assumptions of models were checked and data were square root or log-transformed prior to analysis if necessary to satisfy the conditions of normality and homogeneity of variances. Means by treatment and year were used in analyses except for species richness when total species richness by treatment was used. Pearson correlation was used to study the relationship between the species diversity of the insect groups with vegetation variables.

Species composition was analyzed by exploring the variation in the species composition of Auchenorrhyncha and Heteroptera communities in relation to the seed mixture, study year (YEAR) and vegetation variables with the aid of partial redundancy analysis (pRDA). Vegetation variables used in the analyses were the cover of grass species (COV_GRASS), the cover of dicot species (COV_DICOT), species number of grass species (SP_GRASS) and species number of dicot species (SP_DICOT). In the comparison of wildflower strip treatments with control, two classes for the seed mixture variable (CANARY GRASS and WILDF) along with three classes for the placement of the strips variable (MID_FIELD, FIELD_EDGE and FOREST_EDGE) were included. In the analyses of differences among wildflower strips, six wildflower strips (T1–T6), vegetation variables (COV_GRASS, COV_DICOT, SP_GRASS, SP_DICOT) and study year (YEAR) were included in the analyses. For the data analyses, the plant cover classes were transformed into the mean coverage values for each class (1 = 0.0625%, 2 = 0.3125%, 3 = 1.25%, 4 = 3%, 5 = 6%, 6 = 12%, 7 = 24%, 8 = 48% and 9 = 82%) and pooled across species.

Prior to pRDA analyses, detrended correspondence analysis (DCA) was applied to measure the length of the gradients for the first two axes. The analysis showed the lengths of gradients to be below 3.5 SD units for all data sets indicating the use of linear ordination analysis to be appropriate (Jongman et al., 1995). The default options of RDA (except log transformation of the species data) and field block as a covariable (thus partial RDA (pRDA)) were used in all analyses. The significance of the first pRDA axis and the overall significance of the pRDA models were evaluated with Monte Carlo permutation tests (500 permutations) in all analyses. Variation partitioning was conducted to estimate the share (%) of variation that each variable explained (Borcard et al., 1992). Only the variation explained by statistically significant environmental variables was partitioned (Økland, 1999). The analyses were conducted with the CANOCO for Windows 4.02 statistical package (Ter Braak and Smilauer, 1998).

3. Results

3.1. Species diversity

In total, 9091 individuals and 84 species of Heteroptera and 8606 individuals and 58 species of Auchenorrhyncha were caught. For both species groups, higher species richness was found in wild flower strips (in total 64 Heteroptera species and 48 Auchenorrhyncha species) compared with equally placed control strips (57 and 37, respectively). Both the abundance and the species richness of Auchenorrhyncha increased significantly over the years of the experiment (Table 1, Fig. 2, Appendix A). The same was not observed in Heteroptera.

Wildflower strip treatment was found to have an opposite effect on the abundance of Heteroptera and Auchenorrhyncha. In Heteroptera, species richness and abundance were significantly higher in wildflower strips than in control strips (Table 1, Fig. 2). In species richness, a statistically significant interaction between treatment and year was detected; species richness dropped markedly from the first to the second year in wildflower but not in control strips, lessening the difference between treatments and controls (Fig. 2). On the contrary, the abundance of Auchenorrhyncha was significantly lower in wildflower strips than in control strips. Differences in the species richness of Auchenorrhyncha were statistically insignificant but species diversity (H') was significantly higher in wildflower strips than in control strips (Table 1, Fig. 2, Appendix B).

The differences in species richness among wildflower strips remained minor in both insect groups (Appendix A). The only apparent difference (at significance level $P < 0.06$) was a lower species richness of both insect groups in monoculture strips of *C. jacea* (T6) than the other wild flower strips (except T4 in both groups and T3 in Heteroptera). In addition, significant interactions between treatment and year in abundance of Auchennorrhycha and diversity (H') of Heteroptera were detected (Fig. 2, Appendix B).

Placement of wildflower strips in mid-field resulted in lower Heteroptera abundance and species richness than placement in the field margin or next to a forest (Table 1). The same was also true for the species richness of dicots and grasses. On the contrary, the abundance and species richness of Auchenorrhyncha, and species diversity (H') of the insect groups were not affected by the placement ($P > 0.05$).

Wildflower strip treatment had a positive impact on the species richness of dicots and grasses (Table 1), which both correlated

Table 1
ANOVA for the species richness, abundance and diversity of Heteroptera, Auchenorrhyncha and plants comparing placement (at open field parcel edge, in the middle of field parcel, next to a forest) and sowing treatments (seed mixture: meadow plants ('wildflowers') vs. reed canary grass). Statistically significant *F*-values bolded.

