

**Institute for Ecosystem Research  
of the Christian Albrechts-Universität Kiel**

**Role of grassy strips on the biodiversity and movement of  
ground beetles (Carabidae: Coleoptera) in organic arable  
ecosystems**

**Dissertation**

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## Abstract

The aim of this study was to investigate the role of grassy strips in organic farming using carabids as model organisms. Overall, the invasion of carabids from field margins to field centres was studied along grassy strips compared to adjacent field areas away from grassy strips, the effect of age of grassy strips on biodiversity, and the movement behaviour of selected species.

Carabid assemblages showed no differences between grassy strips of different age, crop fields near the grassy strips, and the field margins. Open field carabids that avoid tree shade mostly took the advantage of the grassy structures. In addition, only a small number of carabid species that like tree cover also used the grassy strips. In contrast, arable crop lands were only exploited by species that elude vegetation cover. All 89 species demanded a soil pH ranging from 4.6 to 5.6. Species that prefer a soil pH lower than 4.6 were not found in the habitats. *Poecilus cupreus*, *Poecilus versicolor*, and *Carabus nemoralis* used the grassy strips to invade into the arable fields, whereas *Pterostichus melanarius*, *Anchomenus dorsalis*, *Nebria brevicollis*, and *Trechus quadristriatus* entered directly into the arable fields from the field margins without using the grassy strips. Endangered carabids did not benefit from grassy strips. On average, medium sized ground beetles (5 - 15 mm) profit from grassy strips. Small sized carabids (<5 mm) were in comparatively higher abundance in the fields and grassy strips than in the field margins.

Age of the grassy strips was the major factor that influenced the biodiversity of the carabids in the grassy strips and in the adjacent arable crop land. Generally, a higher species richness and lower activity density characterised the grassy strips and field margins compared to the cropping areas. The older grassy strips contributed more to higher species richness and biodiversity (Shannon H) in the adjacent crops than younger strips. Increase in distance from the field edges resulted in a decrease of evenness and an increase of the activity density in the grassy strips and the cropping areas. Effect of age was also eminent in different feeding groups of carabids. The major influence was found for carnivorous and phytophagous ground beetles as compared to omnivorous. A positive relationship was found between the age of the grassy strips and the species richness of the most dominant species in the grassy

strips. Age of grassy strips influenced the species richness of the dominant species in the crop centre up to a distance of more than 150 m from the field margins. Like total species richness, the species richness of the most dominant species also declined with the increase in distance from the field margins. Moreover, the older grassy strips influenced the richness of dominant species on the field margins connected to them.

Grassy strips acted as a corridor for the invasion of single dominant ground beetles into the crop centres. Mark and recapture studies revealed a higher displacement and speed in the arable crops than in grassy structures for *P. melanarius*, *Carabus auratus* and *Poecilus* spp. A comparison among the species showed that the displacement and speed of *C. auratus* was significantly higher than of *P. melanarius*, *Pterostichus niger*, and *Poecilus* spp. The behaviour of *P. melanarius* differed for the distance covered and the speed between the crops. The species covered longer distances with higher speed in wheat (*Triticum aestivum*) than in red-clover (*Trifolium pratense*) or pumpkin (*Cucurbita maxima*). In addition, the displacement and speed of *P. melanarius* differed between spring and autumn generation in wheat and clover crops. The carabids behaved differently for their invasion into the crops from the field margins. *Carabus auratus* showed no preference to the grassy structures and arable crops for its invasion into the fields. However, *P. melanarius* preferred to enter into the crop centres from the grassy margins. In contrast, *Poecilus* spp. showed a different behaviour of its invasion into the crops based on the locations of the arable fields. In a marginal field close to a forest, *Poecilus* spp. used the grassy strips to enter into the crop areas and avoided a grassy strip with adjacent hedge. However in a field located in the centre of the huge crop land, *Poecilus* spp. used both crop areas and grassy strips equally. *C. nemoralis* preferred only grassy margins adjacent to a hedge and avoided to enter the crop land directly or the grassy strip without any hedge structure. Unlike *Poecilus* spp. and *C. nemoralis*, *Nebria brevicollis* avoided the grassy strips and preferred to disperse into the cropping areas directly. *P. niger* preferred the grassy strips and their border areas for dispersal.

The investigations support the establishment of grassy structures in the organic arable ecosystems, although some effects are weak and only a few species benefit from the grassy structures. In addition, the grassy structures assist the dispersal of certain species which could not invade without these corridors. If the grassy strips are established for 9 years, they have a higher ecological value than young strips. Furthermore, a positive influence of old grassy strips on the species richness was not only found in the arable field area but also in the adjacent ecosystems.

## Zusammenfassung

Es war das Ziel dieser Studie, die Rolle von Grasstreifen im Ökologischen Landbau mit Hilfe von Carabidae als Modellorganismen zu untersuchen. Folgende einzelnen Probleme sollten studiert werden: Das Eindringen von Carabidae von den Feldrändern in die Feldmitte, in dem die Verteilung der Käfer entlang von Grasstreifen und benachbarten Feldbereichen untersucht wurde, der Effekt des Alters von Grasstreifen auf die Biodiversität und das Bewegungsverhalten ausgewählter Arten entlang verschiedener Grasstreifen.

Die Carabidengemeinschaften zeigten keine deutlichen Unterschiede zwischen Grasstreifen unterschiedlichen Alters, benachbarten Feldbereichen und Feldrändern. Die Grasstreifen wurden von Laufkäferarten dominiert, die offene Flächen präferieren. Schattenliebende Arten waren ausschließlich in den Grasstreifen zu finden, aber nur in geringer Anzahl vorhanden. In den Feldern waren ausschließlich Arten zu finden, die keinen Schatten ertragen. Alle 89 Arten haben bei pH-Werten des Bodens zwischen 4,6 und 5,6 ihr Präferenzoptimum. Arten, die niedrigere pH-Werte bevorzugen, traten nicht auf.

*Poecilus cupreus*, *Poecilus versicolor* und *Carabus nemoralis* nutzten die Grasstreifen, um in die Felder einzudringen, während *Pterostichus melanarius*, *Anchomenus dorsalis*, *Nebria brevicollis* und *Trechus quadristriatus* direkt in die Felder wanderten, ohne die Grasstreifen zu nutzen. Es konnte nicht nachgewiesen werden, dass gefährdete Arten proportional mehr von den Grasstreifen profitierten als ungefährdete. Im Mittel wurden die Grasstreifen von Arten mittlerer Größe (5-15 mm) bevorzugt genutzt. Kleine Arten (< 5) waren vergleichsweise häufiger in den Feldern und den Grasstreifen als in den Feldrändern.

Das Alter der Grasstreifen beeinflusste als wichtigster Faktor die Biodiversität von Carabidae in den Grasstreifen und in den benachbarten Feldbereichen. Im Allgemeinen waren die Grasstreifen und die Feldränder durch eine höhere Artenvielfalt und niedrigere Aktivitätsdichte charakterisiert als die Felder. Alte Grasstreifen trugen mehr zu einer Erhöhung der Artenzahl und der Artendiversität (Shannon H) in den benachbarten Feldbereichen bei als junge Grasstreifen. Mit

zunehmender Entfernung vom Feldrand sank die Evenness, während die Aktivitätsdichte anstieg. Das Alter von Grasstreifen war auch von großer Bedeutung für die verschiedenen Ernährungstypen der Carabidae. Der größte Einfluß wurde auf die carnivoren und phytophagen Laufkäfern gefunden, während er bei den omnivoren gering war. Für die dominanten Arten zeigte die multiple Regression, dass sowohl die Entfernung vom Feldrand als auch das Alter der Grasstreifen die Artenzahl in den Grasstreifen beeinflusst. Die Entfernung vom Feldrand wirkte negativ, das Alter der Grasstreifen positiv auf die Artenzahl in den Grasstreifen. Auch in den benachbarten Feldbereichen und in den Feldrändern wirkte sich das Alter der Grasstreifen positiv auf die Artenzahl der dominanten Arten aus.

Die Grasstreifen wirken als Korridore bei der Einwanderung einzelner dominanter Laufkäferarten in die Felder. Für *Pterostichus melanarius*, *Carabus auratus* und *Poecilus* ssp. ergab die Markierungs- und Wiederfangmethode eine höhere Mobilität und Geschwindigkeit in den Feldern als in den Grasstreifen. Der Vergleich zwischen den Arten zeigte, dass die Mobilität und Geschwindigkeit von *C. auratus* signifikant höher war als von *P. melanarius*, *P. niger* und *Poecilus* ssp. Die Mobilität und Geschwindigkeit von *P. melanarius* war zwischen verschiedenen Anbaufrüchten unterschiedlich. Im Weizen (*Triticum aestivum*) wurden weitere Entfernungen und höhere Geschwindigkeiten erreicht als im Rotklee (*Trifolium pratense*) oder im Kürbisanbau (*Cucurbita maxima*). Außerdem wurden zwischen der Frühjahrs- und Herbstgeneration von *P. melanarius* sowohl im Weizen als auch im Rotklee signifikante Unterschiede gefunden. Die Carabiden verhielten sich unterschiedlich während ihrer Einwanderung vom Feldrand in die Felder. *C. auratus* zeigte keine bevorzugte Nutzung von Grasstreifen während seiner Einwanderung in die Felder, vermied sie aber auch nicht. Dagegen wanderte *P. melanarius* direkt in die Felder ein und vermied die Grasstreifen. Im Gegensatz zu diesen beiden Arten konnte bei *Poecilus* ssp. ein unterschiedliches Verhalten in Abhängigkeit von der Lage der Grasstreifen festgestellt werden. In einem Feld mit einem benachbarten Wald nutzte *Poecilus* ssp. signifikant häufiger den Grasstreifen und vermied den Streifen neben einem Knick, in einem Feld in der Mitte der Agrarflächen wanderte er sowohl entlang der Grasstreifen als auch direkt in das Feld ein. *C. nemoralis* bewegte sich nur entlang des Grasstreifens mit einem benachbarten Knick in die Felder. Eine Einwanderung entlang der Grasstreifen ohne benachbarte Hecke oder eine direkte Einwanderung konnte nicht festgestellt werden. Anders als *Poecilus* ssp. und *C. nemoralis* mied *N. brevicollis* Grasstreifen und wanderte direkt in die Felder ein, während *P. niger* nur die Randbereiche der Grasstreifen für seine Ausbreitung nutzte.

Die Untersuchungsergebnisse unterstützen die positive Wirkung von Grasstrukturen im Ökologischen Landbau, obwohl einige Effekte sehr schwach sind und nur einige wenige Arten davon profitieren. Grasstreifen unterstützen die Ausbreitung einiger Arten in die Felder, die sich ohne diese Korridore nicht in die Agrarflächen ausbreiten könnten. Wenn Grasstreifen ein Alter von 10 Jahren erreichen haben sie einen stärkeren positiven Wert als junge Grasstreifen. Außerdem scheinen alte Grasstreifen nicht nur die Artenvielfalt in den Agrarflächen, sondern auch in den umgebenden Ökosystemen positiv zu beeinflussen.

# **Chapter 1**

## **Introduction**

### **1.1 Motivation of studies**

#### **1.1.1 Agricultural intensification and food security for future**

Throughout human history, the gaps between the dietary demands and the increasing human population have changed many natural sites like forests and grasslands into agricultural areas. Thus, agricultural intensification has a very old history and it began on the advent of agriculture in South-West Asia about 10,500 to 10,100 years ago when the first crop domestication adopted (Zohary et al., 2012). In only last 280 years (from 1700 to 1980) the total area of cultivation increased by 466 % (Meyer & Turner, 1992). The intensification increased with the passage of time and culminates during the first “green revolution” (GR) from the beginning of 1950 to 1960s by a number of measures such as new crop variety and farming practices. It brought many socio-economic, political, environmental, and scientific changes (Reaping the Benefits, 2009; Pingali, 2012).

After a period of 50 years, the positive effects of the green revolution could be seen in gross world production. For example, cereals, coarse grains, roots and tubers, pulses and oil crops increased from 1.84 billion tonnes (in year 1961) to 4.38 billion tonnes (in 2007) which accounts for an increase of 138 % (FAOSTAT, 2009). If the growth is seen continent wise, Africa received only a rise by 140 %, while Latin America by approximately 200 %, and Asia by 280 % (FAOSTAT, 2009). This growth is an integration of many parts of the first green revolution such as crop germplasm improvement; establishment of many scientific institutes like International maize and Wheat Improvement Centre (CIMMYT) in Mexico and International Rice Research Institute (IRRI), and the Consultative Group on International Agricultural Research (CGIAR); new ways for crop production and crop protection; and mechanised farming (Reaping the Benefits, 2009).

The negative impacts of green revolution on the future of agriculture were determined soon, and some works like “Silent spring” (Carson et al., 1962) attracted the attention of farmers, governments, scientists and intelligentsia to adopt some alternative measures to save the environment. An account of the malpractices during the arable intensification is given by Stoate et al. (2001), who found that the destruction of natural habitats, soil and environmental pollution, simplification of crop and animal production on farm disrupted food web and food chains, and declined many species. According to Pingali (2012) the environmental problems were not created by the GR technology, and it was the policies that promoted overuse of inputs and intensified the areas for crop productions which could not sustain them, e.g. sloping lands. Now a new green revolution (GR 2.0) has been started to mitigate the mistakes committed in the GR (Krebs et al., 1999; Pingali, 2012).

As the world population in 2050 is expected to grow to approximately 9 billion, the demand of food will increase two to threefold (Tilman et al., 2002). This process will require the reduction of food system intensification on the environment for future food security (Godfray et al., 2010). To fulfil the expected demand of food (70 to 100 %) by 2050 (Baulcombe et al., 2009), a more sustainable farming system is required. So, some changes such as the increase in food production, change in diet, decreasing yield gaps across the globe, and reducing food wastes should be adopted by reducing the biodiversity costs (Godfray et al., 2010). For this, a wild-life friendly farming is recommended, which support the retention of natural and semi-natural habitats in the countryside and in the arable fields and reduces the threats to beneficial organisms (Green et al., 2005).

In order to counteract the negative impacts of agriculture on biodiversity, many governments and non-governmental organisations support the Agricultural Environmental Schemes (AES). These schemes give financial support to farmers for using environment friendly land and are considered the realistic tool to save environment and biodiversity across European and North American agricultural landscapes (Donald and Evans, 2006; Tschardt et al., 2007). These schemes encourage the preservation of natural habitats on farm scale and support the habitat heterogeneity in the agricultural landscape to increase biodiversity (Benton et al., 2003; Mercks et al., 2009). However, the effectiveness of these schemes is questioned and the results critically evaluated (Kleijn et al., 2001; Kleijn and Sutherland, 2003). However, some positive results by Evans and Green, 2007 show that the schemes



have advantages if the management and efficient and objectives are clearly defined (Reaping the Benefits, 2009).

A number of nature friendly farming systems are adopted among which organic farming exerts a diversified impact on the environment. This impact varies among different taxa and depends on the heterogeneity of landscapes (Clough et al., 2007; Crowder et al., 2010; Fuller et al., 2005; Östman et al., 2001; Purtauf et al., 2005). The independence of organic farming from external inputs (fertilizers, pesticides etc) causes a higher biodiversity and saves soil fertility (Maeder et al., 2002). The reduction of the inputs decreases the danger of pest outbreaks and insect resistance in organic agriculture (Macfadyen et al., 2009; Norton et al., 2009). Moreover, the monoculture in conventional ecosystems causes a higher abundance of specialist herbivores compared to the polycultures (Risch et al., 1983). Maeder et al (2002) found in organic farming systems a more efficient source utilisation and a higher biodiversity than in conventional farming systems. A meta-analysis by Bengtsson et al. (2005) showed that organic farming enhances species richness. A possible reason, combined with many others, might be the conservation of natural or semi-natural habitats in the surroundings of organic fields, e.g., in south-west England (Gibson et al., 2007).

### **1.1.2 Restoration of natural habitats in agroecosystems**

The presence of natural or semi-natural habitats in the agricultural landscape is necessary because the annual crop fields become defaunated islands after the harvest every year (Kruess and Tschardtke, 1994). The natural enemies suffer more than their phytophagous prey, which causes simpler food chains in these “islands” (Kruess and Tschardtke, 1994). The recovery time of the disturbed population is generally longer than the time for its destruction and it becomes longer for those which prey only on few species (Kareiva, 1987). In addition, during some stages of their life many organisms depend on specific resources that annual crops could not provide. Therefore, they become rare or extinct, if their dispersal power is not high enough to access distant resources (Tschardtke and Brandl, 2004).

The restoration or establishment of natural habitats in arable ecosystems has a high social, aesthetic, and cultural significance (Burel and Baudry, 1995; Marshall, 2002). Natural habitats provide food, foraging source, breeding sites, physical shelter, shelter from predation, and dispersal corridors for a number of animals (Hobbs, 1992).

Mostly, these habitats are linear structures such as grassy field margins and hedgerows. They increase the overall habitat diversity in agricultural landscapes and help to suppress pests in annual arable cropping systems (Bianchi et al., 2006; Tschardt et al., 2007). The decline of these habitats dilutes landscape heterogeneity, which ultimately threatens the animal diversity (Manhoudt and De Snoo, 2003).

Among the natural habitats, grassy field margins represent very old and traditional habitats in the agricultural fields. They were already in use in the Bronze Age (Pollard et al., 1974). The types of field margins are discussed in detail along with their role and definitions by Greaves and Marshall (1987). The AES also include the establishment and conservation of field margins. The field margins support many weed plant species (Burel and Baudry, 1995), birds (Canada and Service, 2001; Maeda, 2005; Neumann et al., 2001; Vickery et al., 2009; Vickery et al., 2002), spiders (Drapela et al., 2008; Maudsley et al., 2002; Schmidt and Tschardt, 2005; Schmidt-Entling and Döbeli, 2009), and pollinating insects (Gabriel and Tschardt, 2007; Lagerlöf et al., 1992; Steffan-Dewenter and Tschardt, 1999).

Based on the composition of plants in the field margins and in various other semi-natural habitats in arable ecosystems, the abundance and biodiversity of beneficial insects is supported (Landis et al., 2000). Flower strips with a mixture of wildflowers (Marshall and Moonen, 2002), 'beetle banks' in the crop centres (Thomas et al., 1991), and weed strips in cereals (Lys et al., 1994) are playing a major role for the biodiversity and abundance of many insects. The insects in agroecosystems provide a number of services such as pest control (Nicholls and Altieri, 2004), pollination (Kremen, 2008), weed seed predation (O'Rourke et al., 2006), and decomposition (Irmeler, 2000; Scheu, 2001).

If the ratio between total crop area and natural habitats around the crop fields is very small, some additional grassy structures are needed to provide refuge and overwintering sites in order to support polyphagous predators. Thomas et al. (2001) used specific grassy structures called "beetle banks". Their establishment is also justified by the fact that the effectiveness of the natural habitats decreases with increasing distance from the natural habitats (Saska et al., 2007).

The effect of semi-natural habitats depends on their age as an important factor. If grassy margins or semi-natural habitats become older, they provide a more suitable vegetation cover (Günter, 2000), more nutrients (Frank et al., 2007), more plant species, and more effective predation and parasitism than younger habitats (Thies and

Tscharntke, 1999; Deny and Tscharntke, 2002). So, it is necessary to retain the natural habitats for a longer time in the fields than usually today.

The destruction of natural habitats in intensive farming is usually combined with habitat fragmentation. Habitat fragmentation has been found to be a great threat for the survival of many animals (Fahrig, 2003). Fragmentation directly affects the abundance small sized insect populations with low dispersal capabilities (Niemelä, 2001; Tscharntke et al., 2002). Species with low dispersal capability are restricted to stable habitats (Hedin et al., 2008), while the species with higher dispersal capacity have easier access to disturbed habitats (Denno et al., 1996). Low dispersal potentials are often related to species with specific habitat demands or preferences of specific habitat conditions (Ranius and Hedin, 2001). Brouwers and Newton (2009) reported in a study on woodland carabids that generalist species have a higher rate of movement (11 m day<sup>1</sup>) than carabids with strong relation to woodlands (2.1 m day<sup>1</sup>). Thus, habitat loss mainly affects animals which are relative immobile or have low dispersal rates such as the flightless wood cricket (*Nemobius sylvestris*) (Brouwers and Newton, 2009).

In addition to the dispersal and rate of dispersal, the orientation of animals towards their habitats (Schtickzelle et al., 2007; Zollner and Lima, 1997) and their potentials to cross barriers (Dover and Settele, 2008; Strong et al., 2002) are considered as major factors to evaluate the dispersal potential of a species.

## **1.2 The model organism**

Ground beetles (Coleoptera: Carabidae) were used as model organisms, since they respond either positive or negative to anthropogenic changes especially in agro-ecosystems (Kotze et al., 2011; Kromp, 1990). The ecology and biology of carabids is well investigated (Lindroth, 1945; Thiele, 1977; Lövei and Sunderland, 1996; Rainio and Niemelä, 2003). Especially in the last 40 years in Europe, many detailed investigations were performed on feeding behaviour, dispersal, and taxonomy (Kotze et al., 2011).

The major reasons to use ground beetles as modal organisms were: their function as bio-indicators, their different feeding habits, their interactions with the surrounding habitats, and the easy investigation of their dispersal into crop lands. Apart from these morphological and ecological aspects, the easy sampling of carabids is also an advantage to use them for ecological investigations.

In a detailed review, Koivula (2011) found that carabids have a great potential as model organisms and as bio-indicator organism. Ground beetle fit as model organisms, because they have well investigated taxonomy with a relatively stable systematic. Their role in ecology, their response to biotic and a biotic factors by their morphological flexibility and their life-history strategies, their wide distribution, and their spatio-temporal response to disturbance is well understood (Koivula, 2011). According to Koivula (2011) the indicator function of carabids based on seven characters by Lindenmayer (2000): (a) abundance and species richness, (b) role as keystone organisms, (c) response to anthropogenic changes like pollution, (d) response to environmental changes, (e) signalling problems at early stages, and (f) response to disturbance and management practices. The use of carabids as indicator organisms does not imply that all species can be used as indicators in a landscape on a regional or local scale. For practical reasons, however, single species could be studied to indicate the biodiversity situation on a spatio-temporal scale (Billeter et al., 2008).

