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Effects of herbicide-free field margins on bumblebee and butterfly diversity in and along hedgerows

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The reports are, however, published because the Danish EPA finds that the studies represent a valuable contribution to the debate on environmental policy in Denmark.

Content

Preface

This report presents the results of the project ”Effects of herbicide-free field margins on bumblebee and butterfly diversity in and along hedgerows”. The project was carried out in order to investigate the relationship between flowering herbaceous plants in hedgerows and diversity and activity of bumblebees and butterflies. The project has been carried out by the National Environmental Research Institute – University of Aarhus, and Institute of Agriculture and Ecology – University of Copenhagen. The project was financed by the Danish Ministry of Environment through the pesticide tax funds. This small project (three months of field work) is a contribution to the ongoing three-year project “Indicators for biodiversity improvements in biotopes close to fields by establishment of herbicide free marginal zones” (Strandberg et al. in prep.). The results of the present project will later be part of and discussed in relation to the findings of the main project by Strandberg et al. when reported.

The project group consisted of:

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- Rasmus Nimgaard, Peter Esbjerg and Søren Navntoft, Department of Agriculture and Ecology, University of Copenhagen.

Statistical analyses were carried out by Kristian Kristensen, Department of Genetics and Biotechnology, University of Aarhus.

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Summary

This report summarises the results of a three month study, which is a small addition to the three-year project: “Indicators of improvements in biodiversity in biotopes close to fields by establishing herbicide-free marginal zones” by Strandberg et al. The main aim of the study was to investigate the relationship between density and diversity of flowering herbaceous plants and the activity and diversity of bumblebees and butterflies in hedgerows. A further aim was to investigate if first-year absence of herbicides in 18-24 metres field margins would result in more activity and higher diversity of bumblebees and butterflies in and along hedgerows.

Recordings of bumblebees and butterflies at species level were performed visually during transect walks both right along the hedgerows and 9-12 m within the field margins parallel with the hedgerows. These recordings only took place during certain minimum weather conditions. Four complete set of recordings were carried out during each of the months July, August and September in 2009. The experiment included 10 fields and hedgerows in the Horsens – Vejle - Give area in Eastern Jutland, Denmark.

The main results of the study were:

1. Hedgerow ground layers at conventional farms represent a poor locality for flowers relevant for bumblebees and butterflies. Few food plants were found in this locality and the occurrence was scattered and unaffected by establishment of a one-year herbicide-free field margin.
2. Activity and diversity of both butterflies and bumblebees in the hedgerows were low despite establishment of 18-24 m herbicide-free field margins next to the hedgerows. One-year herbicide-free field margins, therefore, seemed to be an inadequate mitigation method for improvements of bumblebee and butterfly diversity in hedgerows.
3. The results support the hypothesis that there in is a positive relationship between occurrence of selected food plants and diversity of butterflies.
4. The plant species visited by bumblebees and butterflies were among those known to serve as good food plants; mainly belonging to the families Asteraceae, Laminaceae, Rosaceae, Dipsacaeceae (kurveblomst-, læbeblomst-, rosen- og kartebollefamilien) and for butterflies also Brassicaceae and Violaceae (korsblomst- og violfamilien).
5. The herbicide-free field margins had a positive effect on butterfly activity and diversity in the margins on sandy soils.

The low bumblebee activity and diversity found in this study may very well be general for the Danish arable landscape as similar low densities has been found in other Danish investigations (Navntoft et al. 2009, C.I. Henriksen pers. comm).The pronounced positive effect on butterfly activity and diversity of herbicide-free field margins on sandy soils can be ascribed to a denser weed cover here compared to the weed cover on loamy soils.

This study has identified some important areas that need further research in order to secure a higher biodiversity (functional and ***per se***) in the arable

landscape. First of all we need long-term monitoring of bumblebees and butterflies, preferable at the landscape scale, in order to be able to estimate agricultural impacts on their populations. Furthermore we need more knowledge on the quality of the flowers as nectar and pollen resources for pollinating insects. This, in combination with more knowledge of hedgerow management for improved flowering, would make it possible to give more precise guidance/regulation of edge zone management with the aim to improve abundance and diversity of pollinating insects through the promotion of for farmers less problematic wild plant species with a high food value.

Sammenfatning

Denne rapport sammenfatter resultaterne af et 3 måneders studie, som er et mindre tillæg til det 3-årige projekt: ”Indicators of improvements in biodiversity in biotopes close to fields by establishing herbicide-free marginal zones” af Strandberg et al. Hovedformålet med projektet var at undersøge sammenhængen mellem tætheder og diversitet af blomstrende urter og aktiviteten og diversiteten af humlebier og dagsommerfugle i levende hegn. Et yderligere formål var at undersøge, om 1-årige herbicid-frie randstriber (18-24 meter brede) ville resultere i højere aktivitet og diversitet af humlebier og dagsommerfugle i og langs levende hegn.

Opgørelse af humlebier og dagsommerfugle på artsniveau blev udført visuelt ved transekt-tællinger tæt på hegnet og 9-12 m ude i selve markranden. Tællingerne blev kun udført i godt vejr og fire komplette transekttællinger i henholdsvis juli, august og september blev foretaget i 2009. Forsøget omfattede 10 marker og hegn i området mellem Horsens, Vejle og Give.

Projektets hovedresultater var:

1. Levende hegn på konventionelle bedrifter understøtter i ringe grad blomstrende urter relevante for humlebier og dagsommerfugle. Der blev kun fundet få fødeplanter i hvert hegn og deres forekomst var spredt og upåvirket af 1-årige herbicid-frie randstriber.
2. Aktiviteten og diversiteten af både humlebier og dagsommerfugle i levende hegn var lille, selvom der blev etableret 18-24 meter brede herbicid-frie randstriber. Derfor syntes etableringen af 1-årige herbicid-frie randstriber at være en utilstrækkelig metode til at forbedre diversiteten af humlebier og dagsommerfugle i levende hegn.
3. Resultaterne understøtter hypotesen om, at der er en positiv sammenhæng mellem forekomsten af udvalgte arter af fødeplanter og diversiteten af dagsommerfugle.
4. De plantearter, som blev besøgt af humlebier og dagsommerfugle, var alle blandt de allerede kendte vigtige fødeplanter; hovedsageligt tilhørende familierne Asteraceae, Laminaceae, Rosaceae, Dipsacaeceae (kurveblomst-, læbeblomst-, rosen- og kartebollefamilien) og for dagsommerfugle yderligere Brassicaceae og Violaceae (korsblomst- og violfamilien).
5. De herbicid-frie randstriber havde en signifikant positiv effekt på aktiviteten og diversiteten af dagsommerfugle i selve markranden på sandede jorde.

Den lave humlebiaktivitet og diversitet i dette forsøg kan meget vel være generel for det danske agerland. Tilsvarende lave tætheder er også blevet fundet i andre danske studier (Navntoft et al. 2009, C.I Henriksen pers. comm). De positive effekter på dagsommerfugleaktiviteten og diversiteten af herbicid-frie randstriber på sandede jorde kan tilskrives den større ukrudtstæthed på sandede jorde i forhold til lerede jorde.

Dette studie har afdækket nogle vigtige områder, der kræver nærmere studier for at sikre en højere biodiversitet (funktionel og ***per se***) i agerlandet. Først og

fremmest behøves der længerevarende monitering af humlebier og dagsommerfugle, fortrinsvist på landskabsniveau, for at kunne estimere landbrugsdriftens betydning for populationerne i agerlandet. Derudover behøves der mere viden om betydningen af nektar- og pollenkvalitet i forskellige blomster for pollinerende insekter, med det mål at kunne fremme forekomsten af mindre aggressive ukrudtsarter/vilde planter med høj fødemæssig værdi. Dette, i kombination med mere viden om hvordan blomstrende urter fremmes via pleje af levende hegn, vil gøre det muligt at give bedre retningslinjer for pleje af randzone med det mål at forbedre antallet og diversiteten af pollinerende insekter.

1 Introduction

1.1 Background

Species numbers of bumblebees and butterflies and their abundances are declining in Denmark as well as in many other countries (Brittain et al. 2010, Den danske rødliste 2004, Stoltze & Pihl 1998, Asbirk & Søgaard 1991, Williams 1982). Agricultural areas are among the areas with severe declines and among other reasons, decreased availability of preferred food sources is known to play a significant role (Brittain et al. 2010, Osborne et al. 1991, Williams 1982). Apart from periods with mass flowering crops such as red clover (***Trifolium pratense***), oil seed rape (***Brassica napus***) and broad bean (***Vicia faba***), plants within natural and semi-natural habitats act as the main and continuous food source. Both quantity and quality of these habitats have been reduced during the recent decades due to the intensification of the agricultural practice. Among others, the usage of herbicides in agricultural fields may be important for the reduced availability of preferred food plants.