	Placement		Treatment		$P \times T$		Year		$P \times Y$		$T \times Y$		$P \times T \times Y$	
	df	F	df	F	df	F	df	F	df	F	df	F	df	F
Species richness														
Heteroptera	2, 23	**3.62***	1, 23	**20.32*****	2, 23	0.23	2, 10	1.62	4, 42	0.57	2, 42	**4.56***	4, 42	0.70
Auchenorrhyncha	2, 22	0.29	1, 22	1.25	2, 22	0.49	2, 10	**11.90****	4, 36	0.31	2, 36	0.56	4, 36	0.28
Dicots	2, 23	**15.07*****	1, 23	**31.82*****	2, 23	1.70	2, 10	**6.28***	4, 42	1.14	2, 42	1.77	4, 42	2.05
Grass	2, 23	**8.86***	1, 23	**88.86*****	2, 23	**3.00**$^{\circ}$	2, 10	0.36	4, 42	0.77	2, 42	2.17	4, 42	0.19
Abundance														
Heteroptera	2, 23	**4.88***	1, 23	**39.97*****	2, 23	1.66	2, 10	2.66	4, 42	0.09	2, 42	1.32	4, 42	0.05
Auchenorrhyncha	2, 22	0.04	1, 22	**8.35****	2, 22	1.49	2, 10	**15.74*****	4, 36	0.64	2, 36	0.48	4, 36	0.29
Dicots (cover)	2, 23	**4.53***	1, 23	**20.26*****	2, 23	1.68	2, 10	**3.05**$^{\circ}$	4, 42	**3.80****	2, 42	**3.61***	4, 42	0.39
Grass (cover)	2, 23	1.07	1, 23	**4.54***	2, 23	0.91	2, 10	1.24	4, 42	1.45	2, 42	**2.57**$^{\circ}$	4, 42	1.05
Diversity														
Heteroptera	2, 23	1.85	1, 23	0.10	2, 23	0.11	2, 10	0.48	4, 42	0.51	2, 42	0.53	4, 42	1.02
Auchenorrhyncha	2, 22	0.03	1, 22	**4.64***	2, 22	0.13	2, 10	1.77	4, 36	1.07	2, 36	0.17	4, 36	0.58

$^{\circ}P < 0.10$. $^{*}P < 0.05$. $^{**}P < 0.01$. $^{***}P < 0.001$.

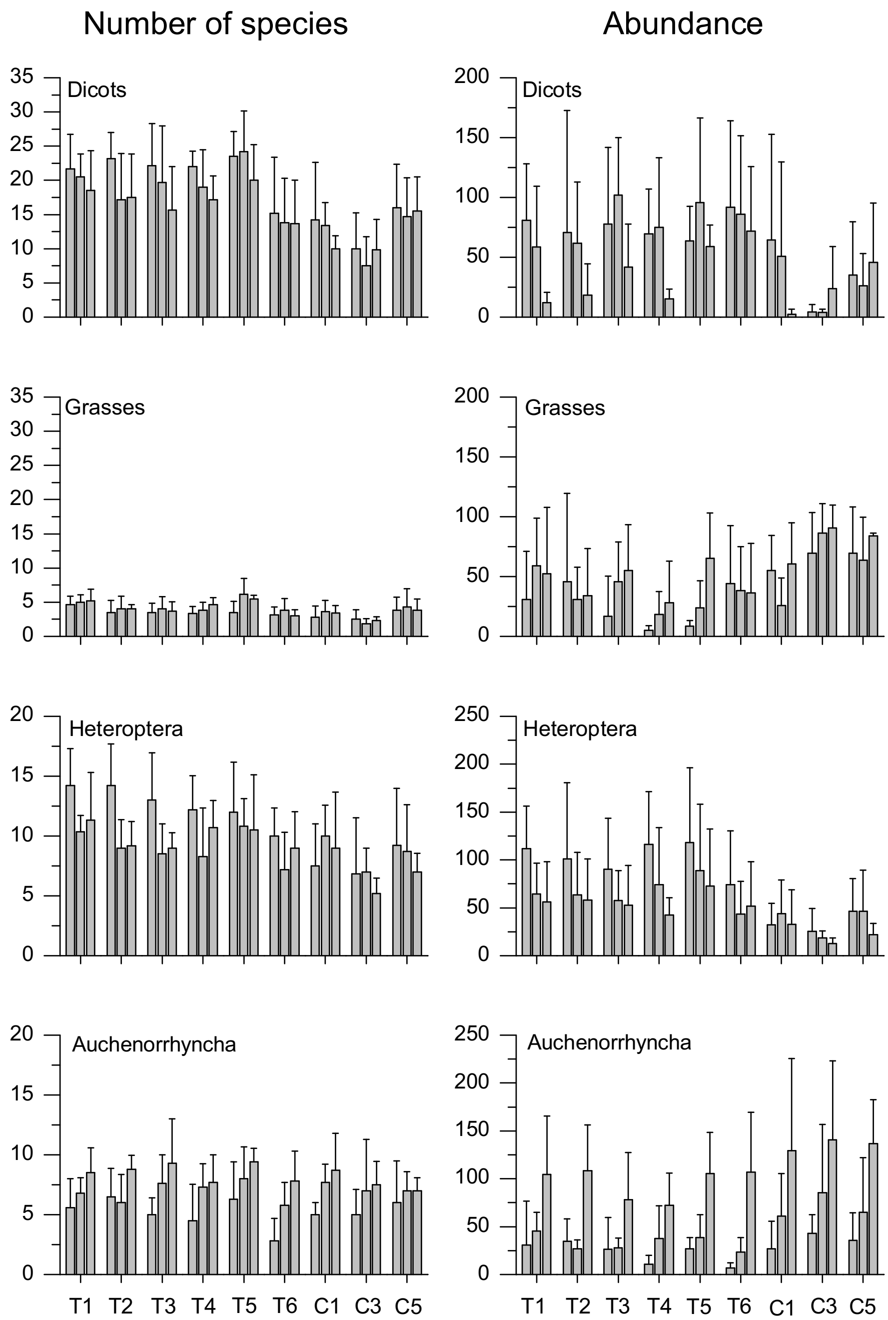

Fig. 2. The number of species (left panel) and abundance (the cover of plants and number of individuals of insects) (right panel) of dicots, grasses, Heteroptera and Auchenorrhyncha in in wildflower and control strips. Columns present the averages (+SD) over field blocks. Three parallel columns represent the years 2008, 2009 and 2010, respectively. For a description of the treatments, see Fig. 1.