A further reason to select carabids for this investigation was their different feeding habits. Most of the carabids are polyphagous predators, carrion feeders, and seed feeders especially of weeds (Luff, 1987; Thiele, 1977). Laroche (1990) documented the food choice of carabids from a world-wide database and found that 73.5 % of carabid species were carnivorous, 19.5 % omnivorous and only 8.1 % phytophagous. Ground beetles prey aphids (Bilde and Toft, 1997; Hajek et al 2007), earthworms (Symondson et al., 2006), snails (Symondson et al., 2001; Oberholzer et al., 2003), slugs (Bohan et al., 2000), weed seeds (Menalled et al., 2001), carrions (von Berg et al., 2012), and amphibians (Wizen and Gasith, 2011).

A third aspect to take carabids was their response to the surrounding habitats. They mostly find their suitable habitats by walking using two patterns. According to Baars (1979) they use “random walk” for their short distance movement and “directed walk” for their long distance movement. If carabids are in unfavourable conditions, they show the “direct walk” behaviour to leave the unfavourable habitat (Baars, 1979).

Furthermore, their size was considered, because it plays an important role to understand ecological functions. Large predators move quickly, detect prey at longer distances, and have higher chances for successful preying (Cohen et al., 1993a,b). The relationship between activity density and specific size could be useful to determine the response to different scales in the agricultural landscape. In addition, the large-sized carabids could be easily used to investigate their dispersal from one habitat to another.

Finally, carabids are sampled by pitfall traps, which are cheap, easy to install, and provide a good number of beetles for statistical analysis (Greenslade, 1964).

### **1.3 Hypotheses and aims**

In the light of the above mentioned problems, the present study has the following aims: (1) which effect on biodiversity have the natural and semi-natural habitats in organic agriculture, (2) which species benefit from grassy strips and what are the selecting environmental factors, and (3) how grassy strips control the dispersal behaviour of ground beetles.

#### **1.3.1 Beneficial carabid species in organic farming systems**

The role of organic farming on many animals including carabids has been intensively studied. Only a few investigations contribute to the species level of the effectiveness of grassy strips in organic agriculture, whereas most investigations referred to conventional practices.

Therefore, hypothesis 1 was:

##### ***(1) Carabids benefit from grassy strips also in organic farming***

The majority of studies compared the role of farming systems (conventional and organic) on carabids and showed that the organic farming support higher abundance and species richness (Booij and Noorlander, 1992; Armstrong, 1995; Pearsall and Walde, 1995; Östman et al., 2001; Maeder et al., 2002; Shah et al., 2003; Purtauf et al., 2005; Clough et al., 2007; Menalled et al., 2007; Legrand et al., 2011; Kromp, 1989, 1999). According to Varchola and Dunn (2001) hedgerows and grassy margins support abundant and diverse populations of ground beetles in conventionally managed corn fields. Hawthorne et al. (1998) investigated to role of margins and strips on different carabid species. They found that the wildlife strips did not create a significant barrier to the movement of *Anchemenus dorsale* and *Bembidion lampros*. On the contrary it was such a favourable habitat that it acted as an additional source of colonising individuals.

Döring and Kromp (2003) used the data from different studies conducted in Germany and Switzerland to find the carabid species that benefit from the organic farming. They evaluated the carabids by using their own indices for activity density and species richness. For ecological and biological traits they included humidity preference, wing dimorphism, seasonal reproduction type, habitat preference, and

body length. But, they did not include the feeding habits and had no data on the effects of grassy strips.

In a recent study, Legrand et al. (2011) used numerical models to investigate one species, i.e. *Pterostichus melanarius* in organic farming. They found that the presence of 20 % of grassy strips caused an asymptotic increase of 25 % of the predator. However, the present study shows that abiotic and biotic factors such as soil pH and tree cover could not be neglected to explain the invasion of carabids into the crop fields.

The size of carabids in urban and in rural habitats is well documented, because the size of carabids indicates habitat disturbance, e.g. disturbed habitats contain a carabid fauna with smaller size, on average (Fujita et al., 2008; Grandchamp et al., 2000; Magura et al., 2004) Only a few studies describe the role of the size of carabids in arable fields in relation to grassy strips (Woodcock et al., 2006). Therefore, (Tscharntke et al., 2002) postulate a need of detailed investigations on the role of the size of carabids concerning habitat fragmentation.

### **1.3.2 Importance of age of the grassy strips in organic agriculture**

During increasing age of grassy strips the stability increases and supports better suitable environmental conditions to polyphagous predators such as carabids.

Thus, hypothesis 2 was:

#### ***(2) Old grassy strips support higher species richness and biodiversity of carabids than younger grassy strips.***

In conventional farming, the age of grassy strips adjacent to the arable crops contributed to biological control (Denys and Tscharntke, 2002). According to Denys and Tscharntke (2002) 6-year-old grassy strips showed higher predator-prey ratios than 1-year-old strips in conventional agricultural farming. In another study with unclear farming management, Frank and Reichhart (2007) reported higher species richness in 3-year-old flower strips than in 1-year-old strips. Further investigations on the role of age in chemically untreated flower strips (2-6 years old) were performed by Anjum-Zubair et al. (2010) in May, 2005, and by Pfiffner and Luka (2000) in 2-16 years old grassy margins to find the overwintering role of the field margins for carabid larvae. However, all three studies show strong disadvantages to interpret the results concerning the role of age of grassy strips. In the study of Frank and Reichhart (2007) the range of the study strips was too narrow, only 1-3 years old; the study of

Anjum-Zubair et al. (2010) was too short, only in May, to reflect representative results; Pfiffner and Luka (2000) had not identified their carabid larvae to species level and, therefore, could not relate their results to the effect of age on biodiversity. According to Hassall et al. (1992) 10-year old uncropped headlands had 80 % greater diversity than 4-year-old one, which had 35 % greater diversity than 1-year old sites.

### **1.3.3 Movement of carabids between natural habitats and crop areas**

In order to know more about the time scale effect of the invasion of carabids, studies on movement and dispersal of carabids are needed. Overall, movement studies on carabids are rare due to the high experimental effort and still less knowledge is available to the effect of grassy strips or margins on the displacement behaviour.

The third hypothesis was:

#### ***(3) Grassy strips control the movement of carabids into the cropping areas***

Few mark-recapture studies have been conducted on carabids in agricultural ecosystems with different kinds of field margins and different crops around them. Frampton et al. (1995) found that untreated grassy strips had a lower permeability than the adjacent barley. In intensive farming, movement of *Pterostichus melanarius* from hedges close to arable crops was investigated by Fournier and Loreau (1999) with the aim to investigate the effect of crop field centres on the food availability. They found that for starved beetles the field centres provide the most favourable habitat to find food rapidly. Lys and Nentwig (1992) investigated beside the speed the direction of three carabid species according to the wheat rows before and after tillage. All three species showed different behaviour according to their parallel or perpendicular walk to rows. Kajak and Oleszczuk (2004) found that large beetles with restricted habitat requirements colonised preferably old shelter belts.

No studies are available that concern the direction of carabid species for their colonisation from the field margins to the crop centre. Similarly, there are only few investigations on the dispersal and rate of dispersal of carabids, especially in organic farming systems, in different crops, and in different seasons.

## Chapter 2

### Methodology

#### 2.1 Description of Experimental area and fields

##### 2.1.1 Experimental site

The experiments were conducted from September 2009 to July 2011 in five organic agricultural fields in Schleswig-Holstein, the northernmost state of Germany. Two of the arable fields were located in Panten and the other three were situated in the neighbouring village Ritzerau (1-3 km apart from Panten) (**Fig. 2.1**). The climate of the region is a moderate Atlantic climate with 691 mm rainfall and 8.1 °C in a 30-year average. The soils of the farms have approximately 23 – 29 % loamy sand, 20 – 35 % loam and 3 – 12 % sand (Reiss et al., 2008).



**Fig. 2.1:** Map of the investigated strips (black lines) in Schleswig-Holstein, northern Germany; p2 and p4 represent 2- and 4-year-old strip fields; R9 is for 9-year-old strip field; Cont (control field); F-2 ( field used for mark recapture in 2011).



The farm in Ritzerau (Hof Ritzerau) consisted of 180 ha of arable fields and changed to organic farming in 2001 and the farm in Panten (Lämmerhof) has been managed according to organic rules for decades and accounted for 410 ha arable fields.

### **2.1.2 Description of the fields**

For the experiments on the role of age of the grassy strips four fields were selected. Three of the fields had grassy strips and one field has no grassy strip (control field). The two fields in Panten had 2- and 4-year-old grassy strips, and a field in Ritzerau had a 9-year-old grassy strip. The control field was selected in Ritzerau, too. The grassy strips bordered either to one or two field margins.

At the 2-year-old grassy strip, one field margin was a hedge along a road and the other field margin was a grassy margin without hedge. The strip was approximately 340 m long and it divided the crop land into two parts.

At the 4-year-old grassy strip, one field margin was a hedge and the other was also a grassy margin with few bushes. The total length of the grassy strip was 150 m.

The field with the 9-year-old grassy strip was at the northernmost arable field of Ritzerauhof adjacent to a forest. The grassy strip was running perpendicular to the forest boundary, starting from the forest. The field margin was a grassy margin adjacent to a hedge separating the forest from the arable crops. The grassy strip was investigated up to 180 m from the forest.

The control field had no grassy strip. One field margin of the control field was a grassy margin with few bushes along the high banks of a small water channel and the other field margin was a grassy margin again. The total length of the control field from one field margin to the other was approximately 900 m.

### **2.1.3 Terminology for natural habitats and arable crops areas**

The control field was used as the initial stage for the age investigation (“0-year-old field”), because grassy strips are usually ploughed after two to three years due the increasing growth of thistles. In order to define the different investigations in the crop land of the control field without grassy strip and the investigations in the crop land adjacent to the grassy strips, the terms “arable land” and “cropping area” were used

for the crop land of the control field and the crop land adjacent to the grassy strips, respectively.

#### **2.1.4 Plant composition of grassy strips**

All grassy strips crossing the arable fields and the grassy strips of the field margins were approximately 3 m wide. A seed mixture having ten herb species and few grass species, e.g., *Hordeum vulgare* L. was used to establish the grassy strips. However, after a period of 2 years all grassy strips were dominated by the main grass species, i.e., *Lolium perenne* L., *Poa trivialis* L., and *Elymus repens* (L.) Gould. Both grass coverage and species richness ranged between 60 % - 70 % and 50 - 60 species, respectively, and represented the typical grassy vegetation in moderately moist sites of northern Germany (Roweck, 2008)

All field edges were characterised by woods or hedges and a grassy strip in front of them adjacent to the field with the same vegetation as in the established grassy strips.

#### **2.2 Layout of the pitfall traps and mark-recapture method**

The effect of age of grassy strips and distance from field margins along the grassy strips on the distribution of species and on the biodiversity was investigated on the four sites described above from September 2009 to October 2010. The carabids were sampled using pitfall traps. Glass jars were used as pitfall traps that had an opening of 5.6 cm diameter and were covered by a transparent shield to protect against direct rainfall. The jars were half filled with 90 % glycol and a surface tension reducing agent. Two parallel rows of pitfall traps were installed: one in the arable field and one in the grassy the strip. The interval between the rows of pitfall traps was 30 m, beginning at a distance of 30 m from the field margins. Distance between the field rows and the strip rows were also 30 m. Since the strips were narrow, only 2 replicate pitfall traps could be installed in each row per 30 m interval in approximately 1.5 m distance from each other. At one field with the 2-year-old grassy strip of the Lämmerhof (Panten), two parallel rows were installed in the arable fields on both sides of the strip. In the control field 50 m intervals were used due to the long distance between the field edges. The fields with two field edges, 2- and 4-year-old grassy strip fields, received two sets of traps for each distance, because the distances used for further calculations referred to the nearest field edge.

Three pitfall traps were set up in each field margin. Pitfall traps were changed at monthly intervals, but intervals changed sometimes due to agronomic practices or the

weather conditions in winter. Since the control field was omitted, a total of 115 traps were used for the analysis of ecological groups and distribution of species along the grassy strips. A total of 150 traps were used to analyse the role of age of the grassy strips on the biodiversity of carabids.

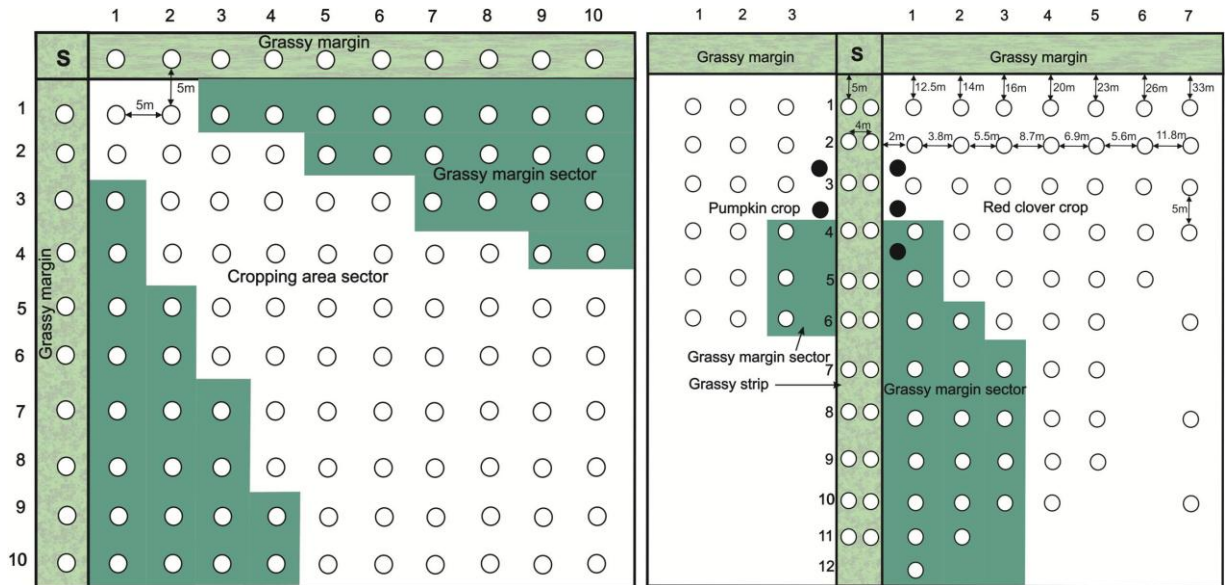
For the movement experiment conducted in 2010 and 2011, three fields were selected: two fields were located on Ritzerauhof (field-1, field-3) and a third on Lämmerhof (field-2). Both field-1 and field-2 of this experiment were identical with the 9-year-old grassy strip field and 2-year-old grassy strip field of the former investigation, respectively. The third field (field-3) was situated in the centre of the agrarian fields of Ritzerauhof, at a distance of approximately 500 m from field-1. Field-1 and field-2 were investigated in 2010 and field-1 and field-3 in 2011.

Pitfall traps without killing agent were used to capture the beetles alive in the movement experiment. For the safety of the living beetles, a transparent plate raised by two iron rods over the traps was used to protect them against birds and rain. In order to provide more shelter within the traps, a piece of cork, some leaves of plants, and few stones were put in the traps. A total of both 250 and 230 pitfall traps were established in 2010 and 2011, respectively.

The pitfall traps were established in rows parallel to the grassy structures at a distance of approximately 5 m from apart each other (**Fig. 2.2**). On field-1 of Ritzerauhof, winter wheat (*Triticum aestivum*) was sown 2010, and red-clover (*Trifolium pratense*) in 2011. In both years, a total 110 traps were installed in a 10 x 11 trap grid.

The field-2 of the Lämmerhof had a grassy strip diving two crop fields planted with red-clover and pumpkin (*Cucurbita maxima*). The grassy strip had of 22 traps in two parallel rows (4 m apart) in distance of 5 m from each other. In the pumpkin crop, 18 traps were installed in three parallel rows at a distance of 5 m apart. In the red-clover crop, 59 pitfall traps were established in 7 rows in different distances. In the red-clover side, the distances from the grassy margin from the first to seventh row were 2, 5.8, 13.3, 20, 26.9, 32.5, and 44.3 m, respectively. Moreover, 2 traps were installed at a distance of 1.5 m from the grassy strip on the pumpkin side and 3 traps on the red clover side, in order to investigate the dispersal of carabid species in the area close to the grassy strip.

Field-3 only investigated in 2011 and provided a similar layout as field-1. In contrast to field-1, field-3 had two grassy strips without hedge. Wheat crop was sown on the arable field and 120 pitfall traps were established in an 11 x 11 minus 1 grid.



**Fig. 2.2:** Experiment layout in Ritzerau fields (field-1 and field-3; left) and Panten (field-2; right); filled circles in Panten field were close to the grassy strip (1.5m distance); traps in rows were at ~ 5m distance; point of release at S (“source”)

All beetles captured were marked and released at the intersection of the two crops and the grassy strip. Mutilation method was used to mark the beetles by a marking-drill machine. This method is easy and fast to mark a high number of beetles. Small but visible scratches were made on the elytra of the beetles according to Southwood and Henerson (2001) which allows the marking of maximum 1023 specimens. The number of *Pterostichus melanarius* exceeded the number 1023, which made it necessary to use the pronotum for further numbering. The marked and recaptured beetles released on the same evening of capture one after another, in the way that the first beetle disappeared before the second beetle was released.

Since the mark-recapture investigations are tedious to conduct, only the following species were selected: *Pterostichus melanarius* (13-17 mm), *P. niger* (16-21 mm), *Carabus auratus* (17-30 mm), *C. nemoralis* (22-25 mm), *Poecilus* spp. (11-13 mm), and *Nebria brevicollis* (11-14 mm). The major reasons for their selection are the large size (e.g. *Carabus* spp., and *Pterostichus* spp.), which helped to identify the specimens in the field with the naked eye and made the marking and reading procedure easy. In addition, they are good indicators of organic farming (e.g. *C.*

*auratus*), associated with grassy strips (e.g. *Poecilus* spp., and *P. niger*) and are the most abundant species in these fields (e.g. *P. melanarius* and *Poecilus* spp.). Only *Poecilus* spp. could not be identified to species level, since the two very similar species, i.e. *Poecilus cupreus* and *P. versicolor*, were found in these fields. According to former investigations *P. cupreus* was the more frequent one (Ranjha and Irmeler, 2013).

### **2.3 Analysis of the data**

The influence of organic farming on the carabid species was found by transforming the activity density into the dominance values, as the capture efficiency of the traps in the three habitats (grassy margins, grassy strips and cropping areas) was distinctly different (e.g. Wallin and Ekbohm, 1988). The activity density was taken as individuals (ind.) 100 trap days<sup>-1</sup>, because the trapping intervals were not equal and uniformity was needed between the sampling periods. The indication values of each species were derived from the information given by Irmeler and Gürlich (2004), who used the relationship between the species and their specific environment conditions at more than 250 sites in Schleswig-Holstein. Only tree cover and soil pH showed significant effects. So, these parameters were taken for each species and the indication value of each group was calculated as the average of the specific indication values per group. Additionally, the correlation coefficient for tree cover was used. For the analysis of the distance effect on the distribution of carabid species the Wilcoxon and Sign-test were used. The Red List classification was derived using the information given by Gürlich et al. (2010). The classification of carabids based on the size data according to Müller-Motzfeld (2004). The carabids were classified into 4 groups: small: < 5 mm, medium > 5 – 10 mm, large: > 10 – 15 mm, and very large: > 15 mm. The groups were statistically compared using the nested ANOVA.

In order to determine the role of the age of the grassy strips, activity density, species richness, and biodiversity indices Shannon' H and evenness were used. The activity density of carabids was calculated in individuals (ind.) 100 trap days<sup>-1</sup>. For species richness the following methods were used: (1) total number of species per trap, (2) sample-rarefaction method and (3) species number needed for 90 % of dominance. For the last parameter, the species were ordered in decreasing order of dominance and the number of species needed to get 90 % of the total specimens was taken. This parameter was selected, because the capture efficiency of traps in arable fields is higher than in grassland or forests (Wallin and Ekbohm, 1988) and to avoid effects by accidental species. The biodiversity was determined by Shannon's H and evenness.

The effects of habitats (field edges, grassy strips, cropping areas, and control field) on the assemblages of the carabids were analysed using the Detrended Correspondence Analysis (DCA). In the DCA, the traps of the cropping areas, strips, and field edges of each of the three fields and of the control field were combined into one sample. In addition, in order to see whether the activity density, species richness, Shannon's  $H$ , and evenness of carabids differ between the four habitats, a nested ANOVA was performed, where all the individual traps were nested within the habitats. In the nested ANOVAs, each grid of two traps was combined to one sample to make a distance gradient. Therefore, the grids at the same distance from the two field edges were considered to be two samples. Similarly, the three traps of each field edge were used as one sample. The nested ANOVAs were performed to overcome the problem of pseudo-replications (Hurlbert, 1984).

The effects of age of grassy strips and the distance from the field edges were analysed by using multiple linear regressions after testing the data on normal distribution. For the analysis of feeding groups, carabids were classified, according to their feeding habits, into three groups, i.e. carnivorous, omnivorous and phytophagous. To find the effect of strips on the cropping areas, only the values of the cropping area traps in at least 60 m distance from the field edges were used in order to omit the edge effect.

To analyse the movement of carabids from natural habitats to crop fields, the distances covered in the grassy strips and cropping areas were measured. The distance from the point of release to the trap where it was captured was defined as the distance covered per time interval. For speed ( $\text{m day}^{-1}$ ), the distance covered was divided by the number of days. Distance and speed was compared between grassy strips and cropping areas by U-test. In addition, distance and speed were compared between the crops by the U-test or Kruskal-Wallis test. The significant differences in Kruskal-Wallis tests were determined using the Bonferroni correction.

In order to determine the direction of movement from the point of release, the traps were divided into two sectors: grassy sector and crop sector. The grassy sector included the traps in the grassy strip plus the traps in the cropping area close to the grassy strip up to at least 15 m away from the releasing point. This method was selected to give the beetles enough time for orientation and space to decide their destination. The numbers of specimens captured in the grassy sector and the crop sector were compared using the Chi-square test to find whether the observed number differs from the expected number. To find the behavioural differences of the carabids in deciding for a certain sector, a Bonferroni adjusted pair-wise Chi-squared tests for

homogeneity were applied to compare the potentially different preference of the species.