Herbicide-free field margins have the potential to reduce spray drift to neighbouring habitats. Such a reduction is anticipated to have a positive effect on the availability of preferred food plants supplying the insects with pollen and nectar. A few investigations have found higher plant diversity and a higher density of flowering plants within hedgerows on organic farms relative to conventional ones (Aude et al. 2003, Strandberg et al. in prep.). Christensen (2008) found that exposure to the herbicide Starane 180S, with the active ingredient fluroxypur, resulted in reduced flowering of ***T. pratense*** and ***Taraxacum*** sp. (rødkløver og mælkebøtter) when added at dosages found in spray drift. This potential of getting higher plant diversity and a more intense flowering of the species present in the hedgerows when establishing herbicide-free field margins is being tested in an ongoing project "Indicators of improvements in biodiversity in biotopes close to fields by establishing herbicide-free marginal zones" (Strandberg et al.). The collection of data on bumblebees and butterflies foraging within these hedgerows will make it possible to look for relationships between food resources, i.e. availability of preferred food plants and flowering of these species, and the diversity of bumblebees and butterflies.

In addition such data gives information on diversity of bumblebees and butterflies within field margins that are free of herbicides and therefore adds new information on the sole effects of herbicides relative to a previous project (Navntoft et al. 2009) that showed significantly positive effects on biodiversity of the combined exclusion of herbicides, insecticides, fungicides and fertilizers within narrow strips along hedgerows (called buffer zones).

Bumblebees are well-adapted pollinators of many wild flowers, and thus important for their conservation. Also, they are adding valuable pollination services to crops. However, in the last decades many bumblebee species have shown serious declines in abundance (e.g. Williams 1982, Den danske rødliste 2004). The habitat requirements of bumblebees include forage, nesting and hibernation sites. Svensson et al. (2000) only found bumblebee queens searching for nesting sites in relative undisturbed habitats such as field

boundaries or permanent grass fields and not in fields with annual crops. Furthermore, it has been suggested that one factor contributing to bumblebee decline is the change in land use resulting in loss of perennial flowers that provide the seasonal succession of forage required to sustain bumblebee colonies (Williams 1982, Osborne et al. 1991).

Butterflies need both nectar from various flowers and specific host plants for their larvae, and butterflies are therefore a good indicator group for other arthropods and plants as well (e.g. van Swaay 1990, New 1997, Thomas 2005, Navntoft et al. 2009). One reason for their population declines is reduced availability of flowers and host plants, and the general trend is that in each version of the Red Data Books more species are listed as threatened (red listed) (Asbirk & Søgaard 1991, Stoltze & Pihl 1998, Den danske rødliste 2004). This trend is not only present in Denmark, but seen all over Europe with extinctions and contractions of ranges for several butterfly species during the 20th century. In England, three-quarter of 54 resident species have declined and 5 species have gone extinct (Fox et al. 2007), most severely in the eastern part where agriculture is the most intensive, and pressure on semi-natural areas are greatest (Pollard & Yates 1993). In the Netherlands, van Swaay (1990) reported of 15 extinctions among the 71 native butterfly species and a further 14 species had contractions of their ranges. Maes & Dyck (2001) showed that in a part of Belgium 19 of 64 indigenous butterfly species had gone extinct and at present half of the remaining species are threatened.

In order to gain more knowledge on how to stop this negative development and to conserve and increase biodiversity in general, and in this case bumblebees and butterflies specifically, this study was started with the aims stated below.

1.2 Aims and hypotheses

The aims of the project were:

- To investigate relationships between flower resources and activity/diversity of bumblebees and butterflies in hedgerows.
- To investigate if first-year absence of herbicides in 18-24 m wide field margins bordering hedgerows results in changed activity/diversity of bumblebees and butterflies in and along hedgerows.

This aims were based on the following hypotheses:

- A positive relationship is found between floral resources and diversity of bumblebees and butterflies (measured as species richness)
- The nectar and pollen resources utilized by bumblebees and butterflies (measured as flower visits) in and along the hedgerows would increase with the absence of herbicides.

The term activity is used as a measure for the number of bumblebees or butterflies observed (number of bumblebees and butterflies observed per 100 m transect walk). Species richness is the simplest form of a diversity measure, although widely recognized, and focuses only on the number of species observed.

1.3 Limitations of the project

As stated above, this project is a small zoological project contribution to the flower indicator project planned and started earlier than the present, dealing with plant indicators for biodiversity improvements by establishment of herbicide-free field margins. This resulted in the limitations stated below:

- Effects of herbicide-free field margins in the spring could not be investigated, as it was not possible to start the insect sampling before July.
- As the original project only concerned flowering, the host farmers were allowed to apply insecticides and other pesticides than herbicides as normal in the experimental plots. These other pesticides may affect insect activity in the experimental plots, and the herbicide effect on bumblebees and butterflies may therefore be confounded with effects of other pesticides.
- Flowering was registered within 0.25 m^2 plots in the hedge ground layers. Bumblebee and butterfly flower visits however, had to be recorded in the entire hedge ground layer in order to collect sufficient data, thereby reducing the possibilities for optimal regression analyses on covariance between flowering and flower visits.
- As flowering was only recorded in the hedge ground layer, estimating relationships between flowers and flower visits in field margins were not possible. Thus, flower visits in the field margins are used as a surrogate indicator of increased floral resources in field margins. This also means that estimated effects of soil types on insect activity and diversity are confounded with effects of soil type on flowering.

2 Methods

2.1 Study sites

For the investigation of the effects of herbicide-free field margins on flowering in hedgerows within the project "Indicators of improvements in biodiversity in biotopes close to fields by establishing herbicide free marginal zones" (Strandberg et al. in prep.), 10 North-South running hedgerows on conventional farms were selected. All 10 hedgerows were located in East-Jutland (Fig. 2.1). The hedgerows represented variation in both age and composition of trees and bushes and the soils varied from sandy clay to coarse sand (see Table 2.1). The crops bordering the hedgerows were spring barley (six fields), winter wheat (three fields) and ryegrass (one field) in 2009 (Table 2.1).

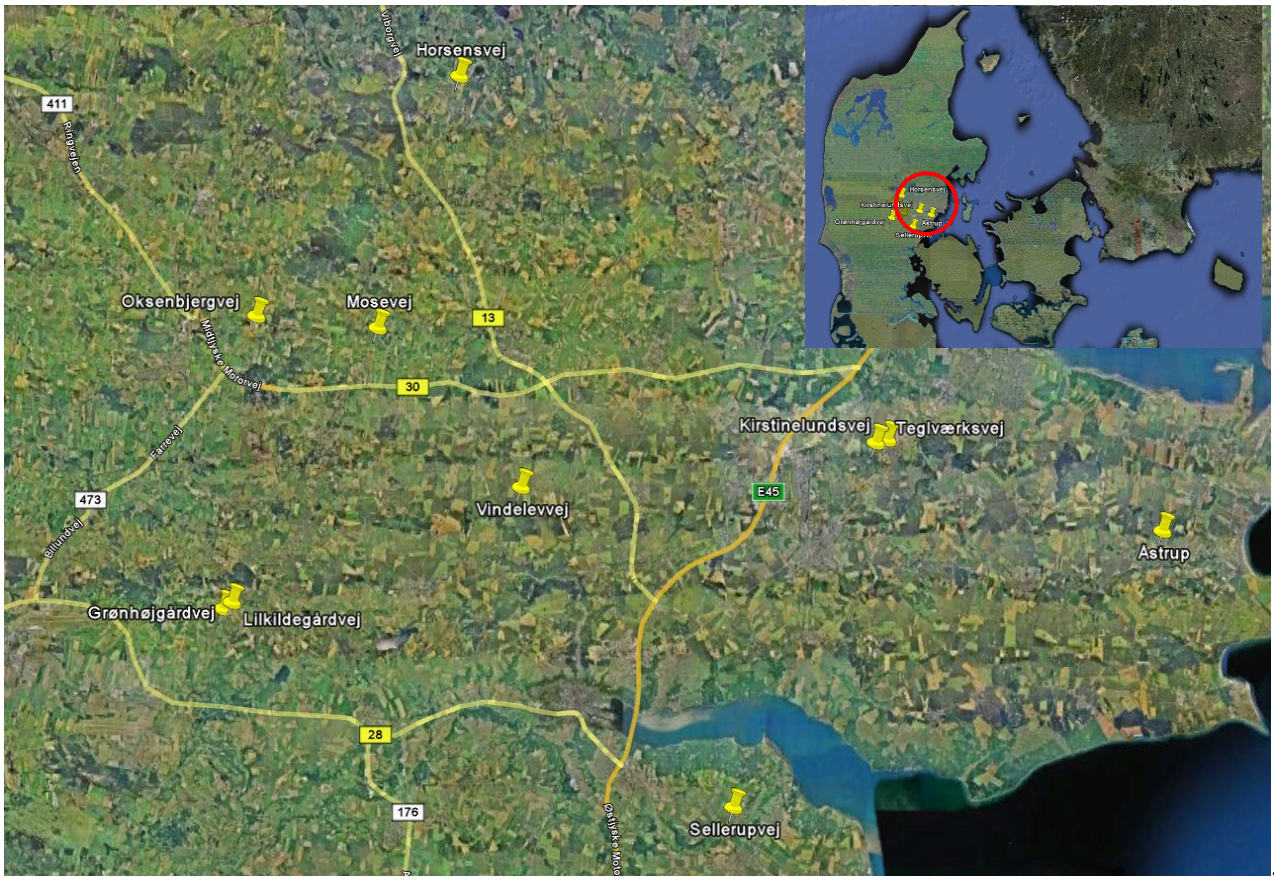

Fig. 2.1. Aerial view of the 10 farms situated in Eastern Jutland. As an indication of scale, there is about 45 km between Åstrup and Grønhøjgårdsvej (East-West straight line) and about 30 km between Horsensvej and Sellerupvej (North-South straight line).

