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Increase in activity density and species number of carabid beetles in cereals as a result of strip-management

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Abstract

In 1990 and 1991, we monitored the abundance of a carabid community in a 8 ha winter cereal field. The field was subdivided by five 1.5 m wide weed-strips leaving 12, 24 and 36 m between the strips. In 1990 significantly higher activity densities and number of species were found in the strips. In 1991, however, both number of species and activity densities of ground beetles in the weed-strips and the cereal parts in between were similar. In 1991, activity density in cereal parts between weed-strips was significantly higher than in a bordering control area. Most of the activity densities of all 23 abundant species were significantly higher in the strip-managed area than in the control area. Furthermore, the number of species in the strip-managed area was higher. In addition, most sampling dates (1990 and 1991) revealed a significant negative regression between activity density and distance from the first strip, i.e. width of the cereal parts between the strips. Strip-management seems to be a way to increase ground beetle densities considerably by providing better food supplies and more suitable overwintering sites.

Introduction

During the past 40 years, the diversity of agroecosystems has been extremely reduced by intensive management practices. The increase of crop monocultures at the expense of plant diversity has seriously affected abundance, diversity and efficiency of predatory arthropods which are closely linked to local habitat and plant diversity (Altieri & Letourneau, 1982). This intensified management led to a large decrease in abundance and species number of Carabidae (Heydemann & Meyer, 1983; Basedow, 1990). Heydemann & Meyer (1983) observed a severe reduction in activity-biomass of ground beetles — a decrease of more than 95% over a period of three decades (in the same root crops and cereal fields). Since ground beetles are an important group of beneficial arthropods, such a reduction will considerably limit their potential as pest control agents. The intensification of agriculture has also included the removal of hedges and field boundaries. These structures are important because they provide overwintering sites for ground beetles and other beneficial arthropods (Desender, 1982; Sotherton, 1984,1985). In addition, they serve as refuges when the crop area is disturbed (i.e. by harvest or ploughing) and as sources of abundant food. From there, predatory arthropods disperse into the crops in spring (Coombes & Sotherton, 1986) where they prey on pest insects. The lack of such structures and the simultaneous increase of field size reduce rapid spring colonization by epigeic predators, especially of the centres of large fields. One of the principal factors lowering peak number of aphids is the abundance of mainly polyphagous predators which are present in crops before aphids arrive (Potts, 1977; Edwards & George, 1981; Luff, 1987).

Reduction of field size and increase of overwintering and refuge sites can be achieved by the introduction of edges as successional strips (Nentwig, 1989; Heitzmann *et al.*, 1992) and/or the creation of within-field habitats (Thomas *et al.*, 1991, 1992). These studies showed that such within-field structures provide overwintering sites for high densities of a diverse predatory arthropod fauna (Thomas *et al.*, 1991; Bürki & Hausammann, 1993). In addition, carabid species were attracted to the successional strips during their migration and revealed significantly higher activity densities in an area containing weed strips than in a bordering control area (Lys & Nentwig, 1992a).

The data presented in this study were collected during mark-recapture studies on carabids (Lys & Nentwig, 1992a). The experimental design therefore relates to that study. In this paper we present data on ground beetle activity densities during 1990/91 in a cereal area containing weed-strips and compare these and number of species in the strip-managed area with a bordering control area (1991). In addition, the attraction of the weed-strips for each species is reported.

Materials and methods

The study was done in the cereal field described by Lys & Nentwig (1992a). The 8 ha field was conventionally cultivated with no insecticide treatments. In one part of the field five strips (1.5 m wide) were seeded with a variety of wild flowering herbs and weeds in 1989 (Heitzmann *et al.*, 1992) and left to grow over the following three years. All farming operations were performed carefully so that the weed-strips were not affected. The strips did not extend to the field margins but left a turning area for farm vehicles. The distances between the four strips in the investigated part of the field were 12, 24 and 36 m (Fig. 1). The winter-cereals in the two years of study were barley (1990) and rye (1991). In both years a regular network of pitfall traps was set up, the traps being 4.15 m from each other. In 1990, 400 pitfall traps were placed in the strip-managed area only. In 1991, the pitfall traps (380) were equally distributed between the strip-managed area and the control area with 190 traps in each area (Fig. 1). The 1990 study-area was twice as wide as in 1991.