## **2.4 Brief introduction to thesis chapters**

The **Chapter 1** give motivation and introduction of the study. The **Chapter 2** contains the methods adopted during the study. The **Chapter 3** of the thesis shows the results of the project. The results in **Chapter 3.1** analyses the carabids which have higher advantages from grassy margins on the basis of their ecological response to abiotic parameters. The findings about the role of the age of field margins on biodiversity of carabids in general and on the basis of their body sizes, their feeding habits, and the endangered species in the study area is presented in **Chapter 3.2**. The dispersal and rate of dispersal of most abundant carabids in the grassy strips and in adjacent crops as well as the direction of their colonisation is documented in **Chapter 3.3**. For the comprehensive summary of results of the whole thesis, **Chapter 4** is added.

## Chapter 3 Results

*Chapter 3 is subdivided into 3 parts according to 3 manuscripts which are published, accepted or submitted.*

### 3.1 Which carabid species benefit from grassy strips in organic agriculture?<sup>a</sup>

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#### **Abstract**

The carabid fauna of three organic arable fields, their grassy strips, and field margins were investigated by pitfall traps in 2009/2010 at Ritzerau and Panten (Schleswig-Holstein, northern Germany). *Bembidion lampros* was mainly found on the organic arable fields, *Amara similata* in grassy strips, and *Carabus nemoralis* and *C. coriaceus* in the field margins. Strips were mainly used by species which prefer open areas without tree cover and also by few species demanding tree cover. In contrast, arable fields were characterised by species avoiding vegetation cover. All species analysed were demand on soil pH ranging from 4.6 to 5.6. Species that occurred on lower soil pH were absent from the investigated habitats. It can be derived from the results that *Poecilus cupreus*, *Poecilus versicolor*, and *Carabus nemoralis* used the grassy strips to invade or cross arable fields, while *Pterostichus melanarius*, *Anchomenus dorsalis*, *Nebria brevicollis*, and *Trechus quadristriatus* passed directly arable fields from field margins. Grassy strips did not affect the species richness of endangered species. Strips and arable fields were characterised by a high species richness of intermediately sized carabids, while field edges had low amounts of small sized species.

**Keywords:** Carabidae, organic agriculture, grassy strip, mobility, invasion into arable fields

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<sup>a</sup> Accepted in Angewandte Carabidologie



### 3.1.1 Introduction

The loss of biodiversity in Central Europe is closely related to the intensification of agriculture and the combined effect of changes in the agricultural landscape by the removal of natural habitats (KREBS et al. 1999, FLYNN et al. 2009). The size of the area and the pattern of natural and semi-natural habitats in the agricultural landscape are important for the retreat and source potentials of the fauna (SMITH et al. 2008). The colonization of arthropods after ploughing or insecticide application depends mainly on the potential of the adjacent non-arable habitats (TSCHARNTKE & KRUESS 1999). Thus, sustainable land use, expected to solve the contradictory challenges of environmental protection and food production, must also integrate the total landscape, including agricultural and non-agricultural areas.

Natural and semi-natural habitats such as grassy strips, hedges and hedgerows prevent the loss of biodiversity in agricultural landscapes (BENTON et al. 2003). Grassy strips are corridors for dispersal, sources of food, sites for refuge and sites for overwintering (THOMAS et al. 1991; BOMMARCO 1998; ASTERAKI et al. 1995; FRANK & REICHHART 2004; DENYS & TSCHARNTKE 2002). The benefit of grassy or floral strips for biodiversity has mainly been found for conventional agriculture (LYS et al. 1994, VARCHOLA & DUNN 2001). In a review study, BENGTTSSON et al. (2005) found positive effects of organic farming on predatory carabids. In addition, the species that benefit from organic agriculture were reviewed by DÖRING (2003). Recent investigations found that after six years of organic agriculture the diversity in the field centres equals that at field margins, which implies that grassy strips are less effective in organic agriculture than in conventional agriculture (SCHRÖTER & IRMLER in press).

Ground beetles are one of the most numerous groups of insects that can be found in agroecosystems in the northern hemisphere (KROMP 1999). Because of their feeding behaviour, they played an important role in pre-industrial farming as natural pest and weed control agents, and may be of further interest for sustainable agriculture. The low dispersal ability of many carabids hampers the rapid recuperation of losses in arable fields within a farming year (THOMAS et al. 1991). Carabids are therefore regarded as useful model organisms and indicators of the diversity processes in agricultural landscapes (KOIVULA 2011).

Using carabids as indicator organisms, this investigation studies the effect of grassy strips in organic fields with the main questions: (1) Which species benefit from grassy strips? (2) Which ecological demands support the use of strips? (3) What effects do the strips have on endangered and differently-sized species?

### 3.1.2 Sites and methods

The investigation was performed from September 2009 to October 2010 in three organic arable fields at Panten and Ritzerau (Schleswig-Holstein, northern Germany) (Fig. 3.1.1). The region is characterised by moderate continental climate with 691 mm rainfall and 8.1 °C in a 30-year average. The two farms are adjacent areas and have soils with approximately 23 – 29 % loamy sand, 20 – 35 % loam and 3 – 12 % sand (REISS et al. 2008). The farm in Ritzerau (Hof Ritzerau) consisted of 180 ha of arable fields and changed to organic farming in 2001. The farm in Panten (Lämmerhof) has been managed according to organic rules for decades accounted for 410 ha arable fields. A 180 m long grassy strip was investigated in Ritzerau and two grassy strips (150 m and 330 m) were selected in Panten. The two grassy strips in Panten connected field margins on both sides, whereas only one end of the strip in Ritzerau connected to a field margin. All field margins were characterised by woods or hedges and a grassy strip in front of them adjacent to the field. All grassy strips crossing the arable fields and the grassy strips of the field margins were approximately 3 m wide. The strips and field margins were dominated by the main grass species, i.e. *Lolium perenne* L., *Poa trivialis* L., and *Elymus repens* (L.) Gould. Both grass coverage and species richness ranged between 60 % - 70 % and 50 - 60 species, respectively, and represented the typical grassy vegetation in moderately moist sites of northern Germany (ROWECK 2008). The crop on the arable fields was wheat.

Ground beetles were sampled by using pitfall traps. The glass jars used as pitfall traps had an opening of 5.6 cm diameter and were covered by a transparent shield to protect from direct rainfall. They were half filled with 90 % glycol and a surface tension reducing agent. Two rows of pitfall traps were installed: one in the arable field and one in the grassy the strip. The traps of the rows were in 30 m intervals, beginning at a distance of 30 m from the field margins and a maximum distance of 180 m. Distance between the field row and the strip row was also 30 m. Due to the narrow width of strips, only 2 replicate pitfall traps were installed in each row per 30 m interval in approximately 1.5 m distance from each other. At one field on the Lämmerhof, two parallel rows were installed in the arable fields on both sides of the strip. Three pitfall traps were set up in each field margin. Thus, a total of 118 pitfall traps were available for the analysis. Pitfall traps were changed at monthly intervals, but intervals changed sometimes due to weather conditions in winter.

For the analysis, activity density was transformed into dominance values, as the capture efficiency of the traps in the three habitats was distinctly different (e.g. WALLIN & EKBOM 1988). The indication values according to IRMLER & GÜRLICH

(2004) for the analysis of the species – environment relationship were used. As only tree cover and soil pH had significant results, these parameters were taken for each species and the indication value of each group was calculated as the average of the specific indication values per group. Additionally, the sign of correlation coefficient for tree cover was used. The values of the intervals in strips or arable fields were analysed using the Wilcoxon and Sign test. The Red List species were selected according to GÜRLICH et al. (2010). For the size analysis, the mean value of the size range of the species was taken (MÜLLER-MOTZFELD 2004). The carabids were classified into 4 groups: small: < 5 mm, medium > 5 – 10 mm, large: > 10 – 15 mm, and very large: > 15 mm. The groups were statistically compared by the nested ANOVA. The program STATISTICA 6.1 (STATSOFT 2004) was used for the statistical analyses.

### **3.1.2 Results**

#### **3.1.2.1 Species composition**

A total of 14,527 specimens were captured during the investigation. Arable fields provided the highest number with 10,159 specimens; grassy strips and field margins contributed to 3675 and 693 specimens, respectively (Table 3.1.1). Concerning species richness, the arable fields, grassy strips and field margins accounted for 61, 60 and 46 species, respectively. Only six species were found to have a significantly higher dominance in one of the three habitats. Among these species, only a single species, i.e. *Bembidion lampros*, showed the highest dominance in arable fields; three species were more dominant in arable fields and grassy strips; two species were more dominant in field margins. The majority of species was found in all three habitats with no significant preference for one of the habitats. The remaining species were rarely captured and could not be analysed statistically. Nevertheless, their distribution was specific in arable fields, strips or field margins.

The species showing no significantly higher dominance in one of the three habitats were characterised by similar indication values as the species found only in arable fields or in arable fields and strips concerning tree cover or soil pH (Table 3.1.2). The field and strip species were generally characterised by their preference of open habitats. In contrast, species found in strips and margins or found only in margins exhibited a higher affinity to tree cover. Both groups were significantly separated according to ANOVA (DF: 4, 43; F: 6.3;  $p < 0.001$ ). The same trend was found when

species with positive or negative correlation to tree cover were separated. In arable fields or additional grassy strips, only 1 species each was found that had a positive correlation to tree cover, whereas 6 to 11 species had negative correlations. In contrast, the majority of species from strips and field margins were positively correlated to tree cover. The pH preference of these species was generally near 5. Species found only in arable fields showed no preference for higher pH than species found only in strips (ANOVA: DF: 4, 40; F: 2.4;  $p < 0.06$ ). Only the group of species that occurred in field margins and strips showed a slight, but significant ( $p < 0.05$ ) lower pH preference than the species of the other groups.

### **3.1.2.2 Distances covered from field margins into arable fields and grassy strips**

The comparison of dominances along the intervals using Wilcoxon and Sign test showed that three species had higher dominance in strips than in adjacent crop areas (Table 3.1.3). However, four species occurred in higher abundance in the crop areas than in the strips. Twenty-two species showed no significant differences between the crop areas and the strips, but six of these species showed significant results with the Wilcoxon test, indicating that the dominances in the two lines of traps were different. In the first group, *Poecilus cupreus* and *P. versicolor* were less dominant in the field edges than in the strips and crop areas, whereas *Carabus nemoralis* was found in higher dominance in the field edges than in the strips and crop areas (Fig. 3.1.2). The dominance of *P. cupreus* increased more or less continuously from the field edges to 180 m distance into crop areas and strips. *P. versicolor* reached a steady state of dominance at a distance of 30 m in both crop areas and strips; however, it reached a dominance that was nearly two times greater in the strips than in the crop area at 180m distance. In contrast, *C. nemoralis* showed a strong decrease of dominance in the first 30 m from the field edges in arable fields; in strips, a slighter decline was found at 30 m and another stronger one at 90 m.

Among the species with higher dominance in the arable fields than in the strips, *Pterostichus melanarius* increased in dominance from field edge to a distance of 120 m, whereas *Anchomenus dorsalis* showed a slight decline from the field edge to a distance of 180 m into the crop areas. *Nebria brevicollis* was equally dominant in field edges and crop areas, but had a strong decline in the strips after a distance of 30 m. Among other species with significant results in the Wilcoxon test, *Carabus coriaceus* and *P. strenuus* were nearly absent from the field traps and were found rarely in the strips (Fig. 3.1.3). In contrast, *Amara similata* and *Harpalus affinis*

occurred in low dominance in the field edges and the crop areas, but had a distinctly higher dominance in the strips.

### 3.1.2.3 Effect of strips on endangered and differently sized species

In total, 15 species were listed as endangered in the Red List of Schleswig-Holstein. Average numbers of species per trap were:  $0.9 \pm 0.5$  ( $n = 18$ ) in the field margins,  $1.4 \pm 0.5$  ( $n = 26$ ) in the strips and  $1.4 \pm 0.8$  ( $n = 44$ ) in the arable fields (DF: 2,115). The differences between the habitats were not significant ( $F = 6.37$ ,  $p = 0.2$ ).

The results of the nested ANOVA reflected an effect of carabid size and habitat type on the number of species ( $F = 78.1$ ,  $p < 0.001$ ). Size had a higher effect (DF: 3, 382;  $F: 169.1$ ;  $p < 0.001$ ) than the habitats (DF: 8, 382;  $F: 18.1$ ;  $p < 0.001$ ). The different size groups showed that the very large species were found in equal numbers in all three habitats (Fig. 3.1.4). Small species were not found as often in the field margins as in the two other habitats, whereas medium and large sized species were more frequent in grassy strips and arable fields. No difference in the size classes of carabids was found between grassy strips and arable fields.

### 3.1.3 Discussion

Concerning the species composition, the investigated arable fields represented the most common carabid assemblage of arable fields on loamy soils in Schleswig-Holstein (SCHRÖTER 2010; IRMLER & GÜRLICH 2004). Compared to that assemblage, the dominance of *Pterostichus melanarius* was low with 12 %, which can be explained by the seven year period of organic farming (SCHRÖTER & IRMLER in press). According to IRMLER & GÜRLICH (2004), the high dominance of *Bembidion lampros* on the fields investigated indicated a higher affinity to smaller-sized arable fields and to organic farming than the typical assemblage with dominance of *P. melanarius*. The positive relationship of *B. lampros* to organic farming was also found by SCHRÖTER (2010), although the correlation was still weak after 2 years of organic farming. Its preference to arable fields showed that the species is not dependent on the field margins or strips. Its dependence on the management of the arable fields makes it a valuable indicator for organic farming. It was astonishing to find that *P. melanarius*, which is generally an indicator of arable fields, also showed high dominances in strips and field margins. In contrast to *B. lampros*, this species also often used habitats adjacent to arable fields. Their nocturnal activity, which is supported by the darker grassy strips, could be an explanation for this behaviour (CHAPMAN et al. 1999). According to WALLIN (1988), *P. melanarius* reproduced and

developed larvae in arable field, but adults also used field margins. Similar results were found for *Poecilus cupreus* as well; reproduction and larval development was reported to occur in arable field areas, while adults used field margins for predation (WALLIN 1988).

The effects of grassy strips in agricultural landscapes were investigated in the last decades in both grassland and arable fields. In grasslands, NENTWIG (1988) found a higher diversity of carabids under strip-managed areas than in mown areas or mown strips. Perennial grass strips also enhanced abundance and species richness of leafhoppers in comparison to cereal fields (HUUSELA-VEISTOLA & VAARAINEN 2000). Our investigation does not support this positive effect of strips and margins on the species richness in organically farmed fields. Under organic farming, species of the field margin invaded the field centres that resembled the field margins after 6 years of organic farming (SCHRÖTER & IRMLER 2013). Nevertheless, seasonal changes based on the invasion process were found even in small organic fields (JUEN & TRAUGOTT 2004).

Invasion in our studies should be understood as a process of one or more years, because strips can also function as overwintering habitats. However, grassy strips only persist usually two to three years and are developed at another site after that time due to the increasing thistle abundance. In our investigation, strips supported the invasion of species preferring no vegetation cover and species preferring vegetation cover, whereas only species avoiding vegetation cover were supported by fields. In particular, species that were found mainly in field margins preferred vegetation cover. In contrast to typical species of forests, all species of arable fields, strips and field margins require a soil pH ranging between 4.6 and 5.6. As described by IRMLER & GÜRLICH (2004), species of forests that prefer lower soil pH ranging between 3.4 and 4.4 avoided the strips and field margins. Typical species mainly occurring in field margins and using the strips as corridors into arable fields are *Carabus nemoralis*, *C. coriaceus*, and *P. strenuus*. All three species can be described as euryecious species having a weak preference for forests (IRMLER & GÜRLICH 2004). Our data showed that they invaded from the field margins using the grassy strips and rarely crossed into arable fields. Among these three species, *C. nemoralis* revealed the highest mobility, as it was found in high dominance at a distance of up to 90 m into the grassy strips. Dominance of *C. coriaceus* drastically declined at a distance of 30 to 60 m from the field margin; the dominance of *P. strenuus* was generally low in strips and arable fields.

In contrast to these species that need at least weak tree cover, species demanding open habitats, e.g. *P. cupreus*, *P. versicolor*, and *Amara similata*, avoided field margins. They increased in dominance with an increase in distance from the field margin, except for *A. similata* that declined in 150 m distance from field margin. Thus, it can be assumed that field strips support these species, in particular, as they were found in higher dominances in strips than in field margins. The specific conditions of strips seemed to have a positive effect on the species. *Anchomenus dorsalis* was considered to overwinter in hedges of field margins and to invade from there into arable fields in the spring (JENSEN et al. 1989; MAUDSLEY et al. 2002). According to our data, grassy strips do not support this invasion. As expected, dominances were highest in field margins, but decreased more in strips than in arable fields.

Strips do not seem to affect endangered and differently-sized species, because the composition of differently-sized carabids was the same in arable fields and grassy strips. In contrast, field margins revealed a different size composition. In field margins, the number of very large species (> 15 mm) was higher than in grassy strips and arable fields, whereas the number of small (< 5 mm) species was lower. In grassy strips and arable fields, intermediate species between 5 mm and 15 mm dominated. This may be referred to the flight ability, since brachypterous carabid species benefit from the age of remote areas (PLATEN et al. 2012). High mobility with high flight potential is generally more developed in small and intermediate sized carbides. Thus, agricultural practices such as intensive grazing can influence the corridor dispersal of flightless species, for example, by *C. nemoralis* which are less tolerant to disturbances than species with flight ability (PETIT & USHER 1998).

### **3.1.4 Acknowledgement**

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**Table 3.1.1:** Dominance and activity density of carabids in field margins, grassy strips and arable fields; +: < 0.2 %; RL SH: Status according to Red List Schleswig-Holstein; different exponents indicate significant differences according to ANOVA (p < 0.05); v: rare species.

	RL SH	Dominance (%)			Ind 100 days <sup>-1</sup>		
		Field	Strip	Margin	Field	Strip	Margin
<i>Bembidion lampros</i>		<sup>a</sup> 9.9	<sup>b</sup> 5.4	<sup>b</sup> 3.1	35.82	12.59	0.23
<i>Poecilus cupreus</i>		<sup>a</sup> 14.2	<sup>a</sup> 16.8	<sup>b</sup> 0.8	64.18	37.32	0.08
<i>Pterostichus melanarius</i>		<sup>a</sup> 12.6	<sup>ab</sup> 7.9	<sup>b</sup> 7.2	67.74	19.29	0.75
<i>Amara similata</i>		<sup>ab</sup> 1.3	<sup>a</sup> 4.2	<sup>b</sup> 0.8	3.28	10.83	0.10
<i>Carabus nemoralis</i>		<sup>b</sup> 0.5	<sup>ab</sup> 4.5	<sup>a</sup> 11.5	1.93	5.42	0.73
<i>Carabus coriaceus</i>		<sup>b</sup> 0.1	<sup>b</sup> 0.5	<sup>a</sup> 2.9	0.23	0.59	0.27
<i>Anchomenus dorsalis</i>		10.3	3.9	11.9	35.59	8.47	1.33
<i>Nebria brevicollis</i>		8.2	3.8	6.6	36.00	5.87	0.73
<i>Harpalus rufipes</i>		9.0	6.9	11.2	36.34	9.38	0.96
<i>Bembidion tetracolum</i>		2.6	3.2	1.8	9.22	4.45	0.21
<i>Calathus fuscipes</i>		0.8	0.3	0.6	3.79	0.80	0.06
<i>Trechus quadristriatus</i>		6.6	3.3	5.9	17.61	4.08	0.64
<i>Carabus auratus</i>	3	6.9	14.4	9.0	29.71	13.60	0.55
<i>Harpalus affinis</i>		6.3	8.0	6.1	21.07	17.16	0.43
<i>Poecilus versicolor</i>		3.0	6.2	1.9	13.73	13.07	0.16
<i>Agonum muelleri</i>		1.5	0.7	0.5	5.21	1.20	0.10
<i>Carabus granulatus</i>		0.6	0.5	0.9	2.46	0.89	0.08
<i>Clivina fossor</i>		1.1	1.9	0.9	2.40	1.80	0.06
<i>Amara aenea</i>		0.7	1.0	0.6	2.31	2.31	0.06
<i>Amara familiaris</i>		0.7	1.1	1.6	1.77	3.00	0.11
<i>Loricera pilicornis</i>		0.3	+	0.3	0.66	0.19	0.02
<i>Pterostichus niger</i>		+	0.7	0.2	0.60	0.47	0.02
<i>Synuchus vivalis</i>		+	0.2	1.9	0.61	0.43	0.25
<i>Pterostichus strenuus</i>		+	0.5	1.5	0.21	0.47	0.11
<i>Harpalus latus</i>		+	0.1	0.2	0.45	0.75	0.04
<i>Amara consularis</i>	v	+	0.2	0.2	0.89	0.25	0.02
<i>Pterostichus diligens</i>		+	0.2	0.3	0.42	0.25	0.02
<i>Harpalus rubripes</i>		+	+	0.3	0.10	0.14	0.02
<i>Amara plebeja</i>		+	+	0.5	0.21	0.05	0.04
<i>Stomis pumicatus</i>		+	+	0.8	0.03	0.05	0.10
<i>Oxypselaphus obscurus</i>		+	+	0.9	0.08	0.15	0.04
<i>Anisodactylus binotatus</i>		+	+	0.2	0.04	0.15	0.02
<i>Trichocellus placidus</i>		+	.	0.2	0.04	.	0.02
<i>Bembidion obtusum</i>	v	0.3	.	.	0.39	.	.
<i>Microlestes minutulus</i>		+	.	.	0.39	.	.
<i>Limodromus assimilis</i>		+	.	.	0.16	.	.
<i>Amara communis</i>		+	.	.	0.13	.	.
<i>Philorizus melanocephalus</i>		+	.	.	0.19	.	.
<i>Poecilus lepidus</i>	3	+	.	.	0.09	.	.
<i>Harpalus neglectus</i>	2	+	.	.	0.04	.	.
<i>Pterostichus nigrita</i>		+	.	.	0.04	.	.
<i>Chlaenius nigricornis</i>	3	+	.	.	0.04	.	.
<i>Zabrus tenebriodes</i>	1	+	.	.	0.04	.	.
<i>Calathus erratus</i>		+	.	.	0.04	.	.
<i>Ophonus rufibarbis</i>		+	.	.	0.04	.	.