2.2 Field margin treatments

All fields were sprayed with herbicides in spring or early summer as part of the conventional practice (Tabel 2.1) and along each of the hedgerows, a herbicide-free margin was established on the West-facing side of the hedgerow. The zone was 200 m (at one site only 180 m) long and 18 or 24 m

wide, and placed randomly in either the Northern or Southern end of the field (Fig. 2.2).

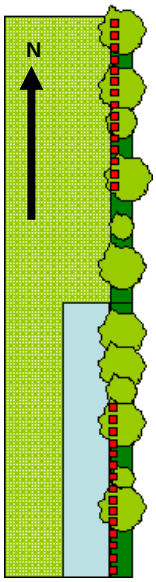

Fig. 2.2. Schematic presentation of the sampling sites with the 180-200 m long and 18 or 24 m wide herbicide-free field margin (indicated by blue color) on the west facing side of the North-South running hedgerows. The red squares show the 0.5 × 0.5 m sampling plots used for flower registration (from Strandberg et al., in prep.)

As insect recordings were not planned when the plant indicator project was initiated, the farmers were allowed to spray the herbicide-free field margins with insecticides and other chemicals applied to the rest of the field. All fields were treated with herbicides (Table 2.1). In addition, one field (Åstrupvej) was treated with an insecticide and all fields were treated with fungicides and /or growth regulators (Table 2.1). Six fields were treated with pesticides with known adverse effects on honeybees. This applies to the insecticide Fastac and the herbicide Oxitril.

Table 2.1. Basic information for the 10 experimental fields in 2009.

Location/ Crop	Soil	Herbicides			Insecticides			(F)ungicides and (G)rowth regulators		
		date	Trade name/ *active ingred.*	BI[3]/dose	date	Trade name/ *active ingred.*	BI/dose (l/ha)	date	Trade name/ *active ingred.*	BI/ Dose (l/ha)
Åstrupvej/ Spring barley	Sandy clay (4)	24/3	DFF/ *Diflufenican*	0.33;0.05 l/ha	3/6	Fastac 50[4]/ *Alpha-cypermethrin*	0.6;0.15	13/5	Zenit 575 EC(F)/ *Propiconazol+ Fenpropidin*	0.24;0.15
		24/3	Starane/ *Fluroxypyr*	0.29;0.2 l/ha				3/6	Amistar (F)/ *Azoxystrobin*	0.15;0.15
		24/3	Express ST/ *Tribenuron-methyl*	0.17;0.33 T /ha				3/6	Zenit 575 EC(F)/ *Propiconazol+ Fenpropidin*	0.24;0.15
								3/6	Cerone (G)/ *Ethephon*	0.2;0.1
Sellerupvej/ Common ryegrass	Sandy clay (4)	15/5	Starane/ *Fluroxypyr*	1.0;0.7 l/ha				15/5	Opera (F)/ *Epoxiconazol+ Pyraclostrobin*	0.19;0.2
								15/5	Folicur EC 250(F)/ *Tebuconazol*	0.2;0.2
Teglværksvej/ winter wheat	Sandy clay (4)	1/5	Ally ST/ *Metsulfuron-methyl*	o.25;0.4 T/ha[2]				27/5	Bell (F)/ *Epoxiconazol+ Boscalid*	0.29;0.35
								27/5	Comet (F)/ *Pyraclostrobin*	0.1;0.1
								1/7	Bell (F)/ *Epoxiconazol+ Boscalid*	0.29;0.35
								1/7	Comet (F)/ *Pyraclostrobin*	0.1;0.1
Kirstinelundsvej/ Spring barley	Sandy clay (4)	14/5	Express ST/ *Tribenuron-methyl*	0.4;0.8 T/ha[2]				26/5	Zenit 575 EC(F)/ *Propiconazol+ Fenpropidin*	0.32;0.2
		14/5	Oxitril CM[4]/ *Ioxynil + bromoxynil*	0.2;0.2 l/ha				10/6	Comet (F)/ *Pyraclostrobin*	0.15;0.15
								10/6	Opus (F)/ *Epoxiconazol*	0.15;0.15
Vindelevvej/ Winter wheat	Sandy clay (4)	23/4	Monitor/ *Sulfosulfuron*	0.51;11.25 g/ha				23/4	Ccc 700 (G)/ Chlormequat-chlorid	0.38;0.5
								29/4	Tern (F)/ *Fenpropidin*	0.2;0.2
								15/5	Opera (F)/ *Epoxiconazol+ Pyraclostrobin*	0.19;0.2
Horsensvej/ spring barley	Loamy sand (3)	5/5	Express ST/ *Tribenuron-methyl*	0.38;0.75 T /ha				5/5	Opera (F)/ *Epoxiconazol+ Pyraclostrobin*	0.23;0.25
			Oxitril CM[4]/ *Ioxynil + bromoxynil*	0.2;0.2 l/ha						
Mosevej/ Spring barley	Coarse sand (1)	5/5	Express ST/ *Tribenuron-methyl*	0.38;0.75 T /ha				1/6	Amistar (F)/ *Azoxystrobin*	0.15;0.15
		5/5	Oxitril CM[4]/ *Ioxynil + bromoxynil*	0.2;0.2 l/ha				1/6	Zenit 575 EC(F)/ *Propiconazol+ Fenpropidin*	0.24;0.15
Oksenbjergevej/ winter wheat	Loamy sand (3)		Data not available[5]/					2/5	Folicur EC 250(F)/ *Tebuconazol*	0.15;0.15
								2/5	Bell (F)/ *Epoxiconazol+ Boscalid*	1.02;0.85
								1/6	Opera (F)/ *Epoxiconazol+ Pyraclostrobin*	0.23;0.25
								1/6	Amistar (F)/ *Azoxystrobin*	0.15;0.15
Grønhøjgårdsvej/ spring barley	Coarse sand (1)	2/5	Express ST/ *Tribenuron-*	0.38;0.75 T /ha				2/5	Opera (F)/ *Epoxiconazol+*	0.23;0.25

Location/ Crop	Soil	Herbicides			Insecticides			(F)ungicides and (G)rowth regulators		
		date	Trade name/ *active ingred.*	BI[3]/dose	date	Trade name/ *active ingred.*	BI/dose (l/ha)	date	Trade name/ *active ingred.*	BI/ Dose (l/ha)
			methyl						*Pyraclostrobin*	
			Oxitril CM[4]/ *loxynil + bromoxynil*	0.2;0.2 l/ha						
Lilkildegårdvej/ Spring barley	Coarse sand (1)	2/5	Express ST/ *Tribenuron-methyl*	0.38;0.75 T /ha				2/5	Opera (F)/ *Epoxiconazol+ Pyraclostrobin*	0.23;0.25
			Oxitril CM[4]/ *loxynil + bromoxynil*	0.2;0.2 l/ha						

[1] The JB-no. is a Danish 1–10 scale used to graduate soils from very sandy (1) to very heavy (10).
[2] Tablets / ha.
[3] BI: Treatment Intensity Index (Behandlingsindex), the applied pesticide dose relative to a full treatment in www.middeldatabasen.dk.
[4] hazards to bees.
[5] The farmer has not made the data on herbicide treatment available but the dense weed cover in the herbicide-free part of the field compared to the rest of the field clearly showed that herbicides had been used

2.3 Flower registration

Flowering of hedgerow ground flora was recorded in 0.5×0.5 m plots on the West-facing side of the hedgerows bordering herbicide-free (15 plots) and herbicide treated (15 plots) parts of the field margin (Fig 2.1). The plots were evenly distributed within the first 100 m at each end of the hedgerow (Fig. 2.1). In each plot, all species were recorded once per month from May to September. For flowering species, the number of plants and the number of flowers per plant for up to ten randomly selected individuals were counted. Here, only data from July to September, i.e. the months with registration of bumblebees and butterflies, was used. Nomenclature follows Hansen (1981).

2.4 Bumblebee and butterfly registration

Standardized transect counts of butterflies (Lepidoptera) and bumblebees (***Bombus*** spp) were carried out following the method of Pollard (1977) and Pollard and Yates (1993) in order to estimate the activity and diversity of these insects in hedgerows next to herbicide-free and conventionally sprayed field margins and within the field margins 9-12 m from the field edge. Transect counts have been used successfully for monitoring butterflies and bumblebees in arable ecosystems by e.g. Sparks et al. (2000), Clausen et al. (2001), Pywell et al. (2004) and Navntoft et al. (2009).