positively with the abundance and species richness of Heteroptera (Appendix C). On the contrary, the abundance of Auchenorrhyncha correlated negatively with the species richness of dicots (Appendix C). Heteroptera species richness also correlated negatively with the cover of grasses.

3.2. Species composition

The study year appeared to be the most important factor explaining the variation in the species composition of both insect groups, being more important for Auchenorrhyncha than for Heteroptera (Fig. 3; Table 2; Appendices D and E). The importance of the study year for Auchenorrhyncha can mostly be explained by the increase in the percentage and abundance of the most numerous species, *Balclutha rhenana* W. Wagner, 1939, during the experiment (Fig. 3A). Other Auchenorrhyncha species whose abundances clearly increased during the experiment were a specialist of reed canary grass, *Erzaleus metrius* (Flor, 1861) and a pest species of cereals *Javesella pellucida* (Fabricius, 1794) (Fig. 3A). Among Heteroptera species, percentage and abundance of the most dominant species *Plagiognathus chrysantemi* (Wolf, 1804) decreased from year to year, likewise did the abundances of two polyphagous species, *Lygus rugulipennis* Poppius, 1911 and *L. pratensis* Linnaeus, 1758, and a grass-feeding species, *Trigonotylus*

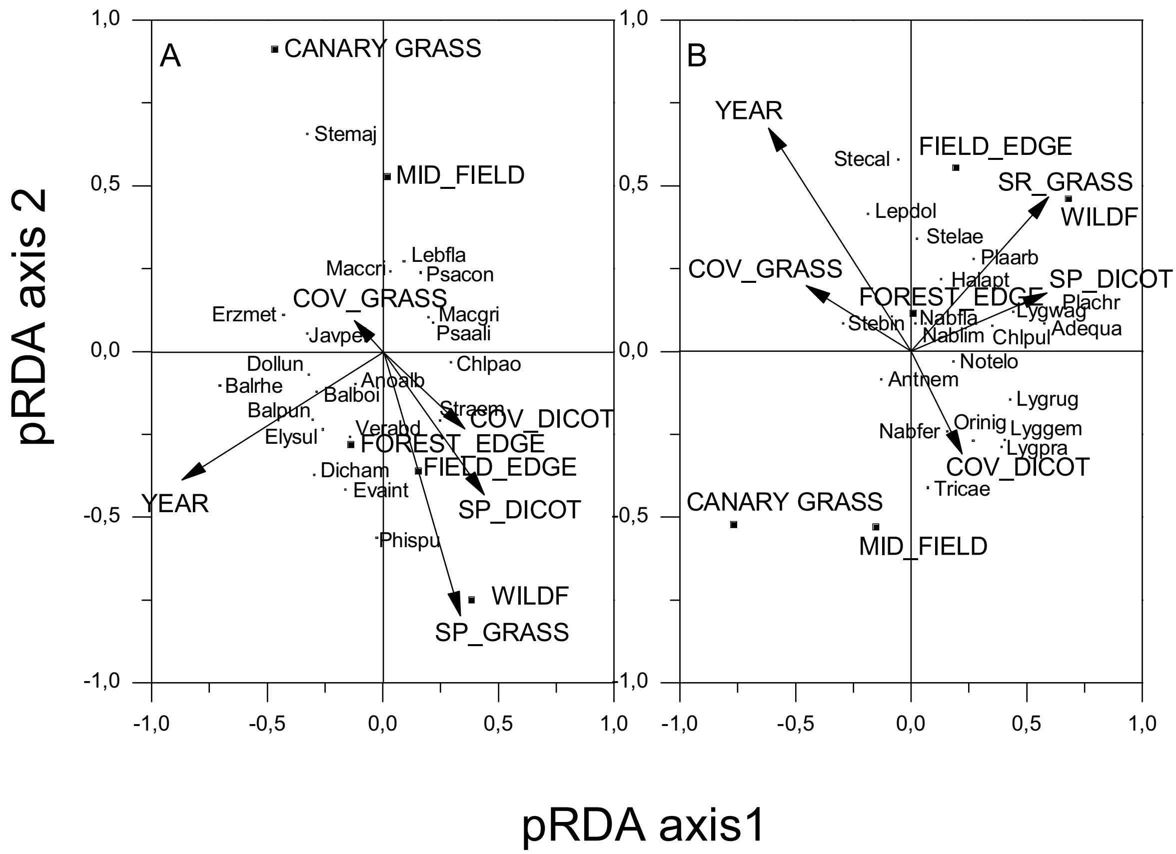

Fig. 3. Partial redundancy analysis (pRDA) of Auchenorrhyncha (A) and Heteroptera (B) species and environment variables for the comparisons of treatment vs. control. Field block was treated as a co-variable in the analyses. The 20 most abundant species of each data set are shown. The abbreviations of environmental variables and species are as follows: environment variables: COV_GRASS = cover of grass species, COV_DICOT = cover of dicot species, SP_GRASS = species number of grass species, SP_DICOT = species number of dicot species, YEAR = year of the study, Seed mixture: CANARY GRASS = reed canary grass control, WILDF = wildflower strip treatment, Placement: MID_FIELD = in the middle of field parcel, FIELD_EDGE = at open field parcel edge, FOREST_EDGE = next to forest.
Auchenorrhyncha species: Anoalb = *Anoscopus albifrons*, Balboi = *Balclutha boica*, Balpun = *Balclutha punctata*, Balrhe = *Balclutha rhenana*, Chlpao = *Chlorita paolii*, Dicham = *Dicranotropis hamata*, Dollun = *Doliotettix lunulatus*, Elysul = *Elymana sulphurella*, Erzmet = *Erzaleus metrius*, Evaint = *Evacanthus interruptus*, Javpel = *Javesella pellucida*, Lebfla = *Lebradea flavovirens*, Maccri = *Macrosteles cristatus*, Macgri = *Macustus grisescens*, Phispu = *Philaenus spumarius*, Psaali = *Psammotettix alienus*, Psacon = *Psammotettix confinis*, Stemaj = *Stenocranus major*, Straem = *Streptanus aemulans*, Verabd = *Verdanus abdominalis*;
Heteroptera species: Adequa = *Adelphocoris quadripunctatus*, Antnem = *Anthocoris nemorum*, Chlpul = *Chlamydatus pulicarius*, Halapt = *Halticus apterus*, Lepdol = *Leptopterna dolabrata*, Lyggem = *Lygus gemellatus*, Lygpra = *Lygus pratensis*, Lygrug = *Lygus rugulipennis*, Lygwag = *Lygus wagneri*, Nabfer = *Nabis ferus*, Nabfla = *Nabis flavomarginatus*, Nablim = *Nabis limbatus*, Notelo = *Notostira elongata*, Orinig = *Orius niger*, Plaarb = *Plagiognathus arbustorum*, Plachr = *Plagiognathus chrysanthemi*, Stebin = *Stenotus binotatus*, Stecal = *Stenodema calcaratum*, Stelae = *Stenodema laevigatum*, Tricae = *Trigonotylus caelestialium*. See Table 2 and Appendix F for the further information on the importance of the axes.