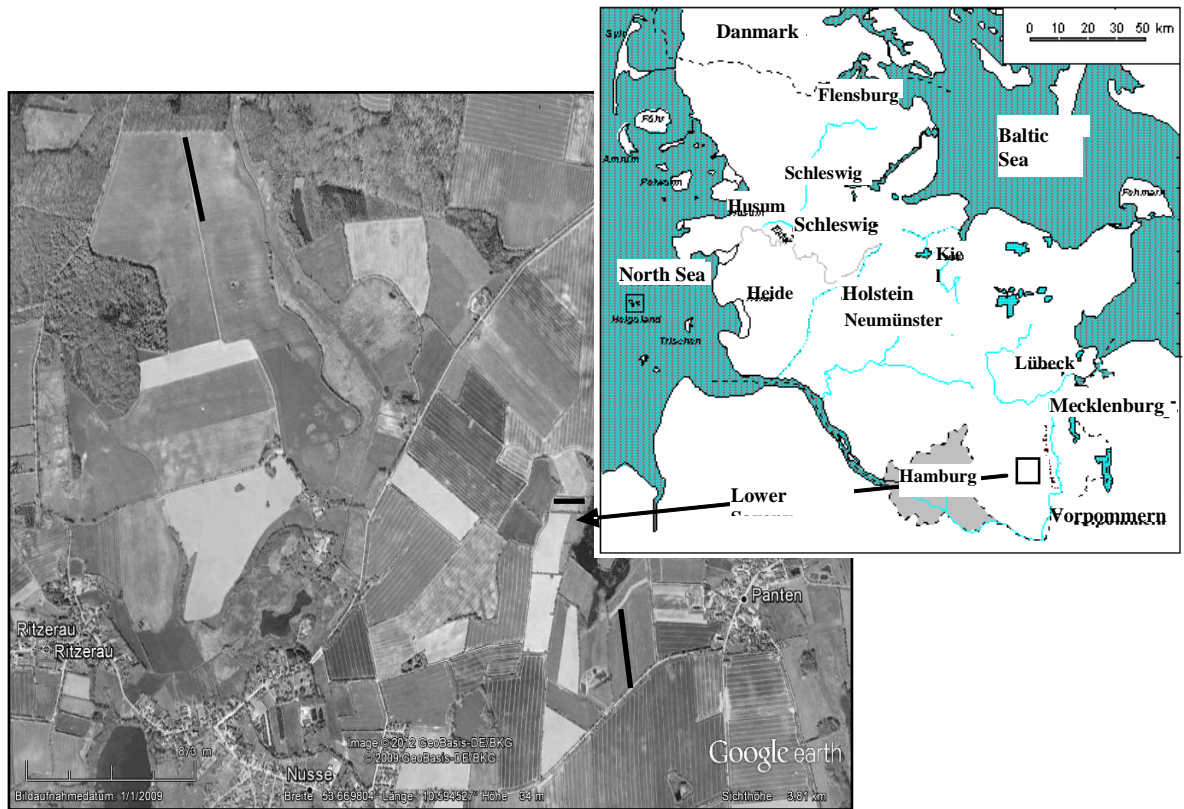
<i>Acupalpus exiguus</i>		+	.	.	0.03	.	.
<i>Demetrias atricapillus</i>		+	.	.	0.03	.	.
<i>Bembidion properans</i>		0.5	0.5	.	1.61	1.12	.
<i>Harpalus tardus</i>		0.3	0.3	.	0.87	0.48	.
<i>Notiophilus biguttatus</i>		0.2	+	.	0.41	+	.
<i>Amara aulica</i>		+	+	.	0.33	0.09	.
<i>Calathus melanocephalus</i>		+	0.2	.	0.23	0.30	.
<i>Harpalus signaticornis</i>	v	+	+	.	0.15	0.19	.
<i>Harpalus distinguendus</i>	3	+	+	.	0.14	0.05	.
<i>Acupalpus meridianus</i>	v	+	+	.	0.22	0.10	.
<i>Pterostichus vernalis</i>		+	+	.	0.18	0.05	.
<i>Amara anthobia</i>	3	+	+	.	0.12	0.05	.
<i>Amara lunicollis</i>		+	+	.	0.03	0.20	.
<i>Harpalus rufipalpis</i>		+	0.2	.	0.04	0.11	.
<i>Trechoblemus micros</i>		+	+	.	0.09	0.05	.
<i>Bradycellus harpalinus</i>		+	+	.	0.04	0.05	.
<i>Leistus terminatus</i>		.	+	.	.	0.05	.
<i>Syntomus truncatellus</i>		.	+	.	.	0.05	.
<i>Syntomus foveatus</i>		.	+	.	.	0.05	.
<i>Badister sodalis</i>		.	+	.	.	0.05	.
<i>Amara tibialis</i>		.	+	.	.	0.10	.
<i>Calathus cinctus</i>	v	.	+	.	.	0.05	.
<i>Calosoma auropunctatum</i>	2	.	+	.	.	0.05	.
<i>Abax parallelepipedus</i>		.	0.8	0.7	.	0.38	0.10
<i>Carabus violaceus</i>		.	+	0.2	.	0.05	0.02
<i>Cychrus caraboides</i>		.	+	0.2	.	0.05	0.02
<i>Bembidion guttula</i>		.	+	0.3	.	0.05	0.02
<i>Pterostichus oblongopunctatus</i>		.	1.0	0.9	.	0.12	0.11
<i>Panagaeus bipustulatus</i>	3	.	+	0.3	.	0.05	0.02
<i>Bembidion lunulatum</i>	2	.	.	0.3	.	.	0.02
<i>Bembidion biguttatum</i>		.	.	0.6	.	.	0.02
<i>Leistus rufomarginatus</i>		.	.	0.2	.	.	0.02
<i>Calathus rotundicollis</i>		.	.	0.2	.	.	0.02
<i>Badister bullatus</i>		.	.	0.4	.	.	0.04
<i>Carabus hortensis</i>		.	.	2.1	.	.	0.12
<i>Notiophilus palustris</i>		.	.	0.3	.	.	0.04

**Table 3.1.2:** Affinity of carabid species to canopy cover and soil pH; different exponents indicate significant difference according to ANOVA ( $p < 0.05$ ); +: positive reaction, -: negative reaction

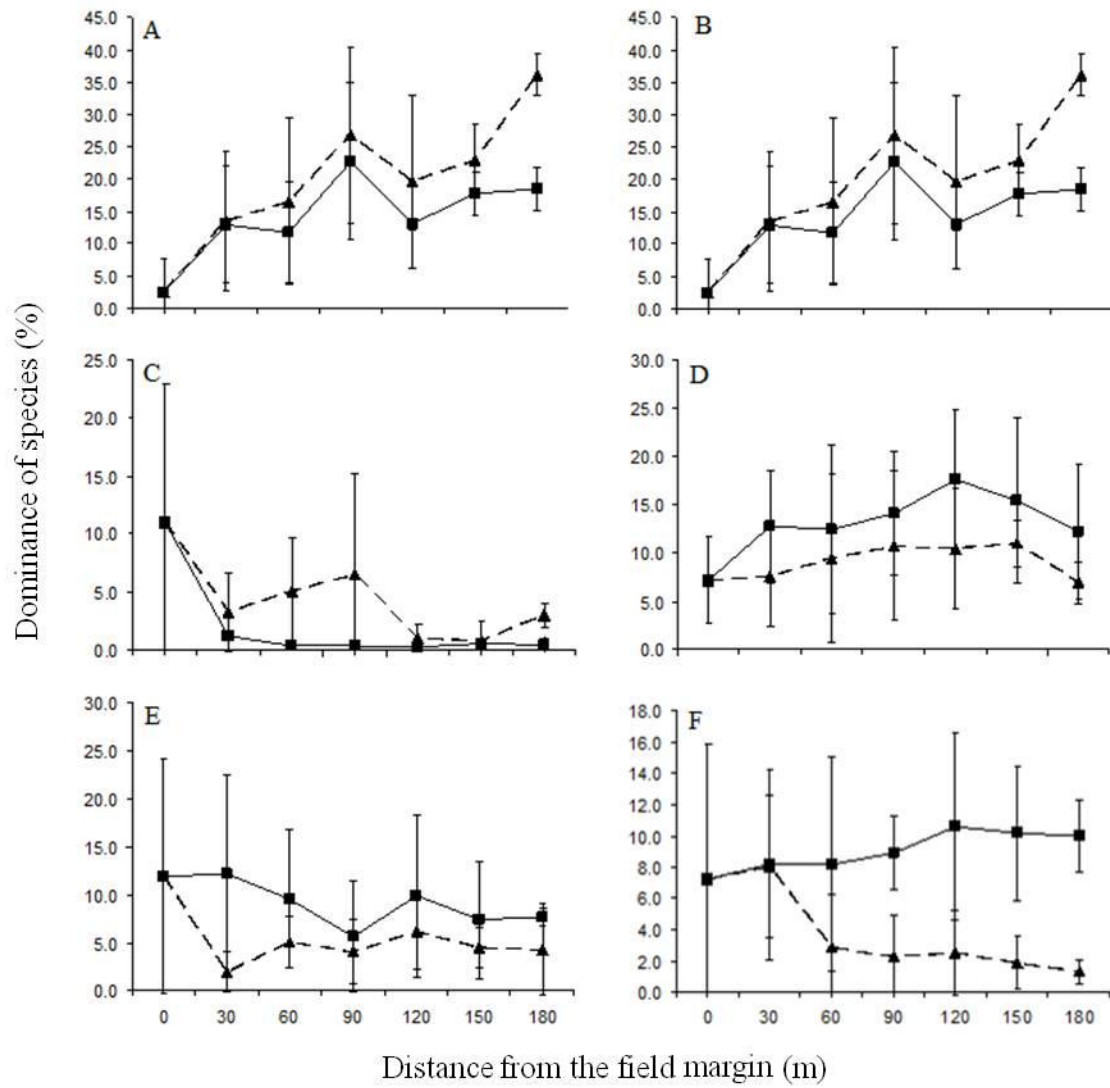
Preference type of species groups	No. of species	Mean tree cover (%)	Species with correlation coefficient to tree cover (n)		pH
			+	-	
Without preference	27	7.4 ± 9.8	1	15	5.5 ± 0.6
<u>Rare carabids</u>					
Only in fields	14	<sup>a</sup> 4.7 ± 13.1	1	6	<sup>a</sup> 5.6 ± 0.4
In fields and strips	15	<sup>a</sup> 6.8 ± 23.9	1	11	<sup>a</sup> 5.5 ± 0.9
Only in strips	7	<sup>a</sup> 13.9 ± 25.1	2	2	<sup>a</sup> 5.5 ± 0.6
In strips and margins	6	<sup>b</sup> 63.4 ± 47.4	4	1	<sup>b</sup> 4.6 ± 0.7
Only in margins	7	<sup>b</sup> 51.4 ± 50.1	5	0	<sup>ab</sup> 5.0 ± 1.3

**Table 3.1.3:** Comparison between crop area and strip in the trap rows from edge to a distance of 180 m, with results of Wilcoxon test and Sign test; F: field, S: strip; Z: Z-value of Wilcoxon test, p: error of probability.

Species	Wilcoxon		F : S ratio	Sign test	
	Z	p		Z	p
<i>Poecilus cupreus</i>	2.2	0.03	F < S	2.0	0.04
<i>Carabus nemoralis</i>	2.2	0.03	F < S	2.0	0.04
<i>Poecilus versicolor</i>	2.2	0.03	F < S	2.0	0.04
<i>Pterostichus melanarius</i>	2.2	0.03	F > S	2.0	0.04
<i>Anchomenus dorsalis</i>	2.2	0.03	F > S	2.0	0.04
<i>Nebria brevicollis</i>	2.2	0.03	F > S	2.0	0.04
<i>Trechus quadristriatus</i>	2.2	0.03	F > S	2.0	0.04
<i>Bembidion lampros</i>	2.0	0.04	-	1.2	n.s.
<i>Amara similata</i>	2.0	0.04	-	1.8	n.s.
<i>Carabus coriaceus</i>	2.0	0.04	-	1.8	n.s.
<i>Harpalus affinis</i>	2.0	0.04	-	1.2	n.s.
<i>Amara aenea</i>	2.0	0.04	-	1.2	n.s.
<i>Pterostichus strenuus</i>	2.0	0.04	-	1.2	n.s.
<i>Pseudoophonus rufipes</i>	1.8	n.s.	-	1.2	n.s.
<i>Pterostichus diligens</i>	1.8	n.s.	-	1.5	n.s.
<i>Harpalus rubripes</i>	1.8	n.s.	-	1.5	n.s.
<i>Amara familiaris</i>	1.6	n.s.	-	1.2	n.s.
<i>Harpalus latus</i>	1.6	n.s.	-	0.4	n.s.
<i>Amara consularis</i>	1.5	n.s.	-	0.5	n.s.
<i>Calathus fuscipes</i>	1.4	n.s.	-	1.2	n.s.
<i>Agonum muelleri</i>	1.4	n.s.	-	1.2	n.s.
<i>Bembidion tetracolum</i>	1.2	n.s.	-	1.2	n.s.
<i>Synuchus vivalis</i>	0.9	n.s.	-	0.9	n.s.
<i>Amara plebeja</i>	0.9	n.s.	-	0.9	n.s.
<i>Loricera pilicornis</i>	0.7	n.s.	-	0.5	n.s.
<i>Pterostichus niger</i>	0.4	n.s.	-	0.0	n.s.
<i>Carabus granulatus</i>	0.3	n.s.	-	0.4	n.s.
<i>Clivina fossor</i>	0.3	n.s.	-	0.4	n.s.
<i>Carabus auratus</i>	0.1	n.s.	-	0.4	n.s.

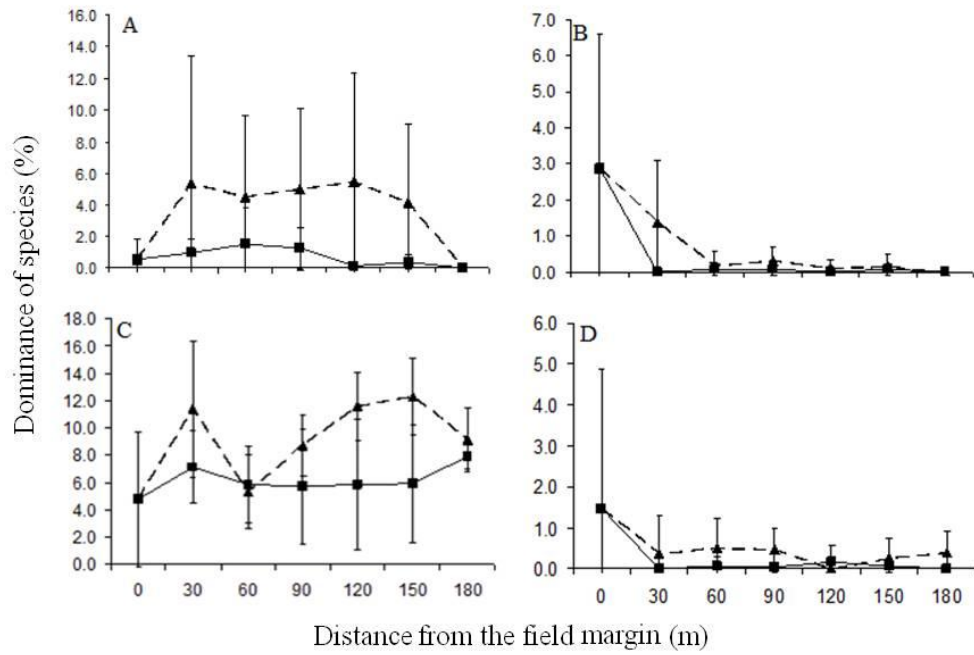


**Fig. 3.1.1:** Map of the investigated strips (black lines) in Schleswig-Holstein, northern Germany.

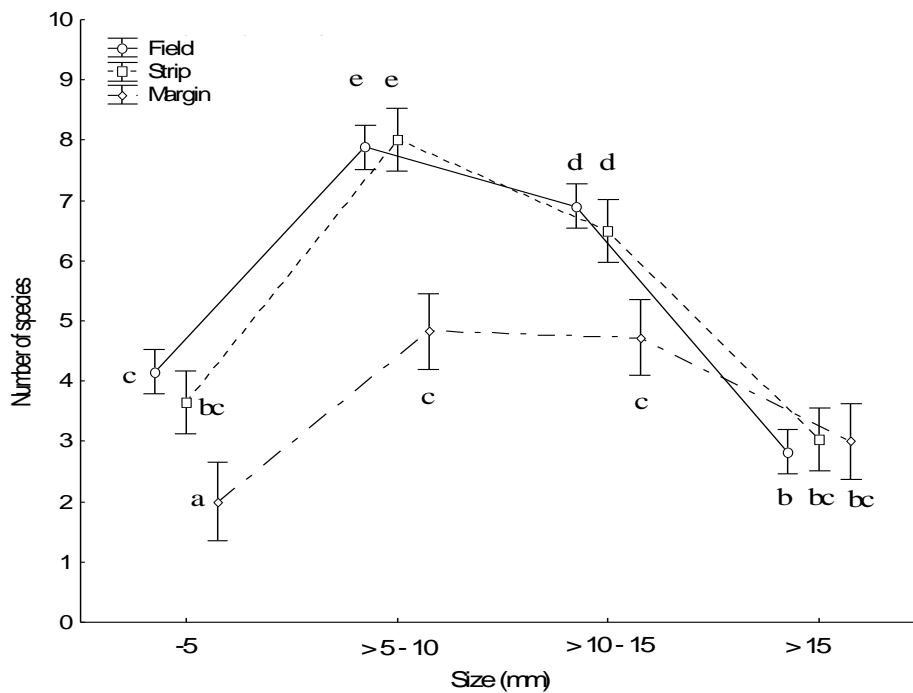


**Fig. 3.1.2:** Dominance pattern of *Poecilus cupreus* (A), *Poecilus versicolor* (B), *Carabus nemoralis* (C), *Pterostichus melanarius* (D), *Anchomenus dorsalis* (E), and *Nebria brevicollis* (F) in the crop area (—■—) and adjacent grassy strips (-▲-)





**Fig. 3.1.3:** Dominance pattern of *Amara similata* (A), *Carabus coriaceus* (B), *Harpalus affinis* (C), *Pterostichus strenuus* (D) in the crop area (—■—) and adjacent grassy strip (-▲-)



**Fig. 3.1.4:** Mean number of differently-sized species in the three habitats with standard error. Different exponents indicate significant difference according to nested ANOVA.

## Chapter 3 Results

### 3.2 Age of grassy strips influences biodiversity of ground beetles in organic agro-ecosystems<sup>b</sup>

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#### Abstract

The following investigations were conducted to evaluate grassy strips of different age for organic arable fields. From September 2009 to October 2010, adult ground beetles were sampled by pitfall traps in three grassy strips (2, 4, and 9 years old), their adjacent cropping areas, their field edges, and a control field (age 0) in Schleswig-Holstein, northern Germany. Carabid assemblages were similar among the fields, strips and edges. Grassy strips and edges had higher species richness and lower activity density than the control field. Activity density increased with increasing distance from the field edge in grassy strips and in the adjacent fields. In cropping areas, species richness and Shannon's H increased with increasing age of strips, whereas evenness and activity density decreased with increasing distance from the field edges. Compared to carnivorous and phytophagous carabids, omnivorous species were affected less by age of strips and distance from field margins. In the strips, species richness of the dominant species increased with age and decreased with distance, but the effect of strip age on species richness was still found in more than 150 m from the margin. A positive effect of the age of grassy strips on species richness was found for cropping fields, grassy strips and field edges. Old grassy strips also exerted greater influence on the species richness and biodiversity of the adjacent arable fields than the younger strips.

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### **3.2.1 Introduction**

The loss of biodiversity in Europe is mainly linked to the after-effects of the intensification of agriculture and the removal of natural habitats [1]. In order to reduce its drastic effects in the future, sustainable intensification of agriculture and the conservation of the biodiversity are recommended for food security [2]. The natural and semi-natural habitats adjacent to the arable fields are important sources of a diverse fauna and support the colonization of arthropods when the fields are empty after the harvest [3]. Among these habitats, grassy strips are considered to function as corridors for dispersal [4], source of food [5], refuge during field work phases [6], and overwinter sites for beneficial insects [7]. Their vegetation diversity supports the insect diversity and density in the adjacent arable fields [8]. After destruction of these habitats, large field areas demand their reconstruction for the invasion of predators into the fields [4, 9].

Among the soil-dwelling predators, the ground beetles (Carabidae) are used as biological indicators because of their diversity, well-known ecology and taxonomy, sensitivity to biotic and abiotic factors, relevance at multiple spatial scales and their ample collection without difficulty for analysis [10]. They consume weed seeds [11], prey on pests [12], and have an integral position in the food web [13].

It has been found in many investigations that organic farming supports beneficial insects [14]. For the conservational strategies and the biological control in organic agriculture, the establishment or augmentation of semi-natural habitats are recommended [15]. Several reports have shown the effect of distance from the natural habitats on ground beetles [16, 17]. Most of the investigations on the positive effects of grassy strips on carabids were executed under conventional agriculture. Recent studies show that the carabid fauna under organic farming in arable field centres resemble that of field margins [18]. Few investigations have been executed concerning influence of age of grassy strips on biodiversity [35]. Therefore, this study focuses on the combined effects of age and length of grassy strips as determining factors on biodiversity of arable fields. Thus, the following questions should be answered: (1) have grassy strips beneficial effects on carabids in organic farming? (2) Does biodiversity change with the distance from field edges? (3) Do older grassy strips support biodiversity better than the younger ones and (4) can we predict the combined effects of age and distance on the species richness in grassy strips and adjacent fields?

## 3.2.2 Material and Methods

### 3.2.2.1 Experimental area and sampling design

The following investigation was performed from September 2009 to October 2010 in four organic arable fields: two in 'Panten' and two on the adjacent 'Hof Ritzerau', Schleswig-Holstein, Northern Germany. The distance between the two locations was approximately 1-3 km. The climate of the area is moderate with 685.5 mm rainfall and 8.1 °C mean yearly temperature over a 30 year period. The soil type is sandy loam [19].