The target species were recorded as the observer walked through the transects at a steady pace. If there were any doubt whether an individual had been counted previously it was counted, thus the term activity is used instead of abundance. Bumblebees and butterflies were recorded to species and categorized as either flying or flower visiting. Two species of butterflies, ***Thymelicus lineola*** and ***T. sylvestris*** (streg- og skråstregbredpande), only have very subtle differences not distinguishable in flight and thus have been pooled. Likewise it is not possible to distinguish between the workers of two species of bumblebees ***Bombus lucorum*** and ***B. terrestris*** (lys og mørk jordhumle) and they were pooled as well. The cuckoo bumblebees (snyltehumler) (formerly in the subgenus ***Psithyrus***), which are brood parasites of other bumblebee species, were counted as one group. When flowers were visited, the plant species was recorded. Nomenclature follows www.FaunaEuropaea.org.

Each of the 10 hedgerows was visited four times during each month of July, August and September. The 10 fields were grouped in 2 × 5 fields, so that a group of five fields could be surveyed twice during the same day and thereby reduce the time used for transportation. The next day the other group of five fields would be surveyed. This sampling order was not followed strictly, but applied to most of the samplings. The order of field visits within each field group, the starting points of the transect walks (North or South) and the person counting insects in hedgerow and field margin, respectively, were all randomised.

In order to ensure consistency between sites, rigid criteria were imposed. The majority of counts were made after 11:30 Danish Summer Time (GMT +2 h) and before 16:30. The wind speed newer exceeded 5 m/s and the air temperature was 17 ºC or higher in both overcast and sunny conditions.

2.5 Weather

The weather during the summer of 2009 (June, July and August) can be summarised as warm and sunny but also with a relatively high precipitation. The mean temperature in Denmark was 16.2 °C which is 1°C higher than the average of 1961-90. The average precipitation in Denmark was 217 mm which is 15% higher than the mean of period 1961-90. The mean, however, covers a high variation between regions but with Eastern Jutland being close to the mean. June was a bit colder than usual but July and August were warmer than usual. Denmark had 700 h of sunshine during the summer which is 18% higher than the mean of 1961-90 (www.dmi.dk).

September was warm (mean temperature was 14 °C being 1.4 °C higher than the average of 1961-90), dry (mean precipitation was 45 mm being 38% below the average of 1961-90) and sunny (mean h of sunshine was 160 being 25% higher than the average of 1961-90) (www.dmi.dk).

2.6 Data analysis

2.6.1 Relationships between flowering and activity of bumblebees and butterflies

The number of flowers recorded and the number of arthropod observations on flowers within the hedgerows was too low for statistical analyses on flower preferences of bumblebees and butterflies. However, data was sufficient to test if there was a positive relationship between the density and diversity of flowers in the hedgerows and the activity and diversity of bumblebees and butterflies in the hedgerows. The total number of individuals and number of species (species richness) was calculated for each field (summed over treatment and sampling period). The possible relationship was analysed using a generalised linear model for number of individuals and a linear model for species richness. Mathematically the models may be written as:

$Y_{ms} \sim Poisson(\eta_{ms})$; $\eta_{ms} = \mu + \alpha_s + \beta \log(x_{ms}) + E_{ms}$ for number of artrhopods

$\log(Y_{ms}) = \mu + \alpha_s + \beta \log(x_{ms}) + E_{ms}$ for numer of species

Y_{ms} is the calculated value for arthropods in the field m with soil type s

x_{ms} is the calculated value for flowers in the field m with soil type s

E_{ms} is the random effect of field m with soil type s

2.6.2 Analyses on activity and diversity of bumblebees and butterflies

The activity of bumblebees and butterflies respectively, was analysed using a generalised linear mixed model where it was assumed that the data were distributed according to a Poisson distribution. The number of species of bumblebees and butterflies, respectively, were analysed using a linear mixed model assuming that the logarithm of number of species was normally distributed.

For all analyses, the effect of soil type, recording period (July, August and September) and treatment (± herbicides), their two-way and three-way interaction were included as fixed effect. The effects of field, field × period and field × treatment were included as random effects. As all plots were not equally long, the length of the recorded transect was included as offset-variable and scaled, so that the number of arthropods was reported as number per 100 m. Mathematically, the models may be written as:

For number of arthropods:

$Y_{mspt} \sim Poisson(\eta_{mspt})$

with

$$\log(\eta_{mspt}) = \log(l_{mspt}) + \mu + \alpha_s + \beta_p + \gamma_t + (\alpha\beta)_{sp} + (\alpha\gamma)_{sy} + (\beta\gamma)_{pt} + (\alpha\beta\gamma)_{spt} + A_m + B_{mp} + C_{mt}$$

For log of number of species :

$$Y_{mspt} = \mu + \alpha_s + \beta_p + \gamma_t + (\alpha\beta)_{sp} + (\alpha\gamma)_{sy} + (\beta\gamma)_{pt} + (\alpha\beta\gamma)_{spt} + A_m + B_{mp} + C_{mt} + E_{mspt}$$

where

Y_{mspt} is the recorded value in the plot with treatment t in periode p in field m with soil type s

l_{mspt} is the scaled length of the transects (length/100) in the plot with treatment t in periode p divided by 100 in field m with soil type s

μ is the general level of the variable

α_s, β_p and γ_t is the main effect of soil type, periode and treatment

$(\alpha\beta)_{sp}, (\alpha\gamma)_{sy}, (\beta\gamma)_{pt}$ and $(\alpha\beta\gamma)_{spt}$ is the two- and three-way effects of the above mentioned three factors

A_m, B_{mp}, C_{mt} and E_{mspt} is random effects that are assumed to be independend and normmally distributed with mean zero and variances $\sigma^2_A, \sigma^2_B, \sigma^2_C$ and σ^2_E.

3 Results

First, the results from the plant registrations and the transect observations of bumblebees and butterflies is presented. Then relationships between flowering and bumblebee and butterfly activity and diversity are presented. Finally, the analyses of effects of herbicide-free field margins on the activity and diversity of butterflies are presented whereas analyses of bumblebees are omitted as the number of bumblebees was too low for reliable statistical analyses.

3.1 Flowering plants used by foraging bumblebees and butterflies in hedgerows

Table 3.1 summarises data on flowering of plants in the hedgerow plots. Only data for flowers used by foraging bumblebees and butterflies are presented.

Table 3.1. Data on flowering of bumblebee and butterfly food plants in thirty 0.25 m^2 plots, 15 plots along the herbicide sprayed field margin and 15 plots along the herbicide-free field margin . Numbers are only shown for plant species visited by bumblebees and/or butterflies within the hedgerows.

Location	Month	Plant species		Mean no. of flowering plants per plot in hedgerows		Mean number of flowers per plant in hedgerows		Mean no. of flowers per plot in hedgerows	
		Scientific name	Danish name	herbicide sprayed margin	Herbicide free margin	herbicide sprayed margin	Herbicide free margin	herbicide sprayed margin	Herbicide free margin
Grønhøjgårdv.	Aug	Campanula rotundifolia	Blåklokke	0.8	0.5	1	1	0.8	0.5
	Total			-	-	-	-	**0.8**	**0.5**
Horsensvej	Jul	Viola Arvensis	Ager-stedmoder	0.8	0.3	2.7	10	2.2	3.0
	Aug	Lapsana communis	Haremad	0.8	0.3	1	1	0.8	0.3
		Viola arvensis	Ager-stedmoder	0.3	0.3	2	8	0.6	2.4
	Sep	Viola arvensis	Ager-stedmoder	0.3	0.3	3	5	0.9	1.5
	Total			-	-	-	-	**4.5**	**7.2**
Kirstinelundv.	Jul	Lapsana communis	Haremad	0	0.5	0	2.5	0	1.3
	Sep	Lapsana communis	Haremad	0	0.3	0	1	0	0.3
	Total			-	-	-	-	**0**	**1.6**
Lilkildegårdsv.	Jul	Hypochoeris radicata	Alm. Kongepen	0	0.3	0	1	0	0.3
		Viola arvensis	Ager-stedmoder	0	0.3	0	1	0	0.3
	Aug	Viola arvensis	Ager-stedmoder	0	1.1	0	1.5	0	1.7
	Sep	Viola arvensis	Ager-stedmoder	0	1.9	0	1	0	1.9
	Total			-	-	-	-	**0**	**4.2**
Mosevej	Jul	Hypochoeris radicata	Alm. Kongepen	0	0.3	0	1	0	0.3
		Trifolium arvense	Harekløver	0	0.3	0	1	0	0.3
		Viola arvensis	Ager-stedmoder	0	1.1	0	1	0	1.1
	Total			-	-	-	-	**0**	**1.7**
Oksenbjergevej	Jul	Lapsana communis	Haremad	0	0.5	0	1.5	0	0.8
		Trifolium arvense	Harekløver	0	0.5	0	2.5	0	1.3
		Viola arvensis	Ager-stedmoder	0	2.1	0	1.9	0	4.0
	Aug	Jasione Montana	Blåmunke	0	0.3	1	4	1	1.2
		Viola arvensis	Ager-stedmoder	0	0.8	0	1.3	0	1.0
	Sep	Jasione Montana	Blåmunke	0	0.3	0	1	0	0.3
		Lapsana communis	Haremad	0	0.5	0	4.5	0	2.3
		Viola arvensis	Ager-stedmoder	0	0.3	0	1	0	0.3
	Total			-	-	-	-	**0**	**11.2**
Sellerupvej	Jul	Lapsana communis	Haremad	0.3	0	4	0	1.2	0
		Rubus *fructicosus*	Brombær	0.5	0.5	14	19.5	7.0	9.8
	Total			-	-	-	-	**8.2**	**9.8**
Teglværksvej	Jul	Lapsana communis	Haremad	0.3	0	2.5	0	0.8	0
	Total			-	-	-	-	**0.8**	**0**
Vindelevvej	Jul	Knautia arvensis	Blåhat	0.3	0	1	0	0.3	0
		Rubus *fructicosus*	Brombær	0	0.3	0	17	0	5.1
	Sep	Lapsana communis	Haremad	0.3	0.3	2	7	0.6	2.1
	Total			-	-	-	-	**0.9**	**7.2**
Åstrupvej	Jul	Achillea millefolium	Alm. Røllike	0.3	0	1	0	0.3	0
		Hypericum perforatum	Prikbladet Perikon	0.8	0	5.4	0	4.3	0
		Knautia arvensis	Blåhat	1.1	0	3	0	3.3	0
		Lapsana communis	Haremad	0.3	0	1	0	0.3	0
		Rubus *fructicosus*	Brombær	0	0.3	0	4	0	1.2
		Trifolium pratense	Rødkløver	0	0.3	0	1	0	0.3
	Aug	Hypericum perforatum	Prikbladet Perikon	0.3	0	4	0	1.2	0
		Lapsana communis	Haremad	0.3	0	4	0	1.2	0
	Sep	Hypericum perforatum	Prikbladet Perikon	0.3	0	1	0	0.3	0
	Total			-	-	-	-	**10.9**	**1.5**