Table 2
Proportion (%) of the variation of the species composition explained by all factors and each factor alone for Auchenorrhyncha and Heteroptera in the partial redundancy analysis (pRDA) in the comparisons of treatment vs. control.

	Auchenorrhyncha	Heteroptera
All factors[a]		
Species data		
1st axis	25.5	16.4
All axes	40.7	27.9
Species-environment relation		
1st axis	61.2	54.3
All axes	97.7	92.1
Individual factors[b]		
Dicot species richness	0.8 ns	3.1 ns
Grass species richness	1.7 ns	1.9 ns
Cover of dicots	1.1 ns	7.6**
Cover of grasses	5.1**	5.7*
Seed mixture	7.1**	8.8**
Placement	4.8 ns	8.8*
Year	41.1**	21.8**

[a] First axis and all axes significant at $P < 0.01$ in all models.
[b] ns = non-significant. $^{*}P < 0.05$. $^{**}P < 0.01$.

caelistialium (Kirkaldy, 1902), along with the cover of dicots (Fig. 2B). On the other hand, abundances of *Stenodema calcaratum* Fallen, 1807 and *Leptopterna dolabrata* (Linnaeus, 1758) increased during the experiment.

Placement of the wildflower strips and the cover of dicots were found to affect the species composition of Heteroptera but not Auchenorrhyncha (Table 2; see also Appendix D). The most numerous Heteroptera species, *P. chrysantemi*, was more abundant in wildflower (59.0% of the total catch) than in control (27.6%) strips (Fig. 3B). This was not the case for the most abundant Auchenorrhyncha species, *B. rhenana* (64.5% vs. 69%, respectively). In Auchenorrhyncha, only numbers of polyphagous *Philaenus spumarius* (Linnaeus, 1758) and grass-feeding *Balclutha boica* W. Wagneri, 1950 and *Streptanus aemulans* (Kirscbaum, 1868) were higher in wildflower strips than in controls (Fig. 3A). Among Heteroptera species, *S. calcaratum* and *L. dolabrata* were more abundant at the field margin or next to a forest than in mid-field. *P. chrysantemi* and *P. arbustorum* were the most numerous in strips located next to a forest. However, predatory species *Nabis ferus* (Linnaeus, 1758), *N. flavomarginatus* Scholtz, 1847, *N. limbatus*

Dahlbom, 1851 and *Orius niger* Wolff, 1811 which are typical of field margin did not show preference for these habitats in our experiment (Fig. 2B).

4. Discussion

As expected, the species groups responded differently to the wildflower strip treatment. Heteroptera species diversity was higher on the wildflower strips as reported in earlier studies (Frank and Künzle, 2006; Zurbrükk and Frank, 2006) but, surprisingly, the impact on the total abundance of Auchenorrhyncha was negative. This difference can largely be explained by the differing responses of the insect groups to vegetation succession of wildflower strips. Auchenorrhyncha, including several grass feeders, could not take advantage on the increasing dicot species richness like Heteroptera species. This was also a likely reason for the unexpected finding that only Heteroptera species richness was higher near field margins than in mid-field. Despite the lack of a positive response to the wildflower strip treatment both species richness and abundance of Auchenorrhyncha were found to increase during the experiment, unlike Heteroptera. In both species groups, species composition differed between wildflower strips and control treatments.