Three of the selected fields had grassy strips and one was chosen to be the control field. Two grassy strips, 2- and 4-years old, were in 'Panten' and the 9-year-old grassy strip was in 'Hof Ritzerau'. All the grassy strips were approximately 3 m wide and established and managed in the same way during their development. The grassy strips were established as "beetle banks" [4, 9], but grass vegetation dominated already in the second year. Original seed mixture contained ten herb species and few grass species, e.g., *Hordeum vulgare* L. However, already in the second year all strips were dominated by the main grass species, i.e., *Lolium perenne* L., *Poa trivialis* L., and *Elymus repens* (L.) Gould. Both grass coverage and species richness ranged between 60% - 70% and 50 - 60 species, respectively, and represented the typical grassy vegetation in moderately moist sites of northern Germany [20]. All field edges were characterized by woods or hedges and a grassy strip in front of them adjacent to the field with the same vegetation as in the established grassy strips. Wheat crop was sown in the fields.

Adjacent to each grassy strip, one cropping area (4- and 9-years old) or two cropping areas (2-years old) were investigated. The definition "cropping area" was selected for the arable field adjacent to the grassy strips to distinguish it from the control field (without grassy strip). Adult ground beetles were collected by using pitfall traps: glass jars, half filled with 90 % glycol and a surface tension reducing agent. The traps were covered with transparent plastic plates elevated by two iron strips fixed into the soil to protect the traps from rain and birds.

Three traps were installed on each field edge. Furthermore, two lines of pitfall traps were installed: one in the arable field and one in the grassy strip. The traps of the two lines were in 30 m distance intervals beginning from the field edges. In the control field 50 m intervals were chosen due to the long distance between the field edges

(Table 3.2.1). The distance between the two lines of traps was 30 m. Due to the narrow width of the grassy strips, only two replicate pitfall traps were installed in each row per 30 m interval in approximately 1.5 m distance from each other. The calculations were based on the distance to the nearest field edge, so the fields with two field edges (2- and 4-year-old fields and control field) provided two sets of traps for each distance. Pitfall traps were generally changed at monthly intervals, except in winter (December – March). However, sampling periods were not consistent because of agronomic activities. All beetles were identified up to species level according to [21].

**Table 3.2.1.** Number of pitfall traps in the four age groups (zero, two, four, nine) and the four habitats (Edge = 0 m, G = grassy strip, C = cropping area, F = control area).

Age	Two		Four		Nine		Zero (Control)		
Habitat	G	C	G	C	G	C	Total	Distance (m)	F
Distance (m)									
Edge	6		6		3		15	Edge	3
30	4	8	4	4	2	2	24	50	4
60	4	8	4	4	2	2	24	100	4
90	4	8	-	-	2	2	16	150	4
120	4	8	-	-	2	2	16	200	4
150	4	8	-	-	2	2	16	250	4
180	-	-	-	-	2	2	4	300	4
-	-	-	-	-	-	-	-	350	4
-	-	-	-	-	-	-	-	400	4
<b>Total</b>	<b>20</b>	<b>40</b>	<b>8</b>	<b>8</b>	<b>12</b>	<b>12</b>	<b>115</b>		<b>32</b>

### 3.2.2.2 Data Analysis

The activity density of carabids was calculated in individuals (ind.) 100 trap days<sup>-1</sup> for further analysis. Species richness was measured by (1) total number of species per trap, (2) sample-rarefaction method and (3) species number needed for 90 % of dominance. For the last parameter, the species were ordered in decreasing order of dominance and the number of species needed to get 90 % of the total specimens was taken. This parameter was selected because the capture efficiency of traps in arable

fields is higher than in grassland or forests [22] and to avoid effects by accidental species. The biodiversity was determined by Shannon's H and evenness. The assemblages of the carabids in different habitats were compared by the Detrended Correspondence Analysis (DCA). In the DCA, the traps of the cropping areas, strips, and field edges of each of the three fields and of the control field were combined into one sample.

To compare differences in the activity density, species richness, Shannon's H, and evenness among the four habitats (field edges, grassy strips, cropping areas, and control field), nested ANOVA was performed, where all the individual traps were nested within the habitats. Due to the unavailability of more grassy strips of the same age in the selected region, we executed the experiment without replication. According to the problems with non-replicated experimental designs [23], nested ANOVA was used. Each grid of two traps was combined to one sample. Therefore, the grids at the same distance from the two field edges were considered to be two samples. Similarly, the three traps of each field edge were used as one sample.

While analysing the effect of age of grassy strips, the control field used was a 0-year-old strip, since strips are usually ploughed after 2 years and established at another place. The effects of age and distance were analysed using multiple linear regression after testing the data on normal distribution. For the analysis of feeding groups, carabids were classified, according to their feeding habits [24, 25], into three groups, i.e. carnivorous, omnivorous and phytophagous. To find the effect of strips on the cropping areas, only the values of the cropping area traps in a distance of more than 30 m from the field edges were used in order to omit the edge effect. The statistical analyses were performed using the program STATISTICA [26]. For DCA and the calculations of biodiversity indices and rarefaction, the PAST program [27] was used.

### **3.2.3 Results**

#### **3.2.3.1 Faunal composition and assemblages**

A total of 23,146 ground beetles (11,068 in Panten, 12,078 in Hof Ritzerau) was found which were classified into 89 species (67 in Panten, and 74 in Hof Ritzerau) (**Table 3.2.2**). The following ten most abundant species contributed 85 % to the total amount: *Pterostichus melanarius* (19.3 %), *Poecilus cupreus* (18.2 %), *Anchomenus*

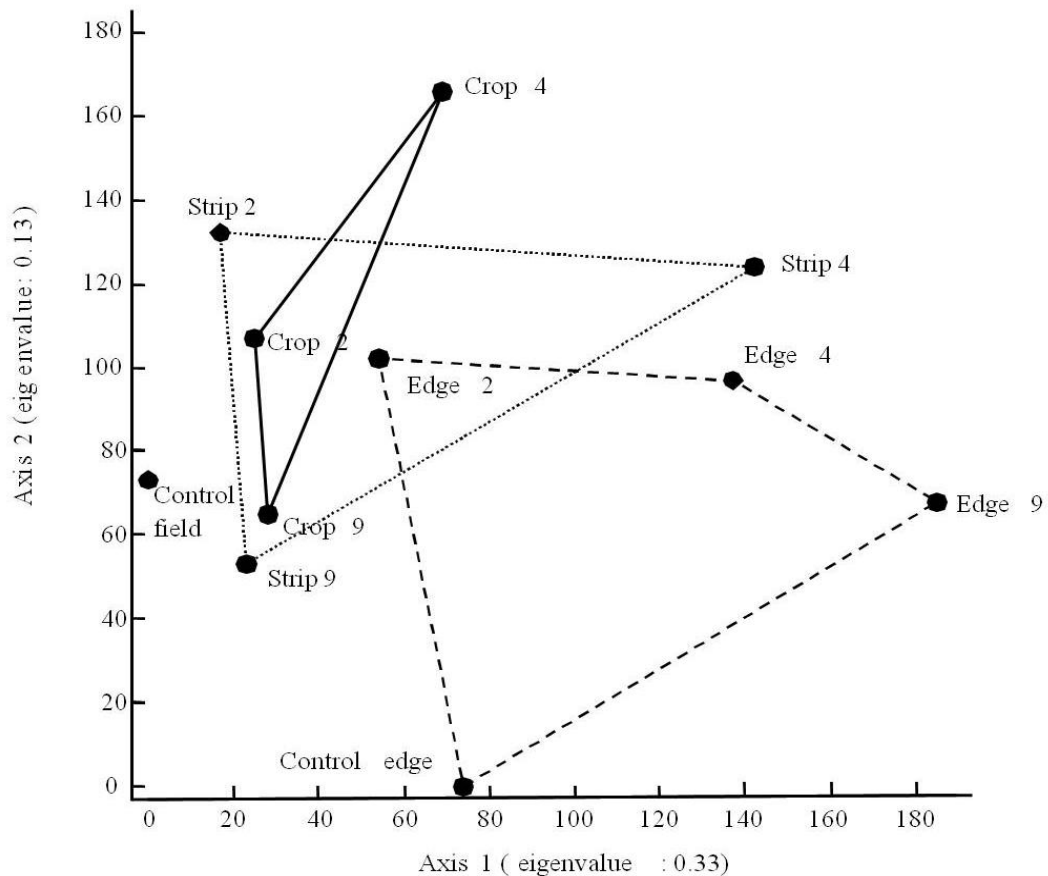
*dorsalis* (10.8 %), *Bembidion lampros* (6.4 %), *Harpalus affinis* (6.2 %),  
*Pseudoophonus rufipes* (5.7 %), *Nebria brevicollis* (5.3 %), *Carabus auratus* (4.8 %),

**Table 3.2.2.** Total activity density of the carabids in the four habitats and the age classes of the grassy strips (0 indicates the control field, 2, 4 and 9 the age (years) of the strips); feedings habits (Feed. habit): C = carnivorous, O = omnivorous, P = Phytophagous; <sup>a</sup> given in Appendix 1

Habitat Species / Age	Feed. habit	Field edges			Grassy strips			Cropping areas			Total		
		0	2	4	9	2	4	9	0	2		4	9
<i>Pterostichus melanarius</i>	C	39	38	8	11	320	6	96	2330	1362	38	215	4463
<i>Poecilus cupreus</i>	O	16	2	9	4	349	9	490	1688	1111	52	482	4212
<i>Anchomenus dorsalis</i>	C	16	82	2	16	104	6	76	1176	715	185	120	2498
<i>Bembidion lampros</i>	C	6	11	7	.	212	8	55	242	662	164	120	1487
<i>Harpalus affinis</i>	O	14	17	7	6	205	11	160	473	257	87	210	1447
<i>Pseudoophonus rufipes</i>	O	14	47	24	2	139	40	17	74	814	129	21	1321
<i>Nebria brevicollis</i>	C	32	46	9	.	69	19	35	58	703	32	223	1226
<i>Carabus auratus</i>	C	.	12	28	1	118	109	48	18	646	71	65	1116
<i>Bembidion tetracolum</i>	C	14	14	.	7	29	14	55	561	110	10	103	1045
<i>Trechus quadristriatus</i>	C	33	7	6	35	14	19	63	200	91	132	271	871
<i>Poecilus versicolor</i>	C	4	2	4	5	58	2	227	5	270	7	75	659
<i>Amara similata</i>	O	1	1	.	4	218	4	9	232	21	34	30	554
<i>Agonum muelleri</i>	C	14	.	2	1	6	2	17	259	26	3	98	428
<i>Carabus nemoralis</i>	O	7	5	38	16	4	25	83	10	33	3	16	240
<i>Calathus fuscipes</i>	C	.	5	.	0	15	.	3	51	89	5	3	171
<i>Clivina fossor</i>	C	.	.	7	0	19	14	3	31	29	30	12	145
<i>Amara aenea</i>	P	.	5	1	1	18	.	32	10	14	6	37	124
<i>Amara familiaris</i>	P	.	3	2	1	60	.	5	3	21	22	5	122
<i>Bembidion properans</i>	C	1	.	.	.	.	.	25	42	1	3	42	114
<i>Carabus granulatus</i>	C	3	4	.	.	7	2	10	9	56	7	2	100
Other species (69) <sup>a</sup>		22	33	17	72	49	31	69	251	126	46	81	803
Total (89)		36	340	171	182	201	321	1578	7723	7157	1066	2231	23146

*Bembidion tetracolum* (4.5 %), and *Trechus quadristriatus* (3.8 %). In the control field, field edges, grassy strips, and adjacent cropping areas, 51, 57, 62, and 63 species, respectively, were found. Classification on feeding habits showed the following order: carnivorous (45 species) > phytophagous (20 species) > omnivorous (7 species).

The four habitats were weakly separated according to the Detrended Correspondence Analysis with an eigenvalue of 0.33 on the first axis (**Figure 3.2.1**). The lowest similarity was shown between the edge site of the 9-year-old strip and the control field, although they both were located on Ritzerau farm. Strips and cropping areas formed no separate clusters, but cropping sites exhibited a stronger similarity than strip sites.



**Fig. 3.2.1:** The first two axes of the Detrended Correspondence Analysis show four habitats (control, grassy strips, cropping areas, and field edges). Suffix 2, 4 and 9 with strip, field edge and crop refers to the habitats related to the 2-, 4-, and 9-year-old grassy strips.

Activity density was the highest in the control field for all carabids, carnivorous, and omnivorous species, but it was the highest in the grassy strips for the phytophagous species (**Table 3.2.3**). In general, the lowest activity density was found in field edges. Species richness, determined as the number of species per trap, was also the lowest in the field edges, whereas it was also lowest in grassy strips for carnivorous species. However, phytophagous species showed the lowest species richness in the control field. In contrast to species richness, diversity determined by Shannon's H was the highest in the field edges or the grassy strips. Evenness was the lowest in the control area, except for phytophagous species.



**Table 3.2.3.** Mean activity density (ind. 100 trap days<sup>-1</sup>), species richness, Shannon (H), and evenness in the different habitats for all species and three feeding groups; different exponents show significant differences found by LSD test at  $p < 0.001$ ; <sup>1</sup> median instead of mean, NS: not significant;  $F_{DF, Gradient}$

Habitat	Control		Cropping areas		Grassy strips		Field edges		$F_{3, 78}$
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
<u>All species</u>									
Activity density <sup>1</sup>	<sup>a</sup> 85.1		<sup>b</sup> 65.3		<sup>c</sup> 48.47		<sup>d</sup> 11.04		149.4
Species richness	<sup>a</sup> 17.60	0.10	<sup>a</sup> 17.40	3.14	<sup>a</sup> 16.52	3.53	<sup>b</sup> 14.44	4.23	8.7
Shannon (H)	<sup>b</sup> 2.03	0.22	<sup>a</sup> 2.27	0.18	<sup>a</sup> 2.27	0.23	<sup>a</sup> 2.23	0.29	12.6
Evenness	<sup>d</sup> 0.44	0.10	<sup>c</sup> 0.57	0.09	<sup>b</sup> 0.61	0.11	<sup>a</sup> 0.68	0.13	32.6
<u>Carnivorous</u>									
Activity density <sup>1</sup>	<sup>a</sup> 58.93		<sup>b</sup> 33.34		<sup>c</sup> 13.45		<sup>d</sup> 7.64		165.3
Species richness	<sup>a</sup> 11.53	1.59	<sup>a</sup> 10.82	1.71	<sup>b</sup> 9.85	2.39	<sup>b</sup> 9.11	3.01	10.3
Shannon (H)	<sup>b</sup> 1.60	0.27	<sup>a</sup> 1.88	0.20	<sup>a</sup> 1.82	0.32	<sup>a</sup> 1.79	0.32	9.3
Evenness	<sup>c</sup> 0.45	0.12	<sup>b</sup> 0.62	0.11	<sup>ab</sup> 0.66	0.13	<sup>a</sup> 0.72	0.17	28.5
<u>Omnivorous</u>									
Activity density <sup>1</sup>	<sup>a</sup> 26.74		<sup>b</sup> 13.33		<sup>c</sup> 10.20		<sup>d</sup> 2.30		91.2
Species richness	<sup>a</sup> 4.66	0.97	<sup>b</sup> 4.18	0.95	<sup>b</sup> 4.15	0.70	<sup>c</sup> 3.28	1.02	11.2
Shannon (H)	<sup>b</sup> 0.95	0.23	<sup>b</sup> 1.00	0.17	<sup>a</sup> 1.12	0.20	<sup>b</sup> 0.94	0.36	6.1
Evenness	<sup>c</sup> 0.58	0.13	<sup>b</sup> 0.68	0.15	<sup>a</sup> 0.76	0.14	<sup>a</sup> 0.83	0.11	20.0
<u>Phytophagous</u>									
Activity density <sup>1</sup>	<sup>c</sup> 0.39		<sup>b</sup> 0.84		<sup>a</sup> 1.12		<sup>c</sup> 0.29		17.9
Species richness	<sup>c</sup> 0.96	0.74	<sup>ab</sup> 1.93	1.30	<sup>a</sup> 2.26	1.5	<sup>bc</sup> 1.40	1.06	11.3
Shannon (H)	<sup>b</sup> 0.14	0.31	<sup>a</sup> 0.56	0.48	<sup>a</sup> 0.63	0.52	<sup>a</sup> 0.41	0.41	10.7
Evenness	0.75	0.44	0.78	0.36	0.76	0.35	0.72	0.45	NS

### 3.2.3.2 Effect of distance and age of grassy strips on adjacent fields

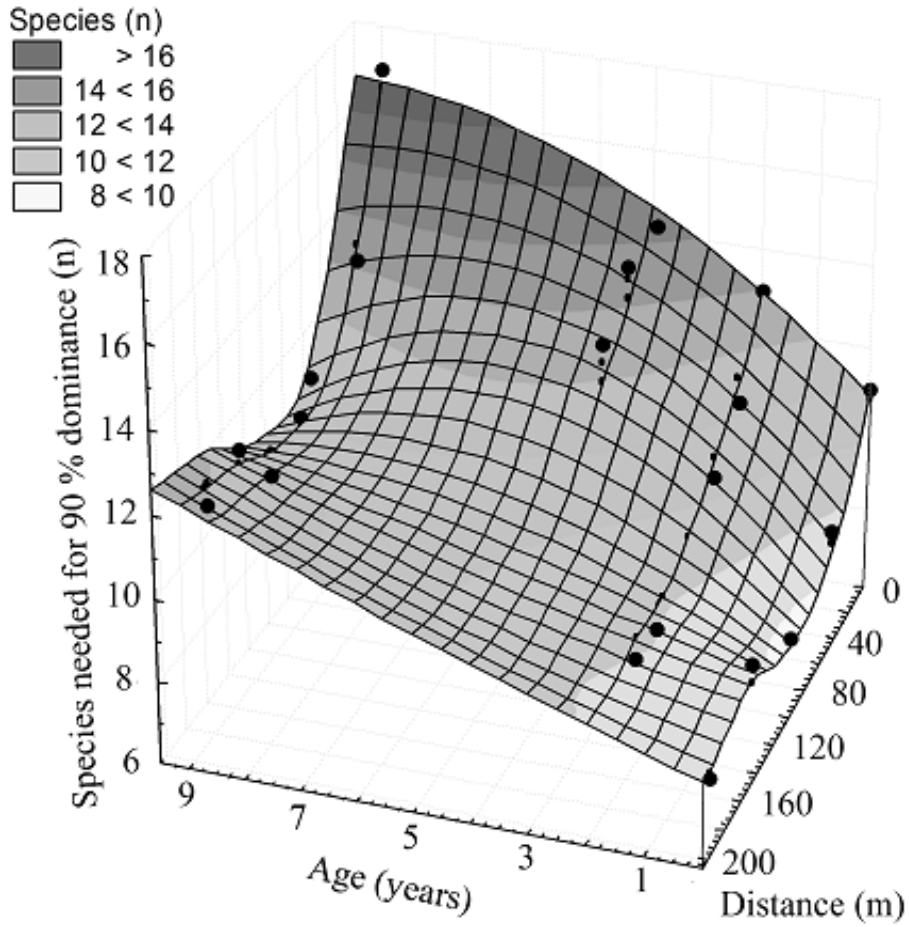
The results of the multiple linear regressions showed that either age or distance had an impact on the various diversity values and activity density, except for species richness of the phytophagous carabids that was affected by both parameters (**Table 3.2.4**). Omnivorous species showed the lowest effects by the two parameters. Overall, Shannon's H was mainly correlated with age, whereas evenness and activity density were mainly correlated with distance. This means that the Shannon's diversity in the cropping field increased with an increase in age, whereas evenness decreased with distance from field edge. In the cropping field, the correlation coefficients were usually closer than in the grassy strips. The number of species needed for 90 % of

total specimens decreased from field edge to strip centre in all strips regardless of age (**Fig. 3.2.2**). Multiple regression revealed significant results for both age ( $r = 0.56$ ) and distance ( $r = 0.57$ ) ( $F = 15.3$ ,  $DF = 2.18$ ,  $p < 0.01$ ). These two factors explained 63 % of the variability ( $r = 0.79$ ). The steepest decrease occurred close to the field edge, while a more or less steady state was reached at 30 m to 60 m distance from field edge.