Generally, plants that serve as pollen and/or nectar resources for bumblebees and butterflies were few both with respect to number of species and density of the species within the hedgerows (Tables 3.1 and 3.2). The plants were not evenly distributed along the hedgerows. In some hedgerows groups of food plants were located only in one part of the hedgerow either next to the herbicide sprayed or the herbicide-free field margin. This was e.g. the case at Åstrupvej and at Oksenbjergevej. A one-year herbicide-free field margin did not influence these patterns. In addition, stands of food plants were found outside the sampling plots. The flowering of these species was not registred and therefore the data on flowering does not reflect the total amount of pollen and nectar available within the hedgerows.

Table 3.2 Number of flowering plant species visited by bumblebees and butterflies within 10 hedgerows bordering fields with and without a 18-24 m wide herbicide-free field margin.

	Herbicide sprayed field margin			Herbicide-free field margin		
	July	August	September	July	August	September
Grønhøjgårdsvej		1			1	
Horsensvej	1	2	1	1	2	1
Kirstinelundvej				1		1
Lilkildegårdsvej				2	1	1
Mosevej					3	
Oksenbjergevej				3	2	3
Sellerupvej	2			1		
Teglværksvej	1					
Vindelevvej	1		1	1		1
Åstrupvej	4	2	1	2		

In six of the 10 hedgerows (Grønhøjgårdvej, Kirstinelundvej, Mosevej, Sellerupvej, Teglværksvej and Vindelevvej), no flowers relevant as pollen and nectar resources for bumblebees and butterflies were observed in at least one of the months of July, August and September (Table 3.2). This indicates that these hedgerows did not supply continuous feeding resourced for bumblebees and butterflies during summer and early autumn.

Among the eight species that were present and flowering in sampling plots within both the herbicide-free and herbicide-affected parts of a hedgerow, six plants had a higher mean number of flowers per plant and two the same number along herbicide-free margins compared to herbicide treated margins (Table 3.1).

3.2 Bumblebees and butterflies recorded in the experiment

In Tables 3.3 and 3.4 the number and species of bumblebees and butterflies registered by transect counts along hedgerows and in the field margins are presented. In total 287 observations of bumblebees were recorded distributed on 6 species or aggregates of species, indicating that the bumblebee populations within these habitats were very poor. None of the bumblebee species recoded are listed as threatened. Almost 75% of the bumblebee observations belong to two species, ***B. pascuorum*** and ***B. terrestris/lucorum*** agg. (Agerhumle og Lys/Mørk jordhumle kompleks).

Table 3.3. Bumblebee species and number of observations. Maximum foraging distance from the nest that the bumblebees will fly in order to collect nectar and pollen (Westphal et al. 2006). Tongue length; is correlated to the depth of the corollas of the preferred flowers. Conservation status; Least concern (LC) (Den danske rødliste 2004).

Genus	Species	Danish name	Maximum foraging distance (m)	Tongue length	Conser-vation status	Flower visits Hedge	Flower visits Field	Flying	Total obser-vations
Bombus		*Humlebier*							
	Bombus pascuorum	Agerhumle	1,000	Medium	LC	41	61	3	105
	Bombus lapidarius	Stenhumle	2,750	Short	LC	22	30	7	59
	Bombus terrestris/lucorum	Lys/Mørk jordhumle	>3,000	Short	LC	45	38	26	109
	Bombus hortorum	Havehumle	?	Long	LC	1	1	-	2
	Bombus hypnorum	Hushumle	?	Short	LC	2	-	2	4
	Bombus (Psithyrus)*sp*	Snyltehumler	-	-	-	8	-	-	8
Total observations						**119**	**130**	**38**	**287**

Transect counts of butterflies yielded 2,081 observations distributed on 20 species of which two species (3 flying individuals at two different locations) are listed as near threatened and the other 18 species are all common (Table 3.4). A little more than half of the observations were comprised of the ubiquitous species ***Pieris rapae*** and ***Pieris napi*** (Lille- og Grønåret kålsommerfugl).

Table 3.4. Butterfly species and number of observations. Population structure; Closed populations with minimum breeding area requirements in intervals of: 0.5-1, 1-2, 2-5, 5-10 and <50 ha. Open or migratory populations are denoted O/M and species with unknown breeding area requirements are denoted U (Pollard and Yates 1993, Stoltze 1996 and Thomas 1984). Mobility class follows Pollard and Yates (1993). Conservation status; Least concern (LC) and Near threatened (NT), (Den danske rødliste 2004).

Family Sub-family	Species	Danish name	Population structure	Mobility	Conser-vation status	Flower visits Hedge	Flower visits Field	Flying	Total obser-vations
Hesperiidae		**Bredpander**							
Hesperiinae	*Thymelicus lineola/ Sylvestris*	Streg-/Skråstreg-bredpande	0.5-1	Sedentary	LC	12	4	11	27
	Ochlodes sylvanus	Stor bredpande	0.5-1	Sedentary	LC	1	-	-	1
Pieridae		**Hvidvinger**							
Pierinae	*Pieris brassicae*	Stor kålsommerfugl	O/M	Wide-ranging	LC	4	6	142	152
	Pieris rapae	Lille kålsommerfugl	O/M	Wide-ranging	LC	22	64	478	564
	Pieris napi	Grønåret kålsommerfugl	O/M	Intermediate	LC	28	133	453	614
Coliadinae	*Gonepteryx rhamni*	Citronsommerfugl	O/M	Wide-ranging	LC	-	1	5	6
Lycaenidae		**Blåfugle**							
Lycaeninae	*Lycaena phlaeas*	Lille ildfugl	1-2	Intermediate	LC	1	3	3	7
	Aricia agestis	Rødplettet blåfugl	1-2	Intermediate	LC	-	4	9	13
	Polyommatus icarus	Almindelig blåfugl	1-2	Intermediate	LC	2	-	1	3
	Lycaerna virgaureae	Dukatsommerfugl	U	?	NT	-	-	1	1
	Plebeius optilete	Bølleblåfugl	U	?	NT	-	-	2	2
Nymphalidae		**Takvinger**							
Heliconiinae	*Issoria lathonia*	Storplettet perlemor-sommerfugl	O/M	Wide-ranging	LC	-	32	138	170
Nymphalinae	*Aglais urticae*	Nældens takvinge	O/M	Wide-ranging	LC	9	9	244	262
	Inachis io	Dagpåfugleøje	O/M	Wide-ranging	LC	3	-	30	33
	Vanessa atalanta	Admiral	O/M	Wide-ranging	LC	-	-	17	17
	Cynthia cardui	Tidselsommerfugl	O/M	Wide-ranging	LC	1	2	55	58
	Araschnia levana	Nældesommerfugl	O/M	Wide-ranging	LC	-	-	1	1
Satyrinae	*Maniola jurtina*	Græsrandøje	0.5-1	Sedentary	LC	6	-	64	70
	Pararge aegeria	Skovrandøje	U	Sedentary	LC	-	-	1	1
	Aphantopus hyperantus	Engrandøje	U	Sedentary	LC	4	2	73	79
Total observations						**93**	**260**	**1,728**	**2,081**

The transect counts of bumblebees and butterflies within the 10 hedgerows are presented in details in Tables 3.5 and 3.6. Generally, the number of observations seemed low, however, with a high variation both within and between the locations.