The distribution of ground beetles was monitored after one 24 h trapping period each week. Beetles were collected alive from the traps (upper diameter 7 cm) and most of them were returned to the trap site after identification (nomenclature after Freude *et al.*, 1976). Activity density and number of species were recorded for each row of pitfall traps (20 rows of 20 traps in 1990; 38 rows of 10 traps in 1991). For comparisons between years only the same weeks were taken into account. The study lasted from May to the end of September in 1990 and in 1991 from April to the end of July.

Data analysis. A 'factor of strip-preference' for each species was obtained by dividing activity density per trap found in the strips by that found in the cereal areas in between. Species with higher activity densities in the weed-strips had a preference factor above one. We only included species which were caught in both habitats. Prior to statistical analysis and in order to stabilize variances activity densities were log-transformed. The distribution of ground beetles was analysed by multiple linear regression of the number of beetles caught per trap row (log NTRAP) and sampling date, habitat type (strip or cereal), distance from the first strip (S* in Fig. 1) and year (1990 or 1991). Habitat type and year are indicator variables coded as either 0 or 1. For each sampling date simple linear regression was used to reveal a possible effect of cereal-strip-width (weed-strip distance) on activity density (log NTRAP). Activity densities (untransformed) in the weed-strips and the cereals and those of cereal strips and the control cereal were compared using the Mann-Whitney U-test. Wilcoxon's signed rank test was used to compare activity density in the strip-managed area as a whole with the one of the control area.

Results

Comparison of strip-managed area 1990 and 1991. The distribution of activity density in the strips and in the cereal parts in between differed considerably between the two years (Fig. 2): in 1990 the activity density within the weed-strips was significantly higher than in the cereal areas ($P<0.001$ for May, June and July; Mann-Whitney U-test), whereas in 1991 no significant difference was found. In 1990 activity density (log NTRAP) of ground beetles decreased linearly with increasing distance from the first strip for four out of eight sampling dates ($F_{1,13}=6.9$ - 20.8, $P<0.05$). In 1991 a similar trend was observed for all sampling dates ($N=13$) for both the strip-managed area ($F_{1,13}=10.5$ - 91.8, $P<0.01$) and the whole area including the control part ($F_{1,32}=54.3$ - 258.5, $P<0.001$). Whereas in 1991 activity density in the cereal part was significantly higher than in 1990, no such effect was observed for the weed-strips.

In both years number of species in the weed-strips was significantly higher than in the cereal parts in between (Mann-Whitney U-test, $P<0.01$), although the overall distribution seemed more even in 1991 (Fig. 3). 'Strip-preference' of many species decreased from 1990 to 1991, i.e. many species which were captured almost exclusively within the strips in 1990 were more dispersed into the adjacent cereals in 1991 (Table 1). Only four species exhibited a slightly higher 'strip-