The major reason for the different response of the species groups to the wildflower strip treatment lies probably in their food plants. Several species of Auchenorrhyncha are grass feeders; the nymph of *B. rhenana*, the dominant species, is monophagous on *P. arundinacea* in Finland (Söderman, 2007). On the contrary, several Heteroptera species are specialized in dicots, e.g., the most numerous species *P. chrysantemi* has several dicot host plants (Rintala and Rinne, 2010). It was also the most dominant Heteropteran in riparian zones studied by Gilbert et al. (2015). Overall, species found in wildflower strips were typical of meadows and grasslands in Finland and strips increased abundances of common species.

Auchenorrhyncha abundance and species richness seem to reflect vegetation structure rather than plant species richness (Brown et al., 1992), increasing during succession as perennial grasses replace annuals. In contrast, abundances of Hemiptera peak in the early stages of succession when annual dicots dominate, leading to a strong but short-term response to wildflower strip establishment. Our results are in accordance with earlier results suggesting that even simple but permanent multilayer grasslands can maintain abundant and diverse assemblages of leafhoppers (Huusela-Veistola and Vasarainen, 2000), while this does not seem to be the case for the diversity of true bugs.

We expected strips at field margins to be colonized more effectively than mid-field strips as the abundance of invertebrates is generally higher in field edges and decreases with distance from the field boundary (Holland et al., 2012). This was the case for Heteroptera but not for Auchenorrhyncha, which often responded more to the structure and density of vegetation (here tall and dense reed canary grass). In Heteroptera, *S. calcaratum* and *L. dolabrata* were more abundant at the field margins or next to forests than in mid-field. Generally, these species feed on grasses and are typical species of forest edges and field margins. Furthermore, *P. chrysantemi* and *P. arbustorum* were the most numerous in strips located next to forests. *Achillea millefolium* L. and *Urtica dioica* L., respectively, are among their common host plants, often growing in field margins.

Several studies have reported the responses of single species groups to wildflower strip treatment (Haaland et al., 2011). Rarely, a multi-target approach has been adopted (Meek et al., 2002). In the current study, we focused on two diverse species groups, furthermore, results on pollinators have been reported previously (Korpela et al., 2013). In general, the results showed that more the species group could take advantage on the sown seed mixture (in our case pollinators and Heteroptera), more positive was the benefits for the species diversity. Placement of the strip within a parcel had only a minor impact. Therefore, the selection of the seed mixture is a key in planning wildflower strips. Often, like in our experiment, the seed mixture was originally planned for pollinators (Korpela et al., 2013). Our results showed that seed mixtures of such kind can also benefit other species groups but less than the species group primarily in focus. The benefits are also dependent on the 'matrix' crop species and its management. In our experiment, *P. arundinacea* was as attractive as wildflower strips for Auchenorrhyncha and especially for *B. rhenana* which could use the crop plant. The positive effects of perennial wildflower strips would probably be greater in annual field crops, where the frequency of disturbance due to cropping measures is higher than in perennial grass. Especially cropping of *P. arundinacea* to bioenergy resembles extensive grassland because pesticides are not used and harvest (cutting) is conducted in the spring before the start of new growing season. Spring cutting reduces abundance and species richness of invertebrates less than summer cutting although effects depend on species phenology (Morris 1979, 1981; Baines et al., 1998). Overall, the optimal planning and implementation of wildflower strips call for the definition of clear goals, the knowledge of the requirements of target species as well as considering the cropping system involved.

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Appendix A. Comparison of wildflower strips (T1–T6)

The differences in species richness among wildflower strips remained minor in both insect groups (Table A1). The main effect of year was significant for abundance, species richness and diversity of Auchennorrhycha, all of which increased during the succession. On the contrary, species richness and cover of dicots decreased year after year. Furthermore, the species richness of Heteroptera was significantly higher in 2008 than in the later years. In 2008, the abundance of Auchennorrhycha was

Table A1
ANOVA for the species richness, abundance and diversity of Heteroptera, Auchenorrhyncha and plants among wildflower strip treatments (T1–T6). Statistically significant *F*-values bolded.

	Treatment		Year		Treatment × year	
	df	*F*	df	*F*	df	*F*
Species richness						
Heteroptera	5, 25	**2.44**$^{\circ}$	2, 10	**9.87****	10, 46	1.11
Auchenorrhyncha	5, 25	**2.38**$^{\circ}$	2, 10	**13.08*****	10, 42	0.83
Dicots	5, 25	**4.63****	2, 10	**9.94****	10, 46	1.46
Grass	5, 25	**6.66*****	2, 10	0.39	10, 46	0.91
Abundance						
Heteroptera	5, 25	1.74	2, 10	2.80	10, 46	0.21
Auchenorrhyncha	5, 25	**2.80***	2, 10	**27.72*****	10, 42	**2.42***
Dicots	5, 25	**3.01***	2, 10	**10.75****	10, 46	0.79
Grass	5, 25	1.49	2, 10	1.16	10, 46	1.06
Diversity						
Heteroptera	5, 25	1.07	2, 10	0.36	10, 46	**2.81***
Auchenorrhyncha	5, 25	0.40	2, 10	**4.28***	10, 40	0.41