In total, more bumblebees visited flowers in hedgerows bordering herbicide sprayed field margin than hedgerows bordering herbicide-free field margins

(76 obs. vs. 43 obs, Table 3.5). A major reason for this was the scattered and random occurrence of selected food plants. In addition, the field at Sellerup had a dense cover of thistles in the herbicide sprayed part resulting in a relatively high number of flower visits by bumblebees (27 obs. vs. 2 obs, Table 3.5) in the sprayed part.

Only at two locations, Oksenbjergevej and Åstrupvej, flower visits by bumblebees in the hedgerow were recorded within all three months. At three locations (Horsensvej, Lilkildegårdsvej, Mosevej) no flower visits by bumblebees were recorded at all and at another three locations flower visits were only observed in the hedgerows during one of three months (Table 3.5).

Table 3.5. Number of flower visits by bumblebees in hedgerows observed during transect walks. The plant species listed are the plants selected by foraging bumblebees.

Locatin	Period	Plant species		Number of flower visiting Bumblebees in hedgerows	
		Scientific name	Danish name	Bordering herbicide sprayed margin	Bordering herbicide free margin
Grønhøjgårdsvej	July	*Campanula rotundifolia*	liden klokke	2	2
		Knautia arvensis	Blåhat	1	0
	August	*Campanula rotundifolia*	liden klokke	1	3
		Knautia arvensis	Blåhat	0	6
		Vicia cracca	Musevikke	0	1
	Total			**4**	**12**
Horsensvej	August	*Cirsium vulgare*	Horse tidsel	0	1
		Knautia arvensis	Blåhat	0	1
	Total			**0**	**2**
Kirstinelundvej	July	*Rosa sp.*	Rose	1	0
	Total			**1**	**0**
Lilkildegårdsvej				0	0
	Total			**0**	**0**
Mosevej				0	0
	Total			**0**	**0**
Oksenbjergevej	July	*Carduus crispus*	kruset tidsel	9	0
		Cirsium arvense	Agertidsel	2	0
		Cirsium vulgare	Horse tidsel	2	0
		Jasione Montana	Blåmunke	0	3
		Trifolium arvense	Harekløver	0	3
	August	*Carduus crispus*	kruset tidsel	1	0
		Cirsium vulgare	Horse tidsel	0	1
		Trifolium arvense	Harekløver	0	1
	September	*Cirsium arvense*	Agertidsel	0	1
		Cirsium vulgare	Horse tidsel	0	3
	Total			**14**	**12**
Sellerupvej	July	*Cirsium vulgare*	Horse tidsel	13	0
		Rubus fructicosus	Brombær	6	1
	August	*Carduus crispus*	kruset tidsel	2	0
		Cirsium vulgare	Horse tidsel	6	0
		Rubus fructicosus	Brombær	0	1
	Total			**27**	**2**
Teglværksvej				0	0
	Total			**0**	**0**
Vindelevvej	July	*Carduus crispus*	kruset tidsel	3	0
		Cirsium vulgare	Horse tidsel	2	0
		Knautia arvensis	Blåhat	1	0
		Rubus fructicosus	Brombær	0	6
		Trifolium pratense	Rødkløver	4	0
	Total			**10**	**6**
Åstrupvej	July	*Cirsium arvense*	Agertidsel	0	1
		Hypericum perforatum	prikbladet perikon	4	2
		Knautia arvensis	Blåhat	5	0
		Rosa sp.	Rose	4	3
		Rubus fructicosus	Brombær	0	2
	August	*Cirsium arvense*	Agertidsel	1	0
		Hypericum perforatum	prikbladet perikon	0	1
		Knautia arvensis	Blåhat	5	0
	September	*Knautia arvensis*	Blåhat	1	0
	Total			**20**	**9**
Total all		**12 species**		**76**	**43**

The number of flower visits by butterflies in the hedgerows were evenly divided between hedgerows along herbicide sprayed and un-sprayed field margins (46 obs. vs. 47. obs, Table 3.6). At three locations, butterflies were observed foraging in the hedgerows throughout all three months, whereas at four locations no flower visiting butterflies were recorded at all (Table 3.6).

Table 3.6. Number of butterfly flower visits in hedgerows observed during transect walks. The plant species listed are the plants selected by foraging butterflies.

Location	Period	Plant species		Number of flower visiting butterflies in hedgerows	
		Scientific name	Danish name	Bordering herbicide sprayed margin	Bordering herbicide free margin
Grønhøjgårdsvej	July	*Campanula rotundifolia*	Liden klokke	0	2
		Cirsium arvense	agertidsel	2	0
		Hypochoeris radicata	alm. kongepen	0	3
		Knautia arvensis	Blåhat	0	1
		Linaria vulgaris	torskemund	0	2
		Vicia cracca	musevikke	0	2
	August	*Campanula rotundifolia*	Liden klokke	0	1
		Cirsium arvense	agertidsel	0	1
		Knautia arvensis	Blåhat	1	4
	September	*Campanula rotundifolia*	liden klokke	0	1
	Total			**3**	**17**
Horsensvej	July	*Stachys arvensis*	ager galtetand	0	1
	Total			**0**	**1**
Kirstinelundsvej				0	0
	Total			**0**	**0**
Lilkildegårdsvej				0	0
	Total			**0**	**0**
Mosevej		*Hypochoeris radicata*	alm. kongepen	0	1
	August	*Viola arvensis*	agerstedmoder	1	0
	Total			**1**	**1**
Oksenbjergevej	July	*Cirsium arvense*	agertidsel	0	9
		Cirsium vulgare	horse tidsel	1	0
		Hypochoeris radicata	alm. kongepen	0	1
		Stachys arvensis	ager galtetand	1	0
	August	*Carduus crispus*	kruset tidsel	1	0
		Cirsium arvense	agertidsel	0	3
		Hypochoeris radicata	alm. kongepen	0	3
		Stellaria media	fuglegræs	0	1
	September	*Cirsium arvense*	agertidsel	0	2
	Total			**3**	**19**
Sellerupvej				0	0
	Total			**0**	**0**
Teglværksvej				0	0
	Total			**0**	**0**
Vindelevvej	July	*Cirsium arvense*	agertidsel	0	1
		Knautia arvensis	Blåhat	6	1
		Rubus fructicosus	Brombær	0	1
	August	*Epilobium montanum*	glat dueurt	0	1
		Knautia arvensis	Blåhat	2	0
		Lapsana communis	Haremad	1	0
	Total			**9**	**4**
Åstrupvej	July	*Cirsium arvense*	agertidsel	4	2
		Knautia arvensis	Blåhat	5	0
		Rosa sp.	Rose	1	2
	August	*Achillea millefolium*	alm. røllike	1	0
		Cirsium arvense	agertidsel	3	0
		Hypericum perforatum	prikbladet perikon	0	1
		Knautia arvensis	Blåhat	8	0
	September	*Knautia arvensis*	Blåhat	7	0
		Linaria vulgaris	torskemund	1	0
	Total			**30**	**5**
Total all		**17 species**		**46**	**47**

In Table 3.7, the number of flower visits by bumblebees to specific plant species is given. The total number of flower visits was evenly distributed between the hedgerow and field margin areas. In the hedgerows, bumblebees visited 12 plant species, with ***Carduus crispus*** (kruset tidsel), ***Cirsium vulgare*** (horse-tidsel), ***Knautia arvensis*** (blåhat) and ***Rubus fructicosus*** (brombær) receiving the most visits.

Table 3.7. Schematic summary of all registered flower visiting bumblebees in July, August and September 2009.

Family	Species	Danish name	Life-cycle	Numbers of recorded flower visits by bumblebees					
				July		August		September	
				Hedge-row	Field	Hedge-row	Field	Hedge-row	Field
Asteraceae	*Cirsium arvense*	ager-tidsel	Per	3	-	1	-	1	-
Asteraceae	*Carduus crispus*	kruset tidsel	Bi	12	1	3	-	-	-
Asteraceae	*Cirsium vulgare*	horse-tidsel	Bi	17	33	8	1	3	-
Asteraceae	*Centaurea cyanus*	kornblomst	Ann	-	23	-	7	-	-
Asteraceae	*Tripleurospermum inodorum*	lugtløs kamille	Ann/Bi	-	2	-	-	-	-
Total Asteraceae				**32**	**59**	**12**	**8**	**4**	**0**
Campanulaceae	*Campanula rotundifolia*	blåklokke	Per	4	-	4	-	-	-
Campanulaceae	*Jasione Montana*	blåmunke	Ann/Bi	3	-	-	-	-	-
Total Campanulaceae				**7**	**0**	**4**	**0**	**0**	**0**
Hypericaceae	*Hypericum perforatum*	prikbladet perikon	Per	6	-	1	-	-	-
Total Hypericaceae				**6**	**0**	**0**	**0**	**0**	**0**
Fabaceae	*Trifolium arvense*	harekløver	Ann	3	-	1	-	-	-
Fabaceae	*Trifolium prantense*	rødkløver	Per	4	1	-	-	-	-
Fabaceae	*Vicia cracca*	Musevikke	Per	-	-	1	-	-	-
Total Fabaceae				**7**	**1**	**2**	**0**	**0**	**0**
Dipsacaceae	*Knautia arvensis*	Blåhat	Per	7	-	12	-	1	-
Total Dipsacaceae				**7**	**0**	**12**	**0**	**0**	**0**
Lamiaceae	*Stachys arvensis*	ager-galtetand	Ann	-	11	-	-	-	1
Lamiaceae	*Lamium sp.*	tvetand sp.	Ann	-	-	-	1	-	-
Total Lamiaceae				**0**	**11**	**0**	**1**	**0**	**1**
Rosaceae	*Rosa sp.*	rose sp.	Per	8	-	-	-	-	-
Rosaceae	*Rubus fructicosus*	brombær	Per	15	-	1	-	-	-
Total Rosaceae				**23**	**0**	**1**	**0**	**0**	**0**
Violaceae	*Viola arvensis*	ager-stedmoder	Ann	-	25	-	20	-	4
Total Violaceae				**0**	**25**	**0**	**20**	**0**	**4**
Total flower visits				**82**	**96**	**32**	**29**	**5**	**5**