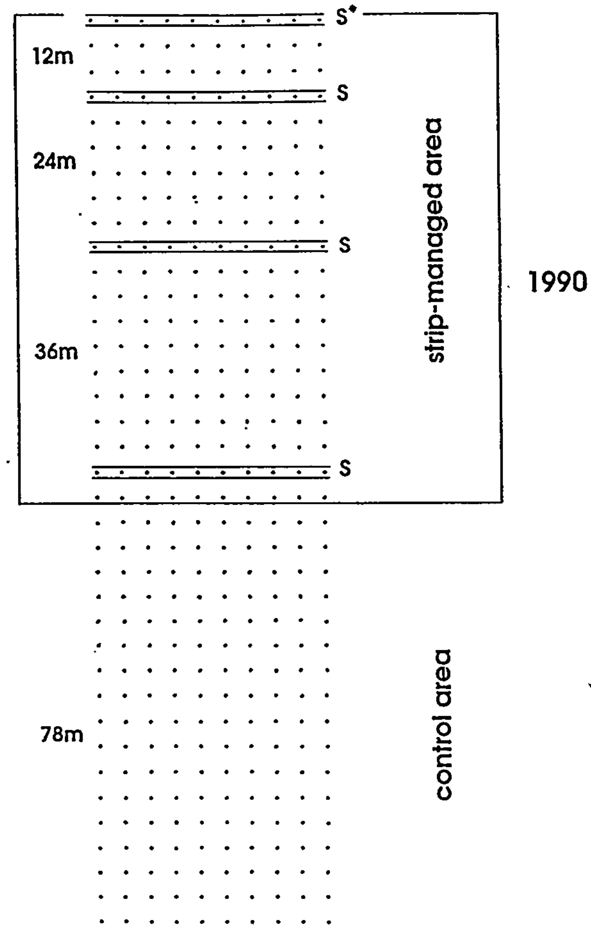

Fig. 1. Schematic overview of the areas studied over the two years. The line indicates the border of the area investigated in 1990 (solid line: strip-managed area). The dots symbolize the arrangements of pitfall traps (4.15 m between the traps) in 1991 with 190 traps in each area (S: weed strips; S*: first strip in the investigated part). The 1990 study-area was twice as wide as in 1991.

preference' in 1991 than in 1990 (*Stomis pumicatus*, *Amara communis*, *Amara convexior*, *Trechus quadristriatus* – Table 1). This phenomenon led to a more equalized distribution of activity density and species number between the strips and cereal parts in 1991.

Strip-managed area in comparison with the control area in 1991. Each sampling date (N=13) in 1991 revealed significantly higher activity density in the cereal parts between the strips than in the bordering control area (Mann-Whitney U-test, ($P<0.001$; Fig. 4). The relatively low numbers trapped in the 19th week were probably due to cold and rainy weather. Except for *Amara aenea*, *Agonum muelleri* and *Stomis pumicatus* all frequent species were caught significantly more often in the strip-managed area than in the control area (Fig. 5). In addition, the number of species caught in the strip-managed area was higher than in the control area (Table 1): 15 species were found only in the strip-managed area, whereas five were caught only in the control area. Four of these were found only close to the border of the field (Table 1: *Paraphonus maculicornis*, *Diachromus germanus*, *Asaphidion flavipes* and *Odacantha melanura*). All 20 species recorded in only one of the two areas were caught in low numbers.

Table 1. Species composition in the two years and 'factor of strip-reference' in 1990 and 1991 in the strip-managed area (CA: control area, SA: strip-managed area)

Frequently found species	1990 (SA)	1991 (SA)	1991 (CA)
Poecilus cupreus (Linné)	4.5	0.9	x
Pterostichus anthracinus (Illiger)	1.4	0.7	x
Pterostichus melanarius (Illiger)	2.0	0.5	x
Pterostichus niger (Schaller)	2.9	~	x
Pterostichus vernalis (Panzer)	2.0	0.7	x
Stomis pumicatus (Panzer)	0.5	1.0	x
Platynus dorsalis (Pontoppidan)	15.0	1.5	x
Agonum muelleri (Herbst)	5.0	1.1	x
Agonum sexpunctatum (Linné)	23.0	3.8	SB
Amara familiaris (Duftschmid)	157	5.0	x
Amara ovata (Fabricius)	24.0	15.5	x
Amara similata (Gyllenhal)	24.0	8.4	x
Amara communis (Panzer)	32.0	65.5	(sS)
Amara convexior (Stephens)	30.2	45.7	(sS)
Amara aenea (Degeer)	24.0	9.8	x
Amara plebeja (Gyllenhal)	5.3	3.8	x
Amara nitida (Sturm)	44.0	±	–
Harpalus rufipes (De Geer)	7.8	1.1	x
Harpalus distinguendus (Duftschmid)	130	22.2	x
Harpalus aeneus (Fabricus)	37.8	20.2	x
Harpalus tardus (Panzer)	±	11.3	SB
Harpalus luteicornis (Duftschmid)	172	18.8	x
Anisodactylus binotatus (Fabricius)	14.3	4.0	x
Anisodactylus signatus (Panzer)	9.5	4.5	x
Bembidion properans (Stephens)	4.5	3.1	x
Bembidion lampros (Herbst)	4.5	3.1	x
Bembidion tetracolum (Say)	1.8	0.7	x
Bembidion quadrimaculatum (Linné)	±	1.9	(SB)
Trechus quadristriatus (Schrank)	0.4	0.5	(s)
Carabus granulatus (Linné)	0.3	0.2	x
Clivina fossor (Linné)	4.1	1.0	x
Microlestes minutulus (Goeze)	72.0	3.0	x
Loricera pilicornis (Fabricius)	0.2	0.8	x
Brachinus explodens (Duftschmid)	688	3.1	x
Rarely found species			
Poecilus versicolor (Sturm)	–	±	–
Calathus fuscipes (Goeze)	±	~	–
Platynus obscurus (Herbst)	(a)	(x)	–
Agonum lugens (Duftschmid)	~	–	–
Agonum moestum (Duftschmid)	–	~	–