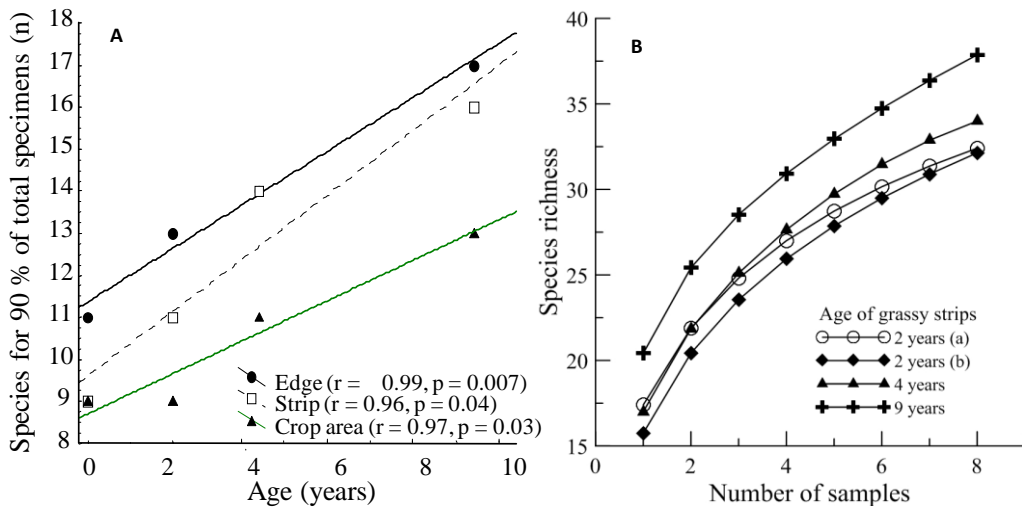
**Table 3.2.4.** Results of the multiple linear regressions using age and distance parameters; Const.: Constant, Dist.: distance; r: correlation coefficient; \* significantly ( $< 0.05$ ) affected by parameter(s); p: refers to model with both parameters. NS: not significant

	Field; DF (2,18)					Strip; DF(2,18)				
	Const.	Age	Dist.	r	p	Const.	Age	Dist.	r	p
<b>All species</b>										
Species richness	15.08	*0.49	0.31	0.58	0.020	14.44	*0.44	0.31	0.54	0.04
Shannon's H	2.20	*0.66	-0.26	0.71	0.002	2.25	0.34	-0.28	0.44	NS
Evenness	0.63	0.30	*-0.67	0.74	0.001	0.69	-0.09	*-0.63	0.63	0.01
Activity density	29.12	-0.06	*0.66	0.66	0.006	25.44	-0.25	*0.54	0.59	0.02
<b>Carnivorous</b>										
Species richness	9.52	0.28	0.44	0.52	NS	8.80	0.41	0.34	0.53	0.04
Shannon's H	1.63	*0.87	0.10	0.88	0.001	1.59	*0.83	0.14	0.84	0.001
Evenness	0.58	*0.70	-0.30	0.76	0.001	0.60	*0.47	-0.24	0.53	NS
Activity density	21.95	-0.13	*0.67	0.60	0.004	19.79	-0.40	0.41	0.57	0.03
<b>Phytophagous</b>										
Species richness	0.72	*0.75	*0.31	0.81	0.001	0.71	*0.50	0.33	0.60	0.02
Shannon's H	0.17	*0.70	0.24	0.74	0.001	0.16	*0.52	0.23	0.57	0.03
Evenness	0.56	*0.53	0.34	0.63	0.010	0.51	0.28	0.36	0.45	NS
Activity density	0.22	*0.69	0.13	0.70	0.002	0.51	0.41	0.36	0.55	NS
<b>Omnivorous</b>										
Species richness	3.92	0.20	0.24	0.31	NS	3.92	-0.10	0.44	0.45	NS
Shannon's H	1.06	0.14	-0.41	0.43	NS	1.16	-0.20	-0.33	0.38	NS
Evenness	0.78	-0.10	*-0.58	0.59	0.02	0.86	-0.17	*-0.62	0.65	0.008
Activity density	10.74	-0.12	*0.56	0.57	0.03	9.16	-0.17	*0.57	0.59	0.02

The higher species richness in the cropping area near the 9-year-old strip was also found by the sample rarefaction method. According to this method, the species richness was highest in the cropping area near the 9-year-old strip, intermediate in the cropping area of the 4-year-old strip and lowest in the cropping areas of 2-year-old strip (**Fig. 3.2.3**).



**Fig. 3.2.2:** Number of species needed for 90 % of total specimens in strips in relation to strip age and distance from the field edge.



**Fig. 3.2.3:** Number of species that account for at least 90 % dominance (A) and species richness of sample rarefaction on crop areas near grassy strips of different ages (B).

**Table 3.2.5.** Mean activity density (ind. 100 trap days<sup>-1</sup>), species richness, Shannon (H), and evenness for all species and the three feeding groups in the central cropping areas; different exponents show significant differences found by LSD test; NS: not significant; \* significant at  $p < 0.05$ , \*\* at  $p < 0.01$ , and \*\*\* at  $p < 0.001$ ; F<sub>DF, Gradient</sub>

Age	Two		Four		Nine		F <sub>2, 23</sub>
	Mean	S.D.	Mean	S.D.	Mean	S.D.	
<u>All species</u>							
Activity density <sup>1</sup>	51.7		39.8		69.3		NS
Species richness	<sup>a</sup> 17.60	0.10	<sup>a</sup> 17.40	3.14	<sup>a</sup> 16.52	3.53	**8.06
Shannon (H)	<sup>b</sup> 2.20	0.16	<sup>a</sup> 2.41	0.18	<sup>a</sup> 2.47	0.17	***10.84
Evenness	0.55	0.10	0.59	0.05	0.09	0.11	NS
<u>Carnivorous</u>							
Activity density <sup>1</sup>	36.00		26.25		47.23		NS
Species richness	10.94	1.62	12.00	0.82	11.20	0.95	NS
Shannon (H)	<sup>b</sup> 1.83	0.17	<sup>ab</sup> 1.95	0.23	<sup>a</sup> 2.11	0.13	**10.39
Evenness	<sup>b</sup> 0.59	0.10	<sup>ab</sup> 0.60	0.12	<sup>a</sup> 0.71	0.07	**6.76
<u>Omnivorous</u>							
Activity density <sup>1</sup>	14.7		13.3		19.65		NS
Species richness	<sup>b</sup> 3.9	0.82	<sup>ab</sup> 4.00	0.82	<sup>a</sup> 4.90	1.2	*4.40
Shannon (H)	0.96	0.16	1.08	0.23	0.99	0.16	NS
Evenness	0.70	0.16	0.75	0.10	0.59	0.14	NS
<u>Phytophagous</u>							
Activity density <sup>1</sup>	<sup>b</sup> 0.67		<sup>a</sup> 1.40		<sup>a</sup> 1.71		***20.82
Species richness	<sup>b</sup> 1.69	1.33	<sup>ab</sup> 2.50	1.29	<sup>a</sup> 3.20	0.92	**6.97
Shannon (H)	<sup>b</sup> 0.48	0.51	<sup>ab</sup> 0.66	0.51	<sup>a</sup> 0.96	0.35	*4.68
Evenness	0.76	0.41	0.88	0.12	0.85	0.11	NS

Using the 90 % level of species richness, significant correlations were also exhibited for cropping areas (**Figure 3.2.3**).

The number of dominant species in the cropping areas increased with increasing age of strips. Cropping areas adjacent to the 9-year-old strip had on average three species more than the control field representing age 0 in the succession. In the control field, the difference between field and edge was small, with 2 species on average, but difference increased with increasing age. If the 30 m distance traps were omitted to focus on the effect of the strips on the cropping areas, the activity density showed no difference among the three cropping areas for all carabids, carnivorous, and omnivorous species except the phytophagous carabids with higher activity density in the cropping areas near the 4- and 9-year-old strips than in the 2-year-old strip (Table 5).

For omnivorous and phytophagous carabid species, species richness exhibited significantly higher values in the cropping area near the 9-year-old strip than in the two other areas. A similar pattern was found when the diversity was determined by Shannon's H. The cropping area near the 9- or 4-year-old strip revealed higher values than the cropping area near the 2-year-old strip. This was true for all carabids, carnivorous, and phytophagous species, whereas Shannon's H for the omnivorous species was equal in all three cropping areas. The results for evenness were mostly insignificant. Only carnivorous species had lower evenness in the cropping area near the 2-year-old strip than that near the 9-year-old strip.

### **3.2.4 Discussion**

In the Detrended Correspondence Analysis, very low eigenvalues depict a close similarity in the species composition of the different habitats. The close relationships among carabid assemblages of arable fields were already stressed [28, 29]. In our study, even the similarity between field edges and arable fields was high. The highest differences along the first canonical axis were found between the control field and the field edges. The organic practices are an explanation for this high similarity. After a six year period of organic farming, [18] found that the species diversity of field centres resembles that of field edges. They also emphasised that the number of species occurring only in field edges under conventional farming increases in field centres of organic arable fields.

We found higher activity densities in arable fields than in the grassy strips, as documented in many studies [e.g., 30, 31]. However, higher activity densities were also reported for grassy structures or flower strips in comparison to arable fields [11, 32]. The higher activity density of the control field and the cropping areas may be due to the open ground surface. When compared to grassland or forests, a significantly higher mobility of species is found in arable fields [22]. The higher activity density in the arable fields in comparison to the field edges or grassy strips is, therefore, contributed to the greater mobility of species and not to their higher population density. Since the ratio between density and activity of species is undetermined for the different habitats, it is assumed that activity density is not an efficient factor for evaluating the ecological processes.

The lowest biodiversity was measured in the control field. Higher diversities were found in the field edges and the grassy strips, which illustrate that carabids benefit from undisturbed habitats even under organic practices. Their higher biodiversity can

be contributed to the stable and diverse environment and better food availability [5, 33, 34].

Our findings that species richness and diversity increased with the age of strips are supported in some other investigations [7, 35, 36]. However, it must be taken into account that local conditions and the number of accidental species can produce a high variability. The significant increase of the dominant species with age of the grassy strips points out the general importance of age for the biodiversity of the habitats investigated. In particular, carnivorous species benefit from older grassy strips. The importance of older field margins for the predatory fauna is shown by a better predator-prey ratio and parasitism than in younger margins [37]; the younger habitats have shorter food chains and simpler food-webs than the older habitats [16].

Field edges play an important role in the overall biodiversity of arable fields. In our investigation, species richness of the most dominant species (accumulated 90% of specimens) in grassy strips increased with an increase in age and decreased with increasing distance from the field edge. In contrast, activity density increased in both cropping areas and grassy strips with increasing distance from the field margin.

No significant decline was seen in the species richness of carabids with an increase in distance from the boundary hedge [38]. However, in another study species richness decreased with increasing distance from the field margin, whereas activity density showed no change at the distances of 30 m and 250 m [39]. They [39] could not find significant differences of species richness between the fields with and without strips at different distances, whereas the results of [40] documented increasing arthropod diversities from the cropping areas to the near hedge cropping area and strip in intensively managed arable fields. According to [16], the population of the arthropods decreases with increasing distance from grassy strips. The effect of distance can be based on the size of the species; the activity density of small carabids decreased, while that of large carabids increased from the field margins [41]. Although the overall results are contradictory, the arthropod diversity decreases from the field edge to the field centre in many investigations. The significant differences in the abundance of the carabids at different distances were also related to the prey availability [42].

Our findings that older grassy strips promote species richness in adjacent arable fields are supported by [43], who found a higher species richness in the cereals between the weed strips than inside the arable field without weed strips. In contrast to [43], our investigation revealed no significant influence of the grassy strips on the overall activity density in the adjacent field. The grassy strips have no influence on the population of the macro-fauna in the nearby fields [38], whereas [39] documented an

increase in the abundance of the carabids in the arable fields near grassy field margins. The positive effect of grassy strips on the biodiversity in arable fields has been documented in many studies [8, 17, 30]. The landscapes with large areas of grassland increase diversity of carabids in soybean fields [44]. The close relationship between landscape and the biodiversity of farmland was also stressed [45]. Our results concerning the significant correlation between age of grassy strips and the species richness in field edges indicate that not only the arable fields benefit from old grassy strips, but also the adjacent semi-natural habitats.

### 3.2.5 Acknowledgement

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## Chapter 3 Results

### 3.3 Movement of carabids from grassy strips to crop land in organic agriculture

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#### Abstract

1.1. The colonization of carabid beetles from grassy strips to crop fields under organic agricultural practices was investigated in 2010 and 2011 in northern Germany. Displacement and speed of *Pterostichus melanarius*, *Carabus auratus* and *Poecilus* spp. were higher in the crops than in the grassy strips, except for the speed of *C. auratus*. Among the four species *C. auratus*, *P. melanarius*, *P. niger*, and *Poecilus* spp., *C. auratus* revealed the highest displacement and speed, whereas no significant differences were found between the other three species. *P. melanarius* showed higher displacement and speed in wheat than in red-clover or pumpkin. Speed and displacement of *P. melanarius* differed between spring and autumn generations in wheat or clover. When they were released at a junction of arable crop and field strips, the direction of dispersion to either arable field or field margins/strips was indifferent for *Carabus auratus*, while *P. melanarius* moved directly to crop centers. The direction of movement of *Poecilus* spp. differed between a marginal and a central site. In the marginal site, it preferred to move along a grassy strip, while in the central site it moved irrespective from the grassy strips. *C. nemoralis* moved along a grassy margin near a hedge only and avoided direct entry into the arable field or along a grassy strip without hedge. *Nebria brevicollis* mostly entered directly into the crop field. In contrast, *P. niger* used grassy strips and their field-side border. It could be shown that grassy strips do not affect the dispersal of typical species in arable fields, i.e. *P. melanarius* and *C. auratus*: however, other species, e.g. *Poecilus* spp., *Carabus*

*nemoralis* and *Pterostichus niger*, can only overcome the barriers of arable fields either by way of strips covered only by grass or even need grassy strips with an adjacent hedge.

**Keywords:** organic agriculture, effect of grassy strips, movement, dispersal, Carabidae

### **3.3.1 Introduction**

The decline of natural habitats in the agricultural ecosystems is correlated to a species decline, especially in those species that have low dispersal power (den Boer 1970, 1990). For conservation strategies, better knowledge of the movement of arthropods in linear structures such as grassy field margins and hedges is highly recommended. In addition, the tracing of the predators is helpful for integrated pest management. Among the soil-dwelling arthropods, insects – especially ground beetles (Carabidae) – have been intensively studied in European agro-ecosystems. They are the natural enemies of pest insects and key model organisms due to their rich diversity. They form assemblages found at various spatio-temporal levels, and are amply collected for analysis.

A better understanding of the dispersal of ground beetles from natural or semi-natural habitats to arable fields is helpful in order to know whether these habitats support the invasion of the beetles or not. In conventional arable ecosystems, intensive agro-mechanization, landscape fragmentation and chemically managed mono-crop ecosystems have caused the extinction or decline of many species. In this situation, the ratio of the arable areas which remain as natural habitats becomes very small. To mitigate these conditions, the development of some grassy strips can accommodate the predatory fauna. In contrast, the organic practices in arable fields are environmentally friendly. The fauna in the field centers of the crops is much like the fauna at field margins after a period of six years. So it seems that, for the biodiversity of the beetles, linear structures such as grassy strips are of less importance in organic agriculture than in conventional agriculture. However, presently the role of grassy strips for the dispersal of carabids is not well-studied in organic arable fields; for example, it is not yet known how long the beetles need to walk in or along the strips. Additionally, it is necessary to know the direction the beetles move from their natural habitats to crop centres, both in the fields and near hedges or forests as well as in the center of huge farms having only grassy margins.

Although many investigations were conducted to analyse the movement of carabids in arable fields using different techniques (e.g. Wallin & Ekblom 1988, Riecken & Rath 1996, Tischendorf et al. 1998), few studies addressed the effect of grassy strips on the movement and dispersal of carabids. Thus, the following questions were investigated: Are (1) the grassy strips used directly by carabids to invade organic arable fields, (2) species supported by grassy margins for dispersal depending on their

specific biology, and (3) grassy strips used as orientation structures to invade arable fields?

### **3.3.2 Material and Methods**

#### **3.3.2.1 Study area, and period of experiment**

The investigations were conducted on three arable sites of two organic farms located in Schleswig-Holstein, northern Germany. One farm (Ritzerauhof; area 280 ha) had been converted to organic farming in 2001, and the other (Lämmerhof; area 410 ha) had already been organically managed for decades. The farms are adjacent to each other and have similar soils with approximately 23 – 29 % loamy sand, 20 – 35 % loam and 3 – 12 % sand (Reiss et al. 2008). The region has a moderate continental climate with 691 mm rainfall and 8.1°C in a 30-year average.

A mosaic of grassy strips and margins existed along the three selected fields. The grassy strips mainly consisted of ten herb species and few grass species, e.g., *Hordeum vulgare* L., *Lolium perenne* L., *Poa trivialis* L., and *Elymus repens* (L.). Both grass coverage and total plant species richness ranged between 60 % - 70 % and 50 - 60 species, respectively, which represent the typical grassy vegetation of moderately moist sites in northern Germany (Roweck, 2008).

The first field was located at Ritzerauhof and investigated from the last week of August to the first week of October in 2010, and again from the first week of May to mid July in 2011. This field was at the margin of the agrarian fields and had a grassy margin along a hedge and a grassy strip. The second field was at the adjacent Lämmerhof (Panten) at a distance of approximately 3 km from the first field. It was only investigated in autumn 2010. The third field was situated in the center of the agrarian fields of Ritzerauhof, at a distance of approximately 500 m from the first. This field was only investigated during the spring and summer of 2011.

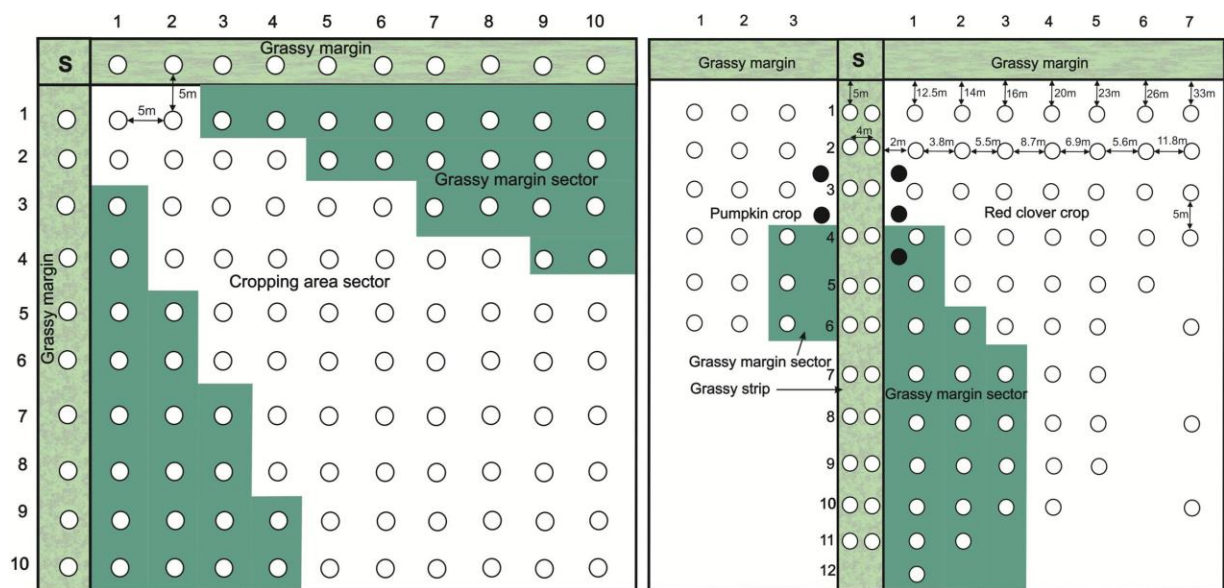
#### **3.3.2.2 Sampling of carabids**

Pitfall traps with no killing agent were used to capture the beetles. A typical trap consisted of a honey-glass, a piece of plastic pipe, a plastic funnel, and a transparent plastic plate. The pipes were inserted vertically into the soil, keeping one opening at ground level. Each pipe was filled with a honey-glass. The plastic pipe protected the honey-glass from the compaction of the soil and facilitated the sampling of the captured beetles. The funnels were inserted with the narrow side into the honey-

glasses while the wider part remained on the upper surface of the plastic pipe. The funnel acted as a slope and prevented beetles from escaping. A transparent plate raised by two iron rods over the traps protected the beetles from birds and rain. In addition, a piece of cork in the honey-glass rescued the beetles from drowning if water got into the traps. A mixture of weed, soil and one or two stones in the honey-glass provided food and shelter for the captured beetles. The mixture was kept away from the narrow part of the funnel. A total of 250 and 230 pitfall traps were established in 2010 and 2011, respectively.

### 3.3.2.3 Experimental layout

The traps were established in rows parallel to the grassy structures at a distance of approximately 5 m from each other (Fig. 3.3.1). The field-1 of Ritzerauhof had a grassy strip that separated two arable fields and ran perpendicular to a forest boundary. The second grassy margin was located along a hedge separating the forest from the arable field. Winter wheat (*Triticum aestivum*) was sown in this field in 2010 and red-clover (*Trifolium pratense*) in 2011. The intersection of the two grassy margins and the crop was selected as a “source”. In both years, a total 110 traps were installed in a 10 x 11 grid. Distance between the traps was 5 m.



**Fig. 3.3.1:** Experiment layout in Ritzerauhof fields (field-1 and field-3; left) and Panten (field-2; right); filled circles in Panten field were close to the grassy strip (1.5m distance); traps in rows were at ~ 5m distance; point of release at S (“source”)

The experimental field-2 of the Lämmerhof had a grassy strip between two crop fields, planted with red clover and pumpkin (*Cucurbita maxima*). All beetles were



marked and released at the junction (S = “source” in Fig. 3.3.1) of the two crops and the grassy strip (Fig. 3.3.1). A total of 22 traps were installed in the grassy strip in two parallel rows at a distance of 4 m apart. In the pumpkin crop, 18 traps were installed in three parallel rows at a distance of 5m apart. Finally, 59 pitfall traps were set in 7 rows in the red-clover. The distance between rows varied. Distance from the grassy strip was 2, 5.8, 13.3, 20, 26.9, 32.5, and 44.3 m. Additionally, 2 traps were installed at a distance of 1.5 m from the grassy strip on the pumpkin side and 3 traps on the red clover side, in order to investigate the dispersal of carabid species in the area close to the grassy strip (dark spots in Fig 3.3.1).

Field-3 provided the same layout as was used for field-1 of Ritzerauhof. In contrast to field-1, neither grassy strip at this site was adjacent to a hedge. This field was only investigated in 2011. A total of 120 traps were used in an 11 x 11 grid. Distance between the traps was again 5 m. Winter wheat crop was sown on this field.

#### **3.3.2.4 Marking of carabids**

The carabids were collected from the traps and marked by the mutilation method using a marking-drill machine. The method is easy and fast when marking a large number of carabids in a short period of time. By holding the beetles between the fingers, small visible marks were made on their elytra. We assigned a specific number to each beetle according to Southwood and Henerson (2001). In one field, the number of *Pterostichus melanarius* exceeded the number 1023 i.e. after both elytra were marked. Therefore, the pronotum was additionally marked.

The freshly marked and the recaptured beetles were carefully kept in baskets with a mixture of soil and plant material to overcome the problem of cannibalism. In the evenings, they were released one after another so that the first beetle disappeared before the second beetle was released.