In field margins, eight plant species were visited by bumblebees with ***Cirsium vulgare*** (horse-tidsel), ***Centaurea cyanus*** (kornblomst), ***Stachys arvensis*** (ager-galtetand) and ***Viola arvensis*** (ager-stedmoder) being visited most frequently (Table 3.7).

For butterflies, the flower visits are shown in Table 3.8. The total number of flower visits was evenly distributed between the hedgerow and field margin areas in July, but the majority of the flower visits were allocated to the field margins in August and September after crop harvest. The butterflies visited almost the same number of plant species in both hedgerows and field margins, 17 and 15 species, respectively. In hedgerows, the most frequently visited plant species were ***Cirsium avensis*** (ager-tidsel) and ***Knautia avensis*** (blåhat), whereas in the field margins ***Cirsium avensis*** (ager-tidsel), ***Brassica napus*** (raps), ***Sinapis arvensis*** (ager-sennep) and ***Viola arvensis*** (ager-stedmoder) were most frequently visited. Especially noteworthy is the sheer number of visits to ***Viola arvensis*** (ager-stedmoder) in the field margins.

Table 3.8. Schematic summary of all registered flower visiting butterflies in July, August and September 2009.

Family	Species	Danish name	Life-cycle	Numbers of recorded flower visits by butterflies					
				July		August		September	
				Hedge-row	Field	Hedge-row	Field	Hedge-row	Field
Asteraceae	*Cirsium arvense*	ager-tidsel	Per	18	-	7	16	2	-
Asteraceae	*Carduus crispus*	kruset tidsel	Bi	-	-	1	-	-	-
Asteraceae	*Cirsium vulgare*	horse-tidsel	Bi	1	3	-	-	-	-
Asteraceae	*Centaurea cyanus*	kornblomst	Ann	-	1	-	-	-	1
Asteraceae	*Hypochoeris radicata*	alm. kongepen	Per	5	-	3	-	-	1
Asteraceae	*Lapsana communis*	Haremad	Ann	-	2	1	-	-	-
Asteraceae	*Tripleurospermum inodorum*	lugtløs kamille	Ann/Bi	-	2	-	-	-	-
Asteraceae	*Achillea millefolium*	alm. røllike	Per	-	-	1	-	-	-
Total Asteraceae				**24**	**8**	**13**	**16**	**2**	**2**
Brassicaceae	*Brassica napus*	Raps	Ann/Bi	-	17	-	5	-	3
Brassicaceae	*Sinapis arvensis*	ager-sennep	Ann	-	1	-	4	-	11
Total Brassicaceae				**0**	**18**	**0**	**9**	**0**	**14**
Campanulaceae	*Campanula rotundifolia*	blåklokke	Per	2	-	1	-	1	-
Total Campanulaceae				**2**	**0**	**1**	**0**	**1**	**0**
Chenopodiaceae	*Chenopodium album*	hvidmelet gåsefod	Ann	-	-	-	1	-	-
Total Chenopodiaceae				**0**	**0**	**0**	**0**	**0**	**0**
Hypericaceae	*Hypericum perforatum*	prikbladet perikon	Per	-	-	1	-	-	-
Total Hypericaceae				**0**	**0**	**1**	**0**	**0**	**0**
Fabaceae	*Vicia cracca*	musevikke	Per	2	1	-	-	-	-
Total Fabaceae				**2**	**1**	**0**	**0**	**0**	**0**
Geraniaceae	*Geranium cicutarium*	hejrenæb	Ann/Bi	-	-	-	4	-	1
Total Geraniaceae				**0**	**0**	**0**	**4**	**0**	**1**
Dipsacaceae	*Knautia arvensis*	blåhat	Per	13	-	15	-	7	-
Total Dipsacaceae				**13**	**0**	**15**	**0**	**7**	**1**
Lamiaceae	*Stachys arvensis*	ager-galtetand	Ann	2	2	-	-	-	-
Lamiaceae	*Galeopsis tetrahit*	alm. hanekro	Ann	-	1	-	-	-	-
Total Lamiaceae				**2**	**3**	**0**	**0**	**0**	**0**
Scrophulariaceae	*Linaria vulgaris*	alm. torskemund	Per	2	-	-	-	1	-
Total Scrophulariaceae				**2**	**0**	**0**	**0**	**1**	**0**
Onagraceae	*Epilobium sp.*	dueurt sp.	Per	-	-	1	4	-	-
Total Onagraceae				**0**	**0**	**1**	**4**	**0**	**0**
Rosaceae	*Rosa sp.*	rose sp.	Per	3	-	-	-	-	-
Rosaceae	*Rubus sect. rubus*	brombær	Per	1	-	-	-	-	-
Total Rosaceae				**4**	**0**	**0**	**0**	**0**	**0**
Caryophyllaceae	*Stellaria media*	fuglegræs	Ann	-	-	1	-	-	-
Total Caryophyllaceae				**0**	**0**	**1**	**0**	**0**	**0**
Violaceae	*Viola arvensis*	ager-stedmoder	Ann	-	8	1	120	-	51
Total Violaceae				**0**	**8**	**1**	**120**	**0**	**51**
Total flower visits				**49**	**38**	**33**	**154**	**11**	**68**

3.3 Estimated relationships between flower resources and activity/diversity of bumblebees and butterflies

The number of observations was not sufficient for analyses on detailed relationships between flower species and arthropod activity and diversity in hedgerows. Neither effects of sampling period nor effect of herbicide treatment could be included in the analyses due to the limited number of data. Instead, data was summed across sampling periods and experimental plots within each of the 10 hedgerows in order to estimate general flower – arthropod relationships in terms of species richness and activity. For more information on the statistical analyses and models see section 2.6.1. Detailed results of the statistical analyses are presented in Appendix A, Table A.1.

Significant relationships between flowering and bumblebees were not found ($\boldsymbol{P} > 0.05$). For butterflies, there were indications of a positive relationship between species richness of flowers and species richness of butterflies ($\boldsymbol{P} \leq 0.1$). The parameter estimate of the covariate "log flower species richness" was 1.8 ± 0.9 (S.E.) with an intercept of -1.98 ± 1.03 and -1.06 ± 1.06 for clay and sandy soils, respectively. For model description see section 2.6.1. This indicates, that when the species richness of plants used by bumblebees and butterflies increases, the corresponding butterfly species richness also increases. If for example the no. of flower species in a hedgerow on clay soil

increases from 3 to 4, the number of butterfly species may increase from 1.0 to 1.7 in the hedgerow.

Summary of results on flowering and activity of bumblebees and butterflies:

- Plants that serve as pollen and/or nectar resources for bumblebees and butterflies were few both with respect to number of species and density of the species within the hedgerows.
- In six of the 10 hedgerows, no flowers relevant for bumblebees and butterflies were observed in the 0.25 m^2 plots in at least one of the months of July, August and September indicating that many hedgerows do not supply continuous feeding resourced for bumblebees and butterflies during summer and early autumn. Only three of the hedgerows had a continuous supply of flowers throughout the three months. This is in accordance with the observed no. of flower visits by bumblebees and butterflies in the hedgerows. The bumblebees found a continuous supply in only two of the hedgerows and the butterflies in three hedgerows.
- Bumblebee flower visits were equally distributed between hedgerow and field margin. Butterfly flower visits were primarily allocated to field margins.
- The majority of bumblebee visits in hedgerows were on the biannual or perennial plant families ***Asteraceae*** and ***Rosasea***, primarily thistles and brambles (tidsler og brombær). Butterfly flower visits in hedgerows were primarily allocated to biannual and perennial species of ***Asteraceae*** and ***Dipsacaceae*** (tidsler og blåhat).
- In the field margins, primarily annual flowers were visited by both bumblebees and butterflies with bumblebees having a strong preference for ***Asteraceae, Lamiaceae, Violaceae*** (kurveblomst-, læbeblomst- og violfamilien) whereas butterflies primarily visited ***Asteraceae, Brassicaceae, Violaceae*** (kurveblomst-, korsblomstrede- og violfamilien).
- There was a tendency towards a positive relationship between flower diversity and butterfly diversity in hedgerows.