Table 1. Continued

Frequently found species	1990 (SA)	1991 (SA)	1991 (CA)
Amara bifrons (Gyllenhal)	(a)	–	–
Amara aulica (Panzer)	(a)	–	–
Amara consularis (Duftschmid)	–	~	–
Zabrus tenebrioides (Goeze)	(a)	(x)	–
Harpalus puncticeps (Stephens)	(a)	±	–
Harpalus stictus (Stephens)	(a)	±	–
Paraphonus maculicornus (Duftschmid)	–	–	B
Stenolophus teutonus (Schrank)	(x)	(x)	–
Acupalpus meridianus (Linné)	±	~	–
Diachromus germanus (Linné)	~	–	B
Bembidion obtusum (Serville)	–	~	(B)
Bembidion biguttatum (Fabricius)	(x)	–	–
Bembidion guttula (Fabricius)	~	–	–
Tachys bistriatus (Duftschmid)	±	–	–
Asaphidion flavipes (Linné)	–	–	B
Licinus depressus (Paykull)	(a)	–	–
Badister bipustulatus (Fabricius)	(x)	~	x
Badister sodalis (Duftschmid)	~	(a)	(a)
Chlaenius tibialis (Dejean)	–	–	(s)
Chlaenius nigricornis (Fabricius)	–	~	–
Lasiotrechus discus (Fabricius)	~	–	–
Trechoblemus micros (Herbst)	(a)	–	–
Carabus nemoralis (Müller)	~	~	(a)
Carabus coriaceus (Linné)	(a)	(x)	(x)
Carabus cancellatus (Illiger)	(x)	(s)	–
Nebria brevicollis (Fabricius)	~	(x)	–
Notiophilus palustris (Duftschmid)	–	~	x
Clivina collaris (Herbst)	(x)	(x)	–
Demetrias atricapillus (Linné)	(a)	–	–
Odacantha melanura (Linné)	–	–	B
In the eight records (May–July)	44	46	35
Total	59	54	44

total: 1990: May–September; 1991: April–July
x: present in one of the eight comparable records (May–July)
(x): found in CA between May and July but not during sampling days
–: absent
(a): present but only in autumn (after mid July), in general after harvest
(s): present but only in early spring (April 1991)
B: Only close to the field border found (as far as 15 m from the border)
S: Only close to the strip found (as far as 15 m from the strip)
±: sporadically found in the strips
~: sporadically found in the cereal parts