$^{\circ}P < 0.10$. $^{*}P < 0.05$. $^{**}P < 0.01$. $^{***}P < 0.001$.

significantly lower in wide and short strips (T4) and monocultures of *Centaurea jacea* (T6) compared with other wildflower strips. In 2009, there was significantly more Auchenorrhyncha in the wildflower strip placed at open field parcel edge (T1) than in the monoculture of *Centaurea jacea* (T6). In 2010, no differences among treatments were detected. In 2009 and 2010, the diversity of Heteroptera was higher in the wildflower strip placed at open field parcel edge (T1) compared with strips placed in the middle of field parcel (T3) or toward the field parcel center (T2) (in 2009 also compared with T4) but in the first year (2008), no significant differences among treatments were detected.

Appendix B.

Fig. B1

Appendix C. Correlations between Heteroptera and Auchenorrhyncha with plant species

Correlations between the species richness and abundance of Heteroptera and Auchenorrhyncha with plant species richness and abundance.

	Species richness		Abundance		n
	Dicots	Grasses	Dicots	Grasses	
Species richness					
Heteroptera	0.377**	0.460**	0.091^{ns}	−0.248*	150
Auchenorrhyncha	−0.193^{ns}	0.101^{ns}	−0.167^{ns}	0.005^{ns}	142
Species diversity					
Heteroptera	0.122^{ns}	0.060^{ns}	0.004^{ns}	−0.045^{ns}	150
Auchenorrhyncha	−0.033^{ns}	0.081^{ns}	0.065^{ns}	−0.072^{ns}	142
Abundance					
Heteroptera	0.246*	0.409**	0.036^{ns}	−0.148^{ns}	150
Auchenorrhyncha	−0.286**	−0.117^{ns}	−0.233°	0.12^{ns}	142

ns = non-significant. °$P < 0.10$. *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$. Bonferroni correction used.

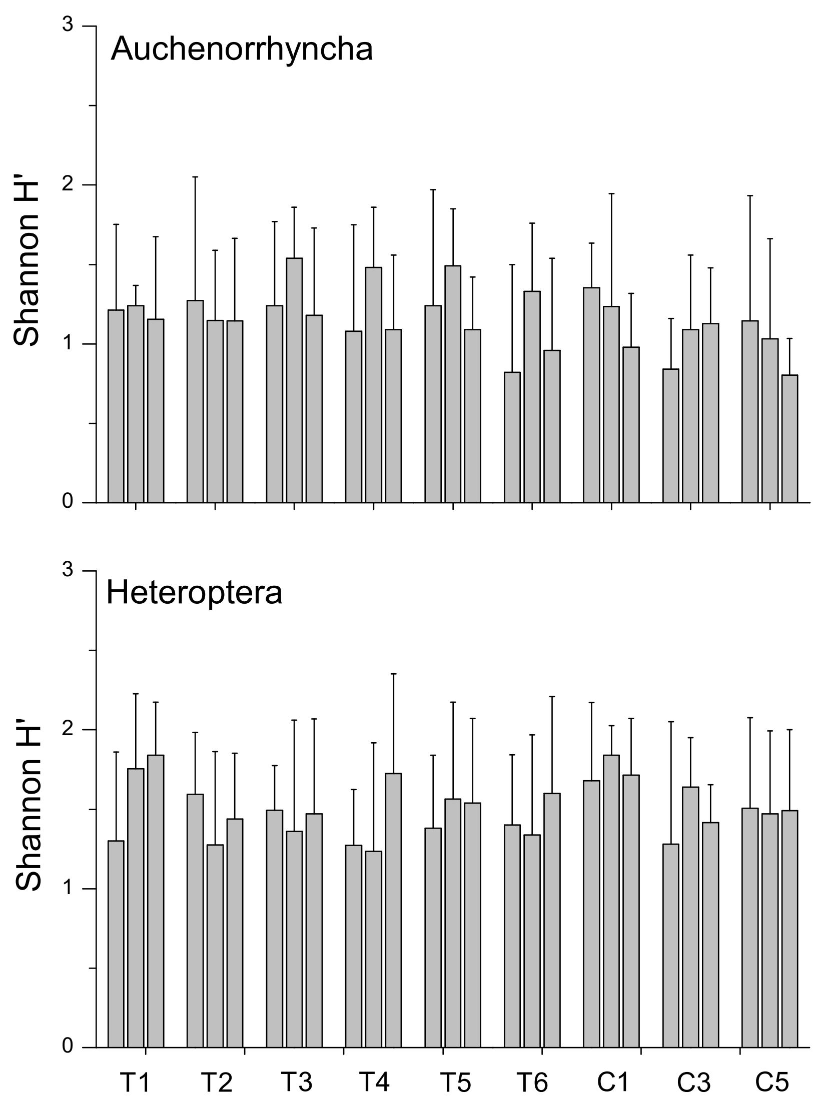

Fig. B1. Shannon diversity values in wildflower and control strips.
Shannon diversity index values (H') for Auchenorrhyncha and Heteroptera in wildflower and control strips. Three parallel bars represent the years 2008, 2009 and 2010, respectively.