#### **3.3.2.5 Experimental species**

The species selected were *Pterostichus melanarius* (13-17 mm), *P. niger* (16-21 mm), *Carabus auratus* (17-30 mm), *C. nemoralis* (22-25 mm), *Poecilus* spp. (11-13 mm), and *Nebria brevicollis* (11-14 mm). These were chosen, because the majority of them are large (e.g. *Carabus* spp., and *Pterostichus* spp.) which helped to identify the specimens in the field with the naked eye and eased the marking and reading procedure. In addition, they are good indicators of organic farming (e.g. *C. auratus*), associated with grassy strips (e.g. *Poecilus* spp., and *P. niger*) and are the most

abundant species in these fields (e.g. *P. melanarius* and *Poecilus* spp.). Only *Poecilus* spp. could not be identified to species level, since the two very similar species, i.e. *Poecilus cupreus* and *P. versicolor*, were found in these fields. According to former investigations *P. cupreus* was the more frequent one (Ranjha and Irmeler, 2013 in press).

### 3.2.2.6 Analysis of data

The distance from the source to the location of the trap in which the specimen was recaptured was defined as the distance covered by the specimen per time interval. The speed of the specimen was measured by dividing the distance by the number of days from release to the day of recapture. This value thus reflects the minimum speed only. The distances from the source to the traps were measured by using the Pythagorean formula, taking the two lines of pitfall traps in the grassy margin as the reference axes.

The program Statistica was used for the statistical tests (Statsoft 2004). The U-test was used for comparing distance and speed in grassy strips and cropping areas. In addition, distance and speed were compared between crops by the U-test or Kruskal-Wallis test. The significant differences in Kruskal-Wallis ANOVA were determined using the multiple comparison test with the Bonferroni correction.

In field-2, only *P. melanarius* revealed sufficient numbers of recapture to allow evaluation. This site was divided into a pumpkin area and a clover area separated by the grassy strip (Fig. 3.3.1). If at least 6 specimens were recaptured in every sector, the numbers of specimens captured in the grassy sector and the crop sector were compared by the Chi-square test. Otherwise, descriptive statistics were used.

Two fields, field-1 and field-3 (Ritzerauhof), were divided into three sectors: two for the grassy sectors and one for the crop sector (Fig. 3.3.1). The pitfall traps in the grassy sectors at these sites mirrored each other, i.e., they had the same distance from the source and from the grassy margins in both grassy sectors. The traps in the crop at a distance of 15 m from the source which were close to the grassy structures were assigned to the grassy sectors. Each grassy sector of field-1 contained 30 traps; the crop sector had 60 traps. Only 10 rows and columns of traps were installed in field-3. Thus, the grassy sectors had 25 traps each and the crop sector 49 traps.

The total number of recaptures was calculated for each sector and a Chi-squared goodness-of-fit test was used for each species to determine whether the observed number differed from the expected number. In case of different numbers, it was

assumed that the species preferred a certain direction i.e., the grassy margins or the crop center. Bonferroni adjusted pair-wise Chi-squared tests for homogeneity were applied to compare the potentially different preference of the species for a certain sector.

### **3.3.3 Results**

#### **3.3.3.1 Marked and recaptured specimens**

Seven species were caught frequently enough to be included into the analysis (Table 3.3.1). In total, 6298 of these specimens were marked and 1109 of them were recaptured, which accounted for 17.6 % of the released specimens. This is slightly less than the expected number (25 %) when assuming that all specimens would be recaptured from a quarter of the potential dispersion area. *Pterostichus melanarius* was the most frequently found species in 2010 and 2011. However, the highest recaptured rate for both years was noted for *C. auratus* (55%), of which 21% was found in the grassy margins in spring 2011. Only *P. melanarius* was caught in both years. It had higher total recaptures in 2010 (33%) than in 2011 (12%). In contrast, recaptures in grassy strips were lower in 2010, at 16 %, in comparison to 33 % in 2011. *Nebria brevicollis* was only captured in 2010. It was the only species absent in the grassy margins. *C. nemoralis* was only captured in field-1 with the grassy margin adjacent to a hedge in 2011. It contributed the most (75%) to the recaptured numbers in field margins, followed by *P. niger* (62%).

#### **3.3.3.2 Comparison for distance and speed in habitats**

Distances covered (m/total period) by the six species were generally greater in the crops than in the grassy strips (Table 3.3.2). Overall, average distances ranged from 5 m to 20 m in the investigated periods, whereas the maximum distance ranged between 24.5 m and 84 m. In the crops, the average distances covered ranged between 13.5 m and 45 m; the maximum ranged from 13.5 m to 84.5 m. The differences in the distances covered between grassy strips and crops were significant according to the U-test, except for *P. niger*. For this species, the number of recaptured specimens was too small for comparison. A comparison between species shows that the size of the species is not the main parameter affecting the distance covered. For example, *Poecilus* ssp., the smallest species of the seven investigated, revealed a greater distance in crops than the larger sized *P. melanarius*, *P. niger*, *N. brevicollis*, and even

**Table 3.3.1.** Total number of carabids released in the fields, total recaptured in different crops (W = wheat, C = clover, P = pumpkin) and in adjacent strips (S = grassy strip, and H = strip with hedge); T.rec.: Total of recaptured.

Species	Field 1			Field 2				Field 3			Total strips (%)	
	Released	Recaptured	T rec. (%)	Released	Recaptured	T rec. (%)	Released	Recaptured	T rec. (%)			
Year 2010 (autumn)												
	W		S	C P S								
<i>P. melanarius</i>	488	147	26	36	382	83	15	18	30			
<i>P. niger</i>	55	8	14	40	60	2	1	4	12			
<i>N. brevicollis</i>	44	1	0	2	105	13	5	0	17			
Year 2011 (spring)												
		C	H	S				W	S			
<i>P. melanarius</i>	2046	141	39	44	11			1826	179	75	14	33
<i>C. auratus</i>	53	21	6	3	57			190	85	20	55	21
<i>C. nemoralis</i>	45	3	8	1	27			5	0	0	0	75
<i>Poecilus</i> spp.	236	34	3	18	24			763	63	12	12	34

**Table 3.3.2.** Distances covered (m/total period) in strips and crops; Med. = median, Min = minimum, Max = maximum; comparison by U- test for two habitats (U) or two crops (U); non-parametric ANOVAs for three crops (H); only one specimen recaptured is given in brackets.

Species	Grassy strips						Cropping areas						Grassy Strips vs. Crops		Among crops				
	Field 1 (Ritzerau)			Field 2 (Panten)			Field 1 (Wheat)			Field 2 (Clover)			Field 2 (Pumpkin)			U	p	H/U	p
2010																			
<i>P. melanarius</i>	12	6	69	16.0	12	35.0	33	8	68.5	16.5	7	57	24	20.0	64.5	2704	0.001	H= 47.9	0.00
<i>P. niger</i>	6	6	84	15.8	12	24.5	19	8	54.5	20.5	20	21	(24)	(24)	(24)	71	0.21	-	-
<i>N. brevicollis</i>	-	-	-	-	-	-	(27)	(27)	(27)	13.5	7.5	66	31	26.5	84.5	-	-	U = 12	0.05
2011																			
	Field 1 (Ritzerau)			Field 3 (Ritzerau)			Field 1 (Clover)			Field 3 (Wheat)									
<i>P. melanarius</i>	5	5	40	15	5	50	28.3	7.1	60.2	32	7.1	71.0				7363	0.001	11150	0.75
<i>Poecilus ssp.</i>	20	5	45	10	5	35	29.2	11.2	64.0	34	7.1	71.0				853	0.001	1065.5	0.94
<i>C. nemoralis</i>	5	5	30	-	-	-	20.6	11.2	29.2	-	-	-							
<i>C. auratus</i>	1.2	2	5	40	15	5	50	30.4	14.1	57.0	45	7.1	64.0			442.5	0.001	646.5	0.05
	0																		

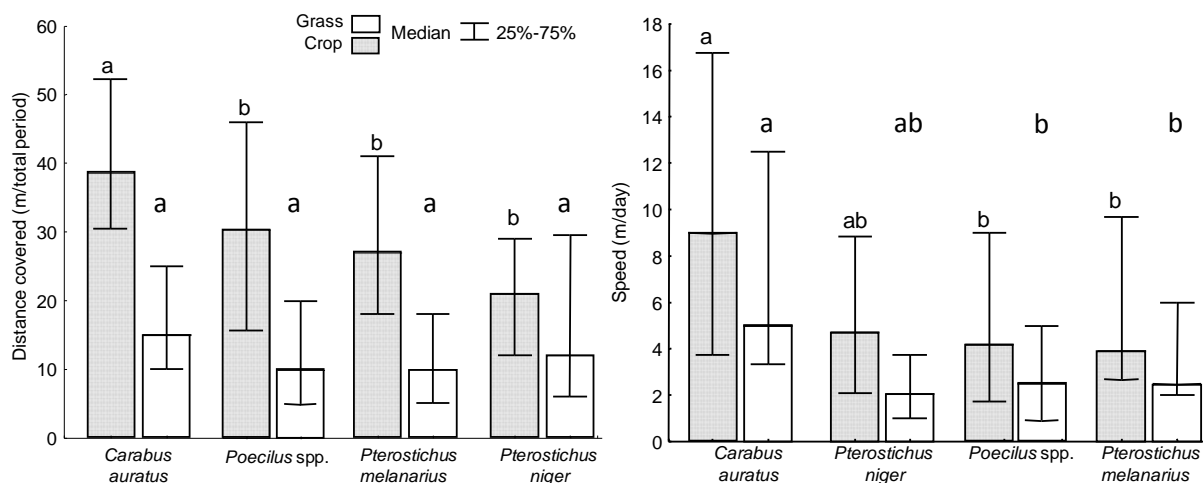
**Table 3.3.3.** Speed (m day<sup>-1</sup>) in grassy strips and crops; Med. = median, Min = minimum, Max = maximum; comparison by U- test for two habitats (U) or two crops (U); non-parametric ANOVAs for three crops (H); only one specimen recaptured is given in brackets.

Species	Grassy strips						Cropping areas						Grassy Strips vs. Crops		Among crops				
	Field 1 (Ritzerau)			Field 2 (Panten)			Field 1 (Wheat)			Field 2 (Clover)			Field 2 (Pumpkin)			U	p	H/U	p
2010																			
<i>P. melanarius</i>	3.0	0.6	23.5	3.1	1.5	6.2	6.2	0.4	25.0	3.5	0.7	14.2	4.7	2.3	10.8	3596	0.001	H = 36.2	0.00
<i>P. niger</i>	2.0	0.9	21.0	4.5	4.1	6.0	4.0	0.5	30.0	2.5	1.6	3.3	(12.0)	(12.0)	(12.0)	84	0.5	-	-
<i>N. brevicollis</i>	-	-	-	-	-	-	(6.8)	(6.8)	(6.8)	1.9	0.6	8.3	4.4	2.1	12.1			U = 8	0.02
2011																			
	Field 1 (Ritzerau)			Field 3 (Ritzerau)			Field 1 (Clover)			Field 3 (Wheat)									
<i>P. melanarius</i>	1.1	0.13	13.3	2.5	0.1	20.0	4.1	0.2	46.1	5.4	0.23	71				15040	0.001	11150	0.75
<i>Poecilus ssp.</i>	2.5	0.22	12.0	2.5	0.1	15.0	4.4	0.5	27.0	4.2	0.30	51				1468	0.001	1065.5	0.94
<i>C. nemoralis</i>	2.5	0.14	15.0	-	-	-	2.8	3	4.1	-	-	-							
<i>C. auratus</i>	1.3	0.20	20.0	5.0	0.9	20.0	5.7	0.4	40.3	10.2	0.71	64				1178	0.05	646.5	0.05

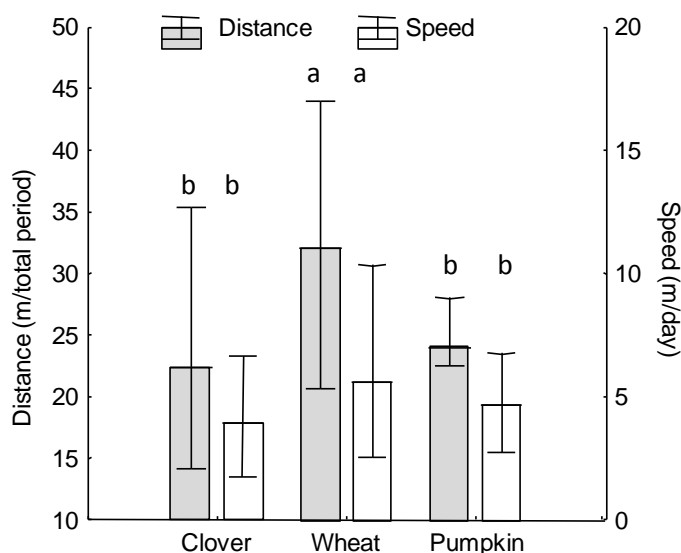
*C. nemoralis*. Only distances covered by *C. auratus* were slightly greater in crops than *Poecilus* spp. The comparison between the different crops provided significant differences for *P. melanarius* and *C. auratus*. This implies that *P. melanarius* covered greater distances in wheat than in clover or pumpkin. A comparison between the 2010 and 2011 values for wheat crops supports these results for *P. melanarius*. In wheat, distances covered were nearly identical in 2010 and in 2011 with 33 m and 32 m on average, respectively, even though different wheat fields were investigated. Similar results were found for clover, although the range was higher, between 16.5 m and 28.3 m. No differences in distances covered in different crops were revealed for *N. brevicollis* and *Poecilus* spp. The two other species, *C. nemoralis* and *P. niger*, avoided the crop areas, making a comparison between different crops impossible. Speed ( $\text{m day}^{-1}$ ) of the species in grassy strips ranged from an average of  $1.1 \text{ m day}^{-1}$  to  $5 \text{ m day}^{-1}$ ; the maximum ranged from  $6 \text{ m day}^{-1}$  to  $23 \text{ m day}^{-1}$  (Table 3.3.3). In the crops, the respective average ranges were  $1.9 \text{ m day}^{-1}$  and  $10.2 \text{ m day}^{-1}$ , and  $3.3 \text{ m day}^{-1}$  and  $71 \text{ m day}^{-1}$  for the maximum. The differences between the strip values and the crop values were once more significant for *P. melanarius* and *Poecilus* spp., but not for *P. niger* and *C. auratus*. The later two species revealed high speed values in grassy strips which ranged from  $2 \text{ m day}^{-1}$  to  $5 \text{ m day}^{-1}$ , whereas the speed range of the two former species in grassy strips was  $1.1 \text{ m day}^{-1}$  and  $3.1 \text{ m day}^{-1}$ . As for the distances covered, no relationship between speed and size of the species was discovered. The lowest speed was found for *P. melanarius* in a grassy strip, but also the highest in a crop. The smaller species *Poecilus* spp. exhibited a speed identical to or higher than the larger species *P. melanarius* and *C. nemoralis*. *Carabus nemoralis* and *C. auratus*, both nearly of the same size, showed distinctly different speed values. In field-1, where they occurred together, *C. auratus* had an average speed of  $4 \text{ m day}^{-1}$  in grassy strips and  $5.7 \text{ m day}^{-1}$  in crops, whereas *C. nemoralis* reached an average speed of  $2.5 \text{ m day}^{-1}$  in grassy strips and  $4.1 \text{ m day}^{-1}$  in crops. The comparison between the different crops revealed significant differences only for *P. melanarius* and *N. brevicollis* in 2010. For *P. melanarius*, speed was significantly higher in wheat crops than in clover or pumpkin crops. Speed in wheat was also higher than in clover in the 2011 experiment, but the difference was not significant. No values could be calculated for wheat for *N. brevicollis*, but the difference between pumpkin and clover was similar to that of *P. melanarius*.

If all crop areas are considered, *Carabus auratus* revealed the greatest distance covered and the highest speed of the four species - in comparison to more than 35 m/total period and more than  $8 \text{ m day}^{-1}$  (Fig. 3.3.2). Using the Kruskal-Wallis test,

significant differences were found for distance covered ( $H = 41.5$ ,  $p < 0.001$ ,  $n = 779$ ,  $DF = 3$ ) when compared to the other three species, according to the multiple comparison. However, for speed ( $H = 34.1$ ,  $p < 0.001$ ;  $n = 779$ ,  $DF = 3$ ), differences were only significant when compared to *Poecilus* spp. and *P. melanarius*, but not in comparison to *P. niger*. Using all margins and grassy strips for the comparison, speed comparison showed the same differences as the crop comparison ( $H = 23.7$ ,  $p < 0.001$ ,  $n = 296$ ,  $DF = 3$ ), whereas distances covered were not different among the four species ( $H = 7.9$ ,  $p = 0.05$ ,  $n = 296$ ,  $DF = 3$ ).



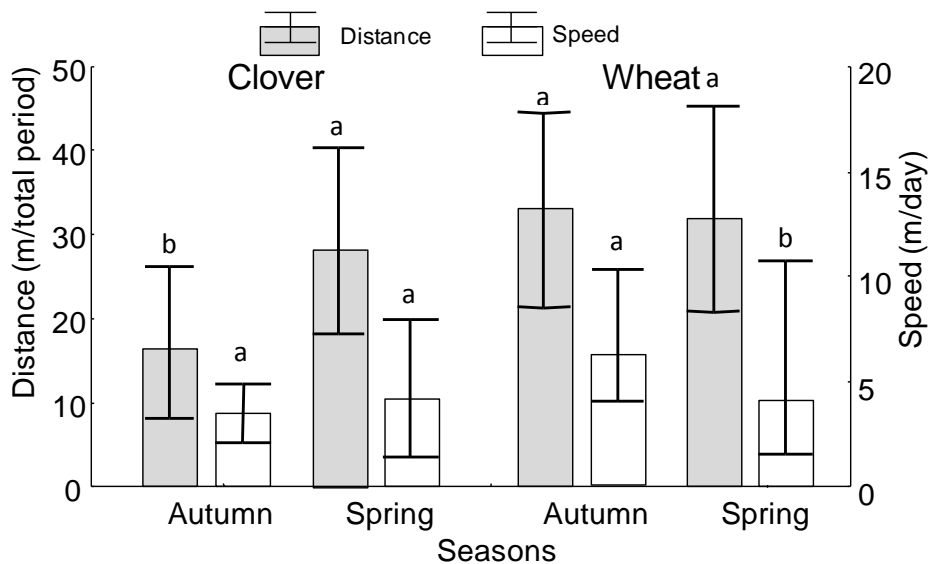
**Fig. 3.3.2:** Medians of distances covered and speed in grassy strips and cropping areas; error bars show upper and lower quartiles; different characters between the grassy strips or the crop fields show significant differences with  $p < 0.001$  according to Kruskal-Wallis ANOVA and multiple comparison test.



**Fig. 3.3.3:** Median of distances covered and speeds for *P. melanarius* in three cropping areas; errors bars show upper and lower quartiles; different characters between distances or between speeds indicate significant differences according to the Kruskal-Wallis ANOVA and multiple comparison test.



Since *P. melanarius* was captured in different crops, the movement behavior could also be analyzed for crops. The species covered greater distances ( $H = 32.8$ ,  $p < 0.001$ ,  $n = 565$ ,  $DF = 2$ ) and showed faster speeds ( $H = 23.0$ ,  $p < 0.001$ ,  $n = 565$ ,  $DF = 2$ ) in wheat than in the pumpkin and clover areas (Fig. 3.3.3). The differences between wheat and pumpkin/clover were significant using the multiple comparisons. If the autumn and spring values are compared for the same crops (clover and wheat), no differences for speed were shown in clover ( $U = 5494$ ,  $p = 0.44$ ), whereas distance covered was greater in the spring than in autumn ( $U = 3286$ ,  $p < 0.001$ ) (Fig. 3.3.4). In wheat, distances covered did not differ between the two seasons ( $U = 12950$ ,  $p = 0.8$ ), however, speed revealed higher values in autumn than in spring ( $U = 11203$ ,  $p = 0.02$ ).



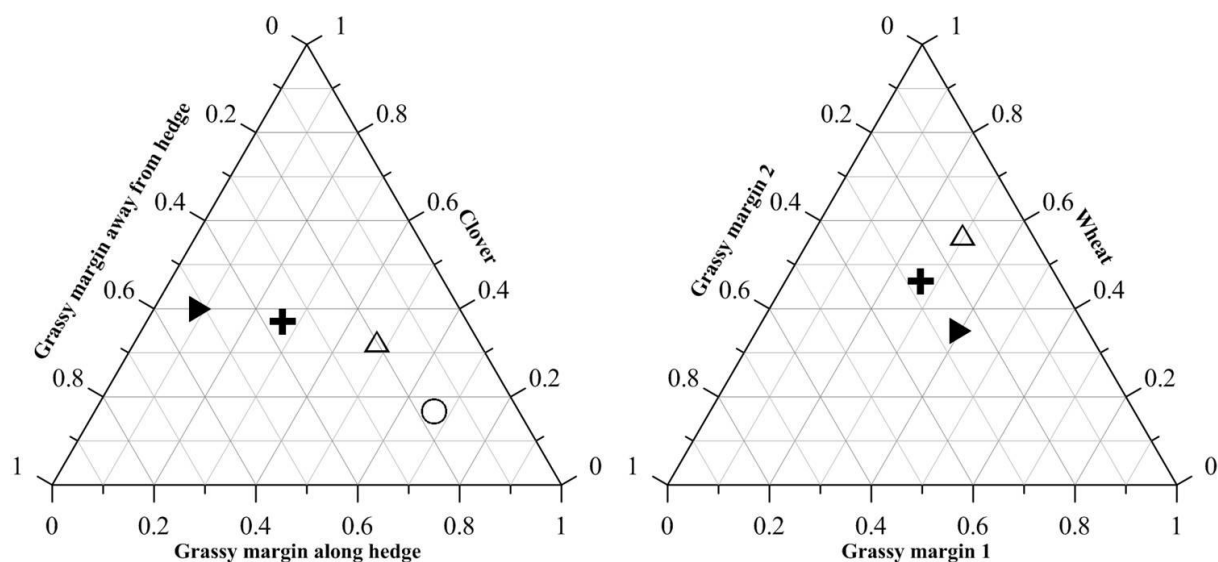
**Fig. 3.3.4:** Medians of distances covered and speeds of *Pterostichus melanarius* in clover and wheat during the two seasons; error bars show upper and lower quartiles; different characters between autumn or spring values indicate significant differences according to the U-test.