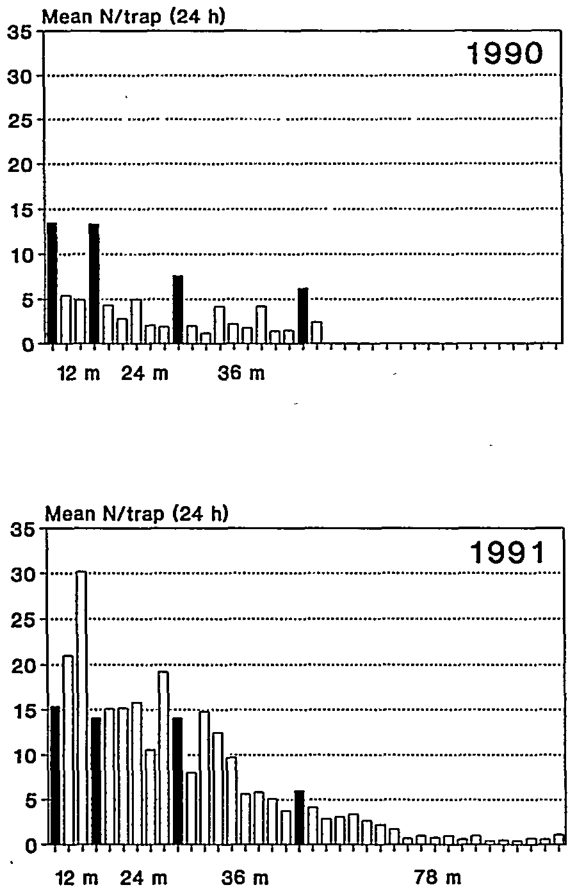

Fig. 2. Mean activity density of ground beetles per trap in each trap-row in 1990 (above 20 rows of 20 traps) and in 1991 (below 38 rows of 10 traps). Black columns represent mean activity density per trap in the weed strips, white columns represent mean activity density per trap in the cereals (N = 8).

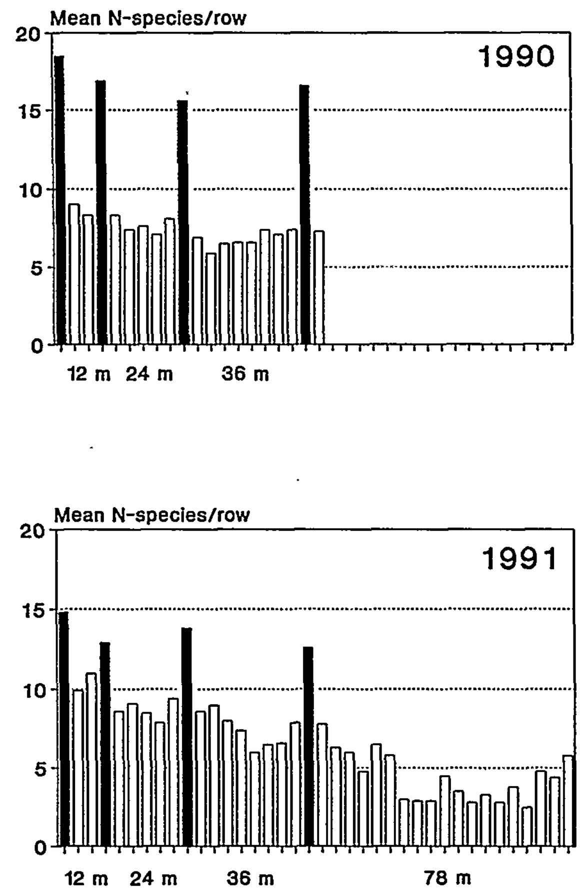

Fig. 3. Mean number of carabid species found per trap row in 1990 (above) and in 1991 (below) during 8 sampling dates (black columns: number of species in the weed strips; white columns: number of species in the cereals).

Discussion

Activity density is a rough and inaccurate method to estimate relative abundance between sites of differing vegetation cover (cereals and weed-strips) because the denser vegetation cover in the weed-strips can impair movements of ground beetles and subsequent catches in pitfall traps (Heydemann, 1956). Marked individuals covered much shorter daily distances within the weed-strips than in the cereals (Lys & Nentwig, 1992a). Nevertheless in 1990 we found much higher activity densities in the weed strips than in the cereal areas in between, i.e. in the site with the denser vegetation cover. The decrease of difference between activity densities in the strips and the cereal parts from 1990 to 1991 might have been caused by the

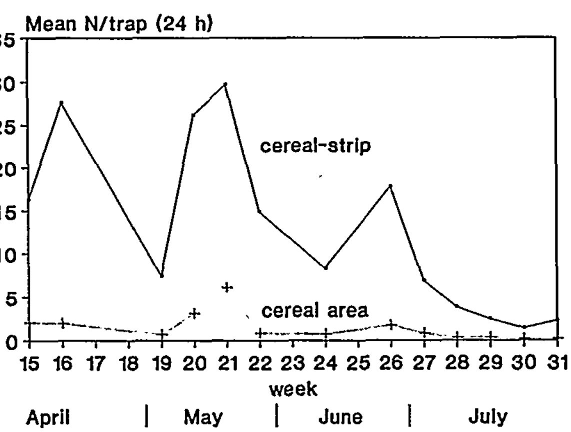

Fig. 4. Mean activity density of ground beetles for each sampling date made in the cereal strips (solid line) and in the control area (dotted line) in 1991 (N = 13).