Appendix D. Partial redundancy analysis of species composition

Proportion (%) of the variation in the species composition explained by all factors and each factor alone for Auchenorrhyncha and Heteroptera in the partial redundancy analysis (pRDA) in the comparisons among wildflower strips (T1–T6).

	Auchenorrhyncha	Heteroptera
All factors[a]		
Species data		
1st axis	28.5	14.3
All axes	33.3	22.4
Species-environment relation		
1st axis	81.5	56.2
All axes	95.3	88.0
Individual factors[b]		
Dicot species richness	1.8[ns]	3.9[ns]
Grass species richness	2.5[ns]	2.9[ns]
Cover of dicots	1.1[ns]	8.7[**]
Cover of grasses	3.2[ns]	4.8[ns]
Wildflower strip	14.0[ns]	23.7[*]
Year	49.3[**]	30.9[**]

[a]First axis and all axes significant at $P < 0.01$ in all models.
[b]ns = non-significant. *$P < 0.05$. **$P < 0.01$.

Appendix E.

See Fig. E1

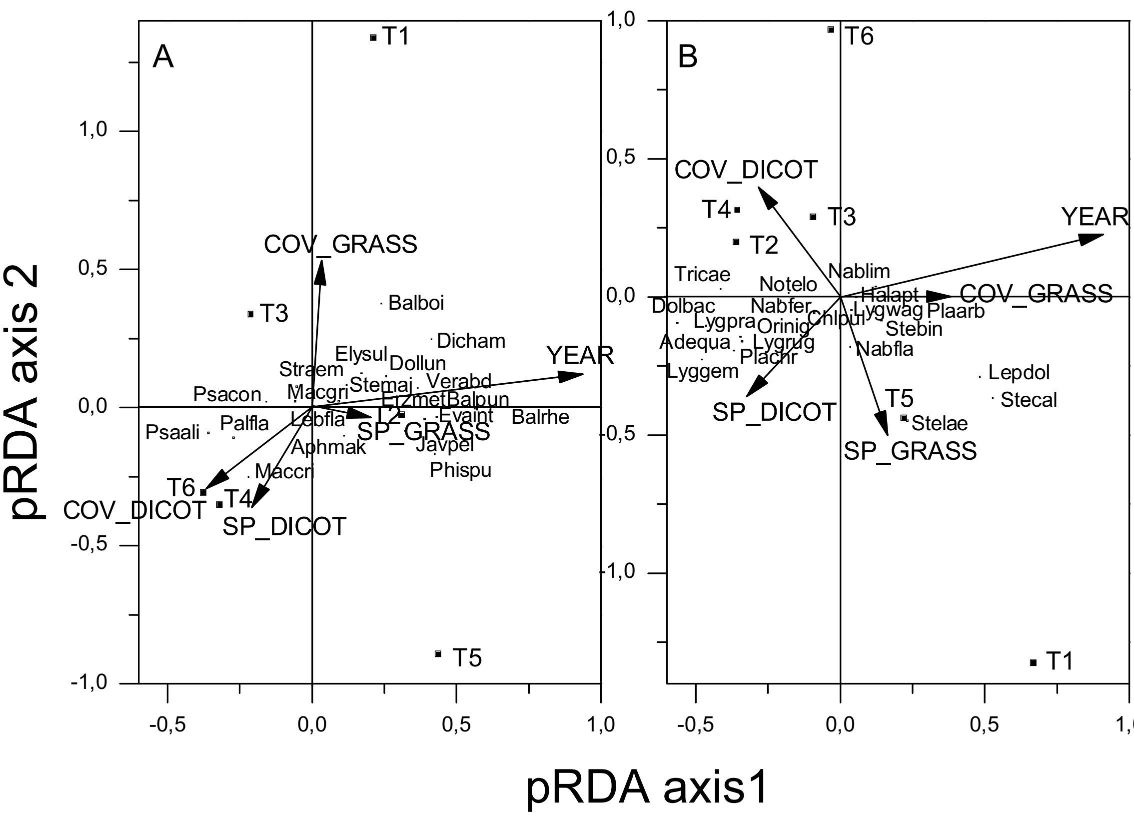

Fig. E1. Partial redundancy analysis of species composition.

Partial Redundancy Analysis (pRDA) of Auchenorrhyncha (A) and Heteroptera (B) species and environment variables for the comparisons of among wildflower strips. The field block was treated as a covariable in the analyses. The 20 most abundant species of each data set are shown.

The abbreviations of environmental variables and species are as follows: Environment variables: COV_GRASS = Cover of grass species, COV_DICOT = Cover of dicot species, SP_GRASS = Species number of grass species, SP_DICOT = Species number of dicot species, YEAR = Year of the study, Wildflower strip treatments: T1 = Wildflower strip parallel to field margin, T2 = Wildflower strip towards the field center, T3 = Wildflower strip in the middle of the field, T4 = Wildflower strip (10 × 25 m) parallel to field margin, T5 = Wildflower strip next to forest and T6 = *Centaurea jacea* monoculture in the middle of field;