### 3.3.3.3 Direction of dispersal

At field-2 in 2010, *P. melanarius* preferred to move in the grassy strip sector on the pumpkin side ( $\chi^2 = 7.8$ ,  $P = 0.02$ ). However, when comparing clover and grassy strips, *P. melanarius* preferred to move directly to the clover ( $\chi^2 = 8.2$ ,  $P = 0.01$ ).

At field-1 of Ritzerauhof, *P. melanarius* moved directly to the arable field center in 2010 ( $\chi^2 = 11.33$ ,  $P = 0.003$ ) and 2011 ( $\chi^2 = 19$ ,  $P < 0.001$ ) instead of using the grassy strip, similar to clover crop at field-2, irrespective of the different crops with wheat in 2010 and red clover in 2011. On field-1 at Ritzerauhof, the two species, *Poecilus* ssp.

and *C. nemoralis*, preferred either crop or grassy strip, while the *C. auratus* remained indifferent ( $\chi^2 = 0.1, P = 0.74$ ) (Fig. 3.3.5). In contrast, *Poecilus* spp. showed a strong association to the grassy strip perpendicular to the forest boundary, but avoided the field margin along the hedge ( $\chi^2 = 21.4, P < 0.001$ ). *C. nemoralis* preferred to move in the grassy strip along the hedge ( $\chi^2 = 11.3, P = 0.003$ ). According to the Bonferroni adjusted pair-wise Chi-squared test for homogeneity when comparing the four species *P. melanarius*, *C. auratus*, *C. nemoralis*, and *Poecilus* spp., only *C. nemoralis* and *Poecilus* spp., differed in their preference to grassy or crop sector ( $P < 0.001$ ).



**Fig. 3.3.5:** Ratios between the direction movement of *P. melanarius* (open triangle), *Carabus auratus* (cross), *C. nemoralis* (open circle) and *Poecilus* spp. (black triangle) at field-1 (left) and field-3 (right) of Ritzerauhof in 2011.

At field-3 which had grassy margins without adjacent hedge, no significant differences among the sectors for the three species were found: *C. auratus* ( $\chi^2 = 6.0, P = 0.05$ ); *P. melanarius* ( $\chi^2 = 1.4, P = 0.49$ ); and *Poecilus* spp., ( $\chi^2 = 1.11, P = 0.57$ ) (Fig. 3.3.5). All species moved in similar directions directly to the arable field center. *Nebria brevicollis* could only be investigated at field-2. There it had no recaptures in the grassy strips, whereas 13 and 5 recaptures were found in the clover and pumpkin crop, respectively. Out of 13 recaptures found in the clover, 70 % moved directly to the crop center and only 30 % were found in the grassy sector. From the 5 specimens recaptured in the pumpkin area, 4 were found in the grassy sectors and 1 in the crop sector.

Unlike *Nebria brevicollis*, *P. niger* had 4 recaptures in the grassy strip. From the 2 specimens of clover crop, 1 specimen was caught in the grassy strip sector at 1.3 m from the strip and 20 m distance from the source and the other one was in the crop

sector. Similarly, in pumpkin crop the 1 specimen was recaptured in the grassy margin sector at 5 m distance from the margin and approximately 10 from the source.

### 3.3.4 Discussion

The selected mark-and-recapture method used to investigate the movement of carabids has advantages and disadvantages. A severe disadvantage is the low recapture rate that is related to the increase in area and the stay of animals on way after their release (Wolfenbarger 1946). The major advantage of this method is the more or less natural conditions compared to e.g. telemetry methods (Riecken and Raths, 1996). The mark-and-recapture method was chosen because it is easy to conduct, cheap and provides carabids with natural conditions for movement. At 17.6 %, the recapture rate was high enough since a great number of specimens had been marked.

Compared to other investigations that used different methods, the results found in this study show that the mark-and-recapture method provides realistic values. Baars (1979) found a daily speed of  $4.0 \text{ m day}^{-1}$  –  $13.0 \text{ m day}^{-1}$  for *Poecilus versicolor*. Our values for *Poecilus* spp. were 2.5 to  $4.4 \text{ m day}^{-1}$  on average, with a range between  $0.1 \text{ m day}^{-1}$  and  $51 \text{ m day}^{-1}$ . Wallin and Ekblom (1988) published speed values between  $24 \text{ m day}^{-1}$  and  $29 \text{ m day}^{-1}$  for *Pterostichus melanarius*,  $41 \text{ m day}^{-1}$  and  $78 \text{ m day}^{-1}$  for *P. niger*, and  $28 \text{ m day}^{-1}$  for *Carabus nemoralis*. The referring values in our study were  $1.1 \text{ m day}^{-1}$  –  $6.2$ ,  $2 - 12 \text{ m day}^{-1}$ , and  $2.5 - 2.8 \text{ m day}^{-1}$ , respectively, for the averages and  $0.1 - 71 \text{ m day}^{-1}$ ,  $0.5 - 30 \text{ m day}^{-1}$ , and  $0.14 - 15 \text{ m day}^{-1}$ , respectively, for the total range. The wide range of values found here and published by other studies show the flexibility of movement behaviour of species living in agricultural ecosystems. In contrast to species from these open ecosystems, carabid species from woods seem to have lower displacement values. Niehues et al. (1996) found values between  $3.5 \text{ m day}^{-1}$  and  $15.0 \text{ m day}^{-1}$  for the large *Carabus auronitens*; Assmann (1995) found  $4.2 \text{ m day}^{-1}$  for the similarly large *Carabus glabratus*, and Charrier et al. (1997) found  $0.2 - 0.6 \text{ m day}^{-1}$  for the smaller *Abax parallelepipedus* living in woods. However, other species from open grassy vegetation also revealed much lower movement values than found in our studies. The two species *Elaphrus cupreus* and *E. uliginosus* only covered an average of  $0.5 \text{ m day}^{-1}$  and  $0.7 \text{ m day}^{-1}$ , respectively (Schreiner and Irmeler 2010). A daily distance greater than 10 m was rare. Compared to these two species, the investigated species of agricultural fields demonstrate the high speed and dispersal potentials of species found in agricultural habitats.

Displacement behavior of carabids is affected by nutrition, the different vegetation structures, e.g. hedges, grassy vegetation etc., and the stability of their ecosystems. Species size, often noted as an important factor for speed and dispersal, is of minor importance for the displacement behaviour according to our investigations. Nevertheless, size does play a role in the movement and dispersal behaviour as can be seen by *C. auratus*, which had the highest values compared to *P. melanarius*, *P. niger*, and *Poecilus* spp. We found that the habitat characteristics, e.g. spatial resistance (Jopp, 2006), exhibit stronger effects on the movement than the size of the species. Only carnivorous species were investigated in the present study. In both years, *P. melanarius* covered longer distances in cropping areas than in grassy margins. Similarly, *C. auratus* and *Poecilus* spp. travelled greater distances in cropping areas than in grassy strips. Only *P. niger* showed no difference for distances covered between grassy strips and crops.

The speed in different habitats depends on physical conditions such as temperature and satiation state of animals, not only for carabids but also for other animals living on the soil surface (Berggren et al., 2002). The behavior of specialist species also differs from the generalist species. Specialist species generally exhibit lower rates of dispersal than generalist species (Hedin et al., 2008). For the two species *P. melanarius* and *P. niger*, Frampton et al. (1995) found that they moved slower in grassy strips than in barley, because of denser vegetation in the grassy strip, better food supply and physical structure in less intensively managed fields. We found that *P. melanarius* moved faster in wheat crop than in pumpkin and clover. The reason may lie in the greater openness of the ground surface and the lower food availability in the wheat crop (Vermeulen, 1994). Most beetles moved more slowly in the clover crop than in wheat or pumpkin, which might be related to the wetter microclimate conditions, denser vegetation on the ground and better food supply in clover (Carcamo and Spence, 1994). It also shows that the environmental conditions of clover resemble those of grassy margins, because there was a greater similarity between the speed on clover and grassy strips than between wheat and grassy strips.

The lower permeability in grassy structures can affect speed and preferred direction of carabids. The interaction and exchange of carabids in arable fields, mosaic of crops and grassy structures, depends on the quality of source and sink habitats and on the species investigated for the studies. This is supported by our findings for *C. nemoralis*, which exclusively preferred to move in the field margin along a hedge and avoided the crop and the other grassy strip without hedge. In general, hedgerows led to a decrease in the movements of insects and delayed dispersal of walking beetles

like carabids (Fry and Robenson, 1994). Hedgerows are important habitats for the agricultural landscape, because they function as sites for overwintering and as retreat habitats during unfavourable periods of farming activities (Fournier and Loreau, 2001). Therefore, the carabids moved from those natural habitats, such as hedgerows, to the surrounding patches of agricultural sites. The most abundant species, *P. melanarius*, made nocturnal foray from dense inter-crop field to mono-crop sites. According to Bohlen and Barret (1990), Coleoptera moved parallel to crop edges instead of crossing them. In our studies, a few specimens of *Nebria brevicollis* were recaptured parallel to the grassy strip. In contrast, *P. niger* moved inside and along the grassy strips. Frampton et al. (1995) found that some individuals of *P. melanarius*, *Harpalus rufipus* and *P. niger* followed field edges and avoided barriers. In another study, hedgerows became barriers for the movement of *Nebria* spp. into the adjacent cereal fields, because temperature was lower in hedgerows than in arable fields. Like arable fields, forest edges can have an impact on the orientation of dispersal, e.g. for *Carabus coriaceus* (Riecken and Raths, 1996). In the present studies, the matrix of grassy strips with and without hedge demonstrated that hedges affect the direction of field species (*P. melanarius*), grass preferring species (*Poecilus* spp.), and species of wood edges (*C. nemoralis*). However, in a matrix of grassy margins and crop in the middle of the huge agricultural fields, the former two species showed no preference of movement for any habitat. Beetles that can invade directly into arable fields, i.e. *P. melanarius*, or run along grassy strips, i.e. *Poecilus* spp., used both grassy strips and crop areas for dispersal into the field centre. The same was true for *C. auratus* in both fields of Ritzerauhof. *C. auratus* is the species that benefits most from organic practices in Germany and Switzerland. Furthermore, the difference in movement behaviour explains why *C. nemoralis* was not found in the centre of the huge arable field area. This species needs hedges to move along grassy strips. If there are no hedges combined with grassy strips, the species is not able to overcome the field barrier.

For other beetles such as the Darkling beetles, the movement was modified by the presence of corridors; they spent more time in abandoned corridors than in mowed grasslands. Collinge (2000) found that the movement in habitat patches depended upon species, landscape, patch size and environment. In contrast to the findings of Collinge (2000), the species specific movement was less important than the habitat characteristics, e.g. vegetation structure between the different crops and between crops and grassy strips, in our experiments. In conclusion, the movement of carabids into agricultural areas depends on a large variety of factors: specific movement

behaviour of species, vegetation structure of field margins and strips, and crops planted on arable fields. Organic farming with a variety of crops and a variety of different field margins and strips provides the opportunity for most abundant carabids to use crop areas and grassy strips for dispersal, which might support their species richness and biodiversity in the organic agro-ecosystems.

### **3.3.5 Acknowledgements**

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## Chapter 4

### General Conclusions

The role of biodiversity for sustainable food production and biological control of notorious pests is well understood. In ecological engineering, the habitat conservation and habitat heterogeneity are considered key elements for biodiversity and future sustainable food production. The present studies present an outlook of the role of grassy field strips in organic agroecosystems to determine their effects on the most common carabid species, on their groups based on the body size, and red-listed species status. It also extends its range on the importance of the age of grassy strips for abundance and biodiversity of arable fields' carabids and on their dispersal and movement for invasion from natural and semi-natural habitats to crop fields. The results of invasion of carabids from grassy strips to arable crops are presented in two ways. First, by interpreting transect data of one year using pitfall traps, and second, by using the mark-recapture method in both spring and autumn season. Thus, the first way uses the place for time method to analyse the invasion of carabids, whereas the second way uses the direct investigation of the invasion process.

The first major findings of this work are related to the carabid species which benefit from grassy strips in organic agriculture. For this the different ecological groups (guilds) were used and only soil pH and tree cover explained the effects significantly. The species composition in the investigations resembled the most common carabid assemblage of arable fields on loamy soils in Schleswig-Holstein. Typical field margin species that used the grassy strips as corridors into arable fields were *Carabus nemoralis*, *C. coriaceus*, and *P. strenuus*. All three species can be described as euryecious species having a weak preference for forests (Irmeler & Gürlich 2004). They invaded from the field margins to crop using the grassy strips and rarely crossed into arable fields. Among these three species, *C. nemoralis* revealed the highest mobility, as it was found in high dominance at a distance of up to 90 m in the grassy strips. Dominance of *C. coriaceus* drastically declined at a distance of 30 to 60 m from the field margin; the dominance of *P. strenuus* was generally low in strips and arable fields.

The species that prefer open habitats, e.g. *P. cupreus*, *P. versicolor*, and *Amara similata*, used field strips. They increased in dominance with an increase in distance from the field margin, except for *A. similata* that declined in 150 m distance from field margin. Thus, it can be assumed that field strips support these species, in particular, as they were found in higher dominances in strips than in field margins. In this study, grassy strips did not support the invasion of *Anchomenus dorsalis* which is considered to overwinter in hedges of field margins and invades arable fields in the spring from overwintering sites (Jensen et al., 1989; Maudsley et al., 2002).

The effects of grassy strips were not found on endangered and differently sized species, because the composition of carabid sizes did not differ between arable fields and grassy strips. However, field margins revealed a different size composition. In field margins, the percentage of very large species (> 15 mm) was higher than in grassy strips and arable fields, whereas the number of small (< 5 mm) species was lower. This can be an effect of the higher stability of field margins compared to grassy strips. Whereas grassy strips in our studies did not exceed an age of 10 years, field margins were much older. In grassy strips and arable fields, intermediate species between 5 mm and 15 mm dominated. Due to their high mobility, the medium sized carabids benefited from the grassy strips and arable crops and they were not sensitive to agricultural practices. In conclusion, the benefits of grassy strips in organic farming could be well understood when the ecological needs of the species using these habitats and their corresponding dispersal potential are considered. The classification of carabids into different food preference type and size groups was necessary to analyse the role of grassy strips and provided specific results, which might be masked if the data are interpreted only for carabid species in total.

Overall, due to environment friendly practices, organic farming brings the arable fields closer to the natural conditions as compared to conventional farming. Thus, the grassy strips might have a minor value for biodiversity in organic agriculture. In addition, mostly the grassy strips are established for two to three years. After this time they are normally rotavated and developed at another site to combat the problem of thistle abundance. As the comparison between grassy strips and field margins shows, the age of semi-natural habitats in the agricultural landscape is of high importance. The higher species richness in the field edges and grassy strips when compared to a huge crop area without grassy strips (control field) and cropping areas close to grassy strips revealed that the need of grassy structures in organic agriculture could not be neglected. When the grassy strips have a promising role in organic agriculture, the

question arises how long the grassy strips should be kept to get higher advantages. In this work, 9-10 years old grassy strips amplified higher species richness and biodiversity than young strips of 1- 2 years. However, the overall farming management causes the highest effects on carabid assemblages that covers the effects of soil conditions, microclimate situations and minor varying practices as already found in studies with a large number of arable fields and different farming practices (Irmeler 2003). Therefore, strong similarities of carabid assemblages in the different habitats (field edges, grassy strips, crops along grassy strips, crop in the crop fields without grassy strip in neighborhood) were also found in the present study. Based on this effect, the biodiversity and species richness in the arable landscape are low in general and provide only small ranges of enhancement.

The effects of natural and semi-natural habitats on the adjacent crops were investigated by using additional pitfall transects in the crop field area close to the grassy strips. If only the field centres are selected in the analyses, the masking effect of field edges could be diminished. The results in grassy strips with an age of 9 years supported our hypothesis that also in organic farming grassy strips can increase species richness and biodiversity in the surrounding arable crops. Moreover, a significant increase in the dominant species was found with the age of the grassy strips. Most importantly, carnivorous species benefited from old grassy strips. So, the old grassy strips seem to share a higher role in biological control as compared to the younger grassy strips. When the distance from the natural habitats increases, the effect on the biodiversity and species richness is decreasing. On the other hand, activity density increases by increasing distance from field margins, which can be referred to the open ground conditions and food supply that causes a higher activity, speed, and dispersion as found in the movement experiment.

Other findings of the present investigations concern the invasion of carabids from semi-natural habitats to the arable crops and the direction used for the invasion. Analysing the invasion process, the distances covered by the invasive species are very important. This study presents a high range of values for distances and speeds as found also in other studies. This variability was explained by the flexible behaviour of field carabids and the different spatio-temporal conditions in the studies.

All major carabids investigated in the mark-recapture experiment (e.g. *P. melanarius*, *C. auratus*, *Poecilus* spp) travelled longer distances in cropping areas than in grassy strips. The rate of displacement was different in different crops for *P. melanarius* that moved faster in wheat crop than in pumpkin and clover. Most of the beetles moved

more slowly in the clover crop than in wheat or pumpkin, which shows that in clover the environmental conditions resemble those in grassy margins.

The importance of hedges in arable ecosystems was found by the results on *C. nemoralis*, which preferred to move along the grassy strips with hedge and avoided to enter into the crop centre, if only grassy strips without hedge are offered. The same species was totally absent in the huge field centres. So, species which are restricted to shadow habitat conditions during their lifetime, only the availability of hedges and grassy strips with hedges could establish them successfully.

While moving from the grassy structures to the crop centres, the carabids reacted in different ways. The species that are mainly found in arable fields, e.g., *Pterostichus melanarius*, preferred to enter the crop directly. *Poecilus* spp. highly preferred a grassy strip to enter into crop land and avoided a grassy strip along a hedge or to enter directly the crop fields. The movement of *Nebria brevicollis* was mainly parallel to the grassy strip. In contrast, *P. niger* moved both inside and along the grassy strips. The diversity of preferences in carabids to use grassy strips for their dispersal shows that the value of grassy strips depend on the specific demands of the species and reflect very complex reactions of the fauna in the arable landscape.

In conclusion, the natural and semi-natural habitats support at least several carabid species based on their ecological needs and support the biodiversity and species richness in the agricultural landscape. With passing time, the benefits of the grassy strips increase. If they are maintained for at least one decade, they provide higher biodiversity both inside their area and in the surrounding arable crops. In general, the grassy structures support at least several specific carabids to move into the arable crop land, which would be not found there if these structures are absent.

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**Appendix 1:** Sixty nice species not included in table 3.2.2 with their abundance in crop areas, grassy strips and field edges; Fields 2,4, and 8 stand for the fields with 2-, 4-, and 9- year old grassy strips; Cont. Stands for the control field

<b>Species/ Fields</b>	Cont.	2	4	9	2	4	9	Cont.	2	4	9
<i>Acupalpus meridianus</i>	15	2	4	0	1	1	0	0	0	0	0
<i>Amara anthobia</i>	0	3	0	0	1	0	0	0	0	0	0
<i>Amara bifrons</i>	2	0	0	0	0	0	0	0	0	0	0
<i>Amara consularis</i>	0	11	0	1	1	0	4	0	1	0	0
<i>Amara plebeja</i>	6	1	0	4	0	0	1	0	1	0	1
<i>Anisodactylus binotatus</i>	1	0	0	1	0	0	3	0	0	0	1
<i>Bembidion guttula</i>	0	0	0	0	0	1	0	0	0	1	0
<i>Bembidion lunulatum</i>	0	0	0	0	0	0	1	1	0	1	0
<i>Bembidion quadrimaculatum</i>	70	2	1	19	0	0	1	0	0	0	1
<i>Bradycellus harpalinus</i>	0	0	1	0	0	1	0	0	0	0	0
<i>Calathus erratus</i>	0	1	0	0	0	0	0	0	0	0	0
<i>Calathus melanocephalus</i>	0	6	0	2	0	0	6	0	1	0	0
<i>Carabus coriaceus</i>	1	5	0	1	8	3	1	0	2	3	15
<i>Carabus hortensis</i>	0	0	0	0	0	0	1	0	0	0	12
<i>Cychrus caraboides</i>	0	0	0	0	0	1	0	0	1	0	0
<i>Harpalus latus</i>	1	2	2	8	3	0	16	1	1	0	2
<i>Harpalus neglectus</i>	0	0	0	1	0	0	0	0	0	0	0
<i>Harpalus rufipalpis</i>	1	0	1	1	0	2	1	0	0	0	0
<i>Harpalus tardus</i>	5	12	4	9	8	1	2	2	2	0	1
<i>Leistus terminatus</i>	0	0	0	0	0	1	0	0	0	0	0
<i>Loricera pilicornis</i>	33	4	12	2	2	0	2	1	1	0	0
<i>Notiophilus biguttatus</i>	3	0	3	7	0	1	1	0	0	0	1
<i>Notiophilus palustris</i>	0	0	0	0	0	0	0	1	0	0	3
<i>Patrobus atrorufus</i>	0	0	0	0	0	0	0	1	0	0	0
<i>Pterostichus diligens</i>	5	9	0	1	1	1	3	2	0	1	0
<i>Pterostichus niger</i>	4	15	1	0	3	6	0	0	3	0	0
<i>Pterostichus nigrita</i>	1	0	0	1	0	0	0	0	0	0	0
<i>Pterostichus strenuus</i>	2	5	0	0	0	3	7	0	0	2	6
<i>Pterostichus vernalis</i>	2	3	2	0	0	0	1	0	0	0	0
<i>Trechoblemus micros</i>	1	0	0	2	0	1	0	0	0	1	0
<i>Trichocellus cognatus</i>	0	1	0	0	0	0	0	0	1	0	0
<i>Bembidion biguttatum</i>	0	0	0	0	0	0	0	0	0	1	0
<i>Leistus rufomarginatus</i>	0	0	0	0	0	0	0	0	1	0	0
<i>Harpalus signaticornis</i>	2	4	0	0	4	0	0	1	0	0	0
<i>Pterostichus oblongopunctatus</i>	0	0	0	0	0	0	0	0	0	0	8

## *Résumé*

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### Publications

2013 Which carabid species benefit from grassy strips in organic agriculture? Accepted in **Angwandte Carabidologie**  
2013 Age of grassy strips influences biodiversity of ground beetles in organic agro-ecosystems: Published in **Agricultural Sciences**  
2013 Movement of carabids from grassy strips to crop land in organic agriculture: Submitted in **Journal of Insect Conservation**