large increase in activity density from 1990 to 1991 in the strip-managed area. Several small species e.g. *Microlestes minutulus*, *Brachinus explodens*, *Amara familiaris*, *Harpalus luteicornis* and *Agonum sexpunctatum* showed the strongest dispersal into cereals from 1990 to 1991 which indicates that competition (Lenski, 1982, 1984; Loreau, 1990) might also have been involved in this changed distribution. This assumption is also supported by individually marked beetles which frequented the weeds-trips less often in 1991 than in 1990 (Lys & Nentwig, 1992a). In addition, a significant positive year effect on activity density was observed only in the cereals but not within the strips; i.e. mean activity density within the strips remained on about the same level in both years (Fig. 2) whereas in the cereals it increased greatly. This might indicate that the carrying capacity of the weed-strips was reached in 1990 and that the ground beetles had to move to the cereal parts in 1991.

Food seems to be the most important limiting factor for many insect populations (Dempster & Pollard, 1981; Whitcomb & Godfrey, 1991). The high density and diversity of arthropods found on the strip vegetation suggests that food availability could be considerably increased by strip-management (Frei & Manhart, 1992). In ground beetles egg production correlates with the amount of food (Heessen, 1980; van Dijk, 1983, 1986; Baars & van Dijk, 1984; Ernsting & Huyer, 1984). Furthermore, larval mortality and survival of pre-adult stages are influenced by food supply (Heessen & Brunsting, 1981; Juliano, 1986; Kinsley & Juliano, 1988; Nelemans *et al.*, 1989). Increased abundance of suitable prey is very often associated with a rise in predator abundance (Whitcomb &Godfrey, 1991). This can result from enhanced predator reproduction and/or survival or it may be due to immigration of predators from surrounding areas (Whitcomb & Godfrey, 1991). In the strip-managed area we could ascertain both phenomena. *Poecilus cupreus*, the most abundant species in the field was not only better fed and in general females carried more eggs in their ovaries in the strip-managed area than in the control area in 1991 (Zangger *et al.*, 1994), but its reproduction period lasted also longer in the strip-managed area (Lys & Nentwig, 1992a; Zangger *et al.*, 1994). Both phenomena may lead to higher densities in the next generation. Furthermore, significantly larger numbers of marked *Poecilus cupreus* and *Pterostichus melanarius* moved from the control area to the strip-managed area than vice versa (Lys & Nentwig, 1992a) which supports the assumption that the living conditions were improved by the introduction of weed-strips.

Weed-strips not only offer higher food availability but also more suitable overwintering sites as shown by Bürki & Hausammann (1993). In addition, these weed-strips offer refuges during field disturbance or during unfavorable climatic conditions, e.g. droughts. We have observed that the relationship between activity density in the strips and the cereal areas in between was most pronounced after long, dry periods (Lys, unpubl.). The most important improvement following the use of weed strips is the possibility of rapid spring colonization of ground beetles and high ground beetles abundance in the cereal areas between them. In spring their potential as pest control agents is greatest (Wratten *et al.*, 1984; Coombes & Sotherton, 1986). Furthermore, several authors have shown a negative correlation between the density of ground beetles and the density of aphids (Sunderland *et al.*, 1985; Chiverton, 1986; Basedow, 1990; Winder, 1990). The predatory pressure of these ground beetles is certainly much higher in narrower cereal parts than in larger ones because of higher activity density in the former ones. Transect measurements on water content, pH, organic matter and 19 nutritional elements (N, P, K, Mg, Na....) did not show any gradient which could offer an alternative explanation for the differences in activity density between the cereal strips of different width (Heitzmann, unpubl.).

Besides the marked increase in activity density, a large increase in the diversity of ground beetle species was observed. The most marked increase in number of species was found in the first year (from 1989 to 1990; Lys & Nentwig, 1992b). The vegetation structure of the cereal field was enriched following the use of weed strips. Higher plant and structural diversity leads to a higher animal diversity and can increase natural enemies of agricultural pests (Altieri & Letourneau, 1982). This has been confirmed for ground beetles in this study. Large ground beetles with poor powers of dispersal which are highly affected by farming operations (Tietze, 1985; Eyre *et al.*, 1990) also increased, e.g. *Carabus granulatus*, which was only found occasionally in 1989 (Lys, unpubl.). All the frequent species showed higher activity densities in the strip-managed area than in the control area (Fig. 5).