Auchenorrhyncha species: Aphmak = *Aphrodes makarovi*, Balboi = *Balclutha boica*, Balpun = *Balclutha punctata*, Balrhe = *Balclutha rhenana*, Dicham = *Dicranotropis hamata*, Dollun = *Doliotettix lunulatus*, Elysul = *Elymana sulphurella*, Erzmet = *Erzaleus metrius*, Evaint = *Evacanthus interruptus*, Javpel = *Javesella pellucida*, Lebfla = *Lebradea flavovirens*, Maccri = *Macrosteles cristatus*, Macgri = *Macustus grisescens*, Palfla = *Paluda flaveola*, Phispu = *Philaenus spumarius*, Psaali = *Psammotettix alienus*, Psacon = *Psammotettix confinis*, Stemaj = *Stenocranus major*, Straem = *Streptanus aemulans*, Verabd = *Verdanus abdominalis*; Heteroptera species: Adequa = *Adelphocoris quadripunctatus*, Chlpul = *Chlamydatus pulicarius*, Dolbac = *Dolycoris baccarum*, Halapt = *Halticus apterus*, Lepdol = *Leptopterna dolabrata*, Lyggem = *Lygus gemellatus*, Lygpra = *Lygus pratensis*, Lygrug = *Lygus rugulipennis*, Lygwag = *Lygus wagneri*, Nabfer = *Nabis ferus*, Nabfla = *Nabis flavomarginatus*, Nablim = *Nabis limbatus*, Notelo = *Notostira elongata*, Orinig = *Orius niger*, Plaarb = *Plagiognathus arbustorum*, Plachr = *Plagiognathus chrysanthemi*, Stebin = *Stenotus binotatus*, Stecal = *Stenodema calcaratum*, Stelae = *Stenodema laevigatum*, Tricae = *Trigonotylus caelestialium*. See Appendices C and E for the further information on the importance of the axes.

Appendix F.

Eigenvalues and inter set correlations of environmental variables with partial redundancy analysis axes. The highest values of the inter set correlations of each environmental variable marked with bold.

	Axis			
	1	2	3	4
Wildflower strip treatment vs. reed canary grass control				
Auchenorrhyncha				
Eigenvalue	0.2159	0.1044	0.0143	0.0099
Wildf	0.3561	**−0.6899**	0.0797	−0.1107
Canary grass	−0.3561	**0.6899**	−0.0797	0.1107
Forest edge	−0.0858	−0.1707	**−0.2423**	−0.1111
Field edge	0.0798	−0.1854	0.066	**0.4636**
Mid field	0.0118	**0.3382**	0.1792	−0.3139
Dicot species richness	**0.4158**	−0.4246	−0.1966	−0.0454
Grass species richness	0.2882	**−0.6935**	−0.0299	0.0516
Cover of dicots	**0.2994**	−0.1988	−0.0113	−0.1446
Cover of grasses	−0.109	0.0817	**0.3772**	0.0429
Year	**−0.7259**	−0.3042	0.137	−0.0203
Heteroptera				
Eigenvalue	0.1422	0.0718	0.016	0.0113
Wildf	**0.5695**	0.3626	0.113	−0.0997
Canary grass	**−0.5695**	−0.3626	−0.113	0.0997
Forest edge	0.0044	0.0642	**0.3931**	0.2052
Field edge	0.0952	0.2533	**−0.3846**	0.1503
Mid field	−0.0921	−0.2973	−0.0359	**−0.3423**
Dicot species richness	**0.5316**	0.1484	0.0675	0.2752
Grass species richness	**0.4895**	0.356	0.1057	0.1947
Cover of dicots	0.1836	−0.2393	0.2435	**0.2815**
Cover of grasses	**−0.371**	0.1523	−0.1059	−0.039
Year	−0.4853	**0.4918**	0.1406	−0.0573
Among wildflower strips				
Auchenorrhyncha				
Eigenvalue	0.2266	0.0171	0.0126	0.0087
T1	0.0755	**0.3158**	0.1907	−0.117
T2	0.1109	−0.0059	−0.0159	**0.3037**
T3	−0.0787	0.0825	**−0.2116**	−0.0433
T4	−0.122	−0.0889	0.1623	**0.2414**
T5	0.161	−0.2174	0.1052	**−0.3069**
T6	−0.1387	−0.0748	**−0.2296**	−0.0791
Dicot species richness	−0.2115	**−0.2412**	0.1343	−0.0733
Grass species richness	0.1857	−0.0217	**0.3241**	−0.0996
Cover of dicots	**−0.3126**	−0.1671	0.041	−0.0906
Cover of grasses	0.0294	**0.3008**	−0.1705	−0.0833
Year	**0.7672**	0.0654	−0.0863	0.0629
Heteroptera				
Eigenvalue	0.1165	0.0353	0.0208	0.0095
T1	0.2436	**−0.3749**	−0.3145	0.1713
T2	−0.1359	0.0582	−0.0549	**−0.227**
T3	−0.0351	**0.085**	−0.0016	−0.0844
T4	−0.1344	0.0923	−0.1545	**0.2034**
T5	0.08	−0.1236	**0.5453**	0.1382
T6	−0.0111	**0.2646**	−0.0159	−0.2046
Dicot species richness	**−0.305**	−0.2632	0.1528	−0.0521
Grass species richness	0.1412	**−0.351**	0.1497	0.2578
Cover of dicots	−0.2402	0.2546	0.0703	**0.3177**
Cover of grasses	**0.3317**	0.0001	−0.0636	−0.2266
Year	**0.7539**	0.1451	0.0244	−0.0473

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