Thus strip-management improves the living conditions of many carabid species by offering higher food availability, by providing more overwintering sites and refuge, i.e. a wider range of niches. It therefore promotes the chance of survival of many species in arable

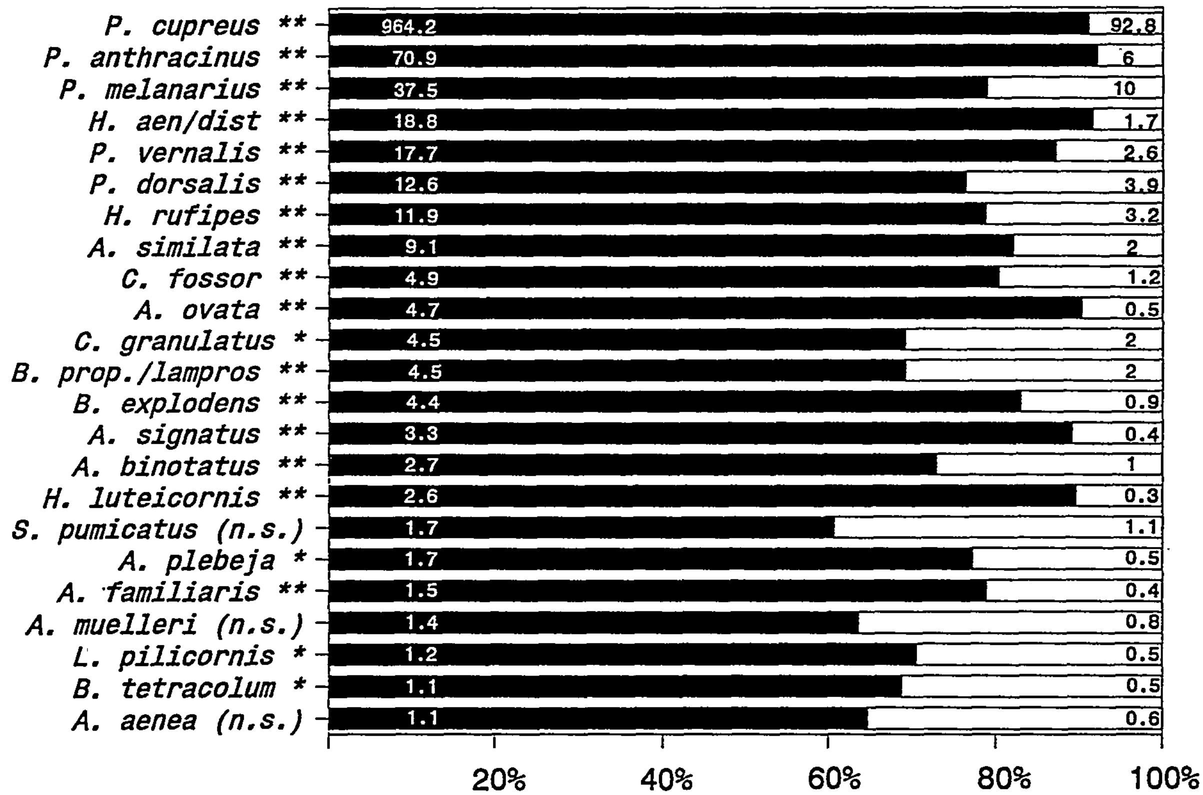

Fig. 5. Comparison of mean activity density of frequent species (i.e.>one individual/100 traps in 24 h in one of the two areas) represented as a percentage-distribution between strip-managed area (black parts of column) and the control area (white parts of column) in 1991 (N=13). The numbers within the columns show mean N/100 traps in 24 h for the two areas. **=P<0.01; *=P<0.05, n.s.=not significant (Wilcoxon signed rank test).

fields and counteracts the faunal impoverishment in agroecosystems.

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