3.4 Activity and diversity of butterflies in hedgerows and field margins

Generally, the activity and species richness of bumblebees was so low that reliable statistical analyses could not be carried out. Therefore only results on butterflies are presented below.

3.4.1 Butterfly activity

The activity of butterflies in the hedgerows was too low for reliable statistical analyses. In the field margins, the butterfly activity was affected significantly by a combination of soil type (an indirect measure of weed density) and sampling period ($\boldsymbol{P} < 0.01$) (for more information on the results of the statistical analyses see Table A.2 in appendix A). The activity of flower visiting individuals in the field margin was highest in August followed by July and September. In August and September, significantly more flower visiting butterflies were observed on sandy soils compared to loamy soils (Fig. 3.1),

presumably due to the denser and more frequently flowering weeds, mainly ***Viola arvensis***, found here following crop harvest.

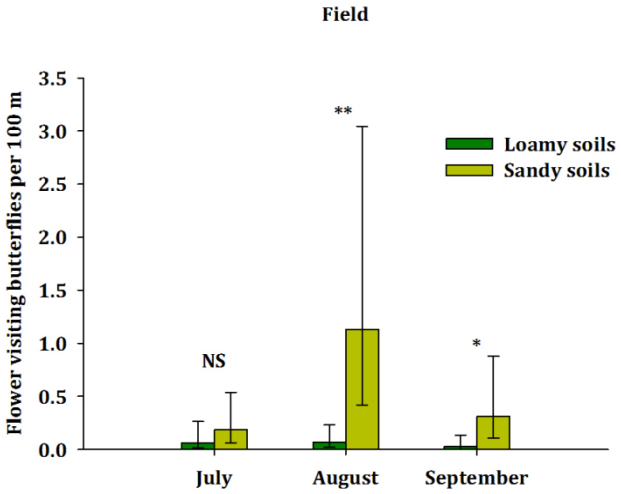

Fig. 3.1. Estimated activity (no. observed per 100 m transect) of flower visiting butterflies within the field. $^{NS}P \geq 0.05$, $^{*}P < 0.05$, $^{**}P < 0.01$.

Furthermore, a slightly higher general activity of flower visiting butterflies was found in field margins without herbicide applications compared to field margins treated with herbicides, despite low estimates and high variation (Fig. 3.2).

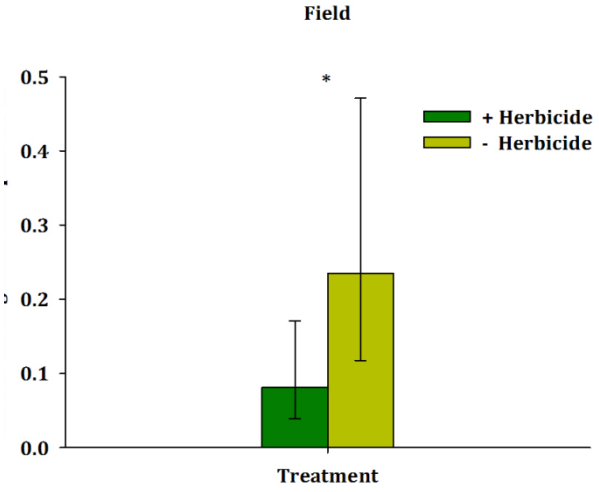

Fig. 3.2. Estimated activity (no. observed per 100 m transect) of flower visiting butterflies within the field margin. $^{*}P < 0.05$.

When combining flower visiting butterflies in the hedgerow and field margin, the activity of butterflies was significantly ($\boldsymbol{P} < 0.05$) affected by a combination of sampling period, soil type and herbicide treatment (Fig. 3.3).

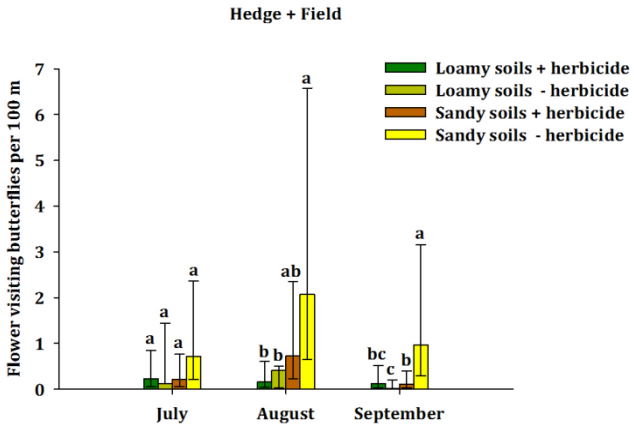

Fig. 3.3. Estimated activity (no. observed per 100 m transect) of flower visiting butterflies within the combined hedgerow + field margin. Columns within each month with different lower case letters are significantly different $P < 0.05$.

The estimated activity of butterflies in September was significantly higher in the combined hedgerow+field area on sandy soils not treated with herbicides. In July and September there was a tendency towards more flower visiting butterflies in and along herbicide-free hedgerows on sandy soils (Fig. 3.3).

3.4.2 Butterfly diversity

The species richness of butterflies in the hedgerows was too low for reliable statistical analyses. Within the field margins, the species richness was affected by an interaction between soil type (an indirect measure of weed density) and herbicide treatment (***P*** = 0.06, Table A.3 in appendix A). Significantly more flower visiting species were observed in herbicide-free field margins on sandy soils compared to sprayed sandy margins (Fig. 3.4). On loamy soils, there was no difference in species richness and the estimated species number was low (Fig. 3.4).

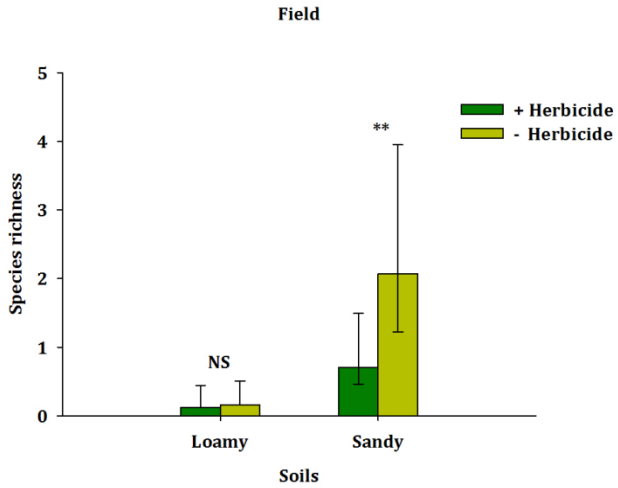

Fig. 3.4. Estimated species richness of flower visiting butterflies in the hedgerow. $^{NS}P \geq 0.05$, $^{**}P < 0.01$.

When combining the hedgerow and field margin areas, butterfly species richness of flower visiting individuals was significantly affected by a combination of soil type, sampling period and herbicide treatment (***P*** < 0.05, Table A.3 in appendix A). In July, significantly higher species richness was found in hedgerow+field margin areas on sandy soils compared to herbicide treated area on sandy soils (Fig. 3.5). In August, there was no difference in

species richness between herbicide treated and herbicide-free areas within soil types, but significantly more butterfly species were observed on sandy soils compared to loamy soils. In September, significantly more butterfly species were observed on sandy soils not treated with herbicides compared to other areas (Fig. 3.5).

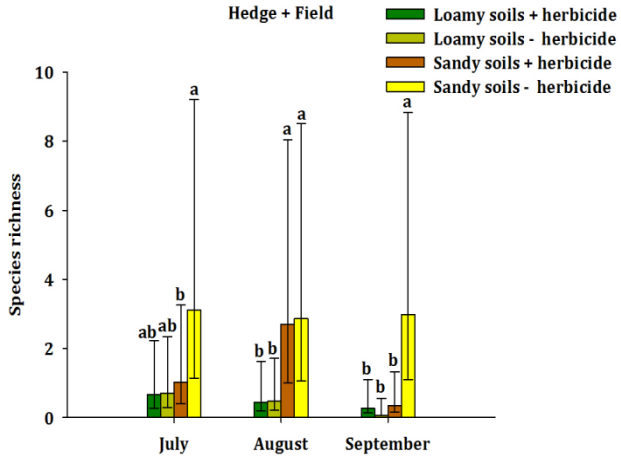

Fig. 3.5. Estimated species richness of flower visiting butterflies in hedgerow + field margin. columns with different Letters within each month are significantly different ($P < 0.05$).

Summary of results of the statistical analyses on bumblebee and butterfly activity related to pesticide treatments:

- Bumblebee and butterfly activity and diversity in the hedgerows was generally so low that reliable statistical analyses could not be carried out in relation to herbicide treatments.
- For butterflies in the field margins, there was a positive effect of herbicide exclusion on both their activity and diversity on sandy soils.

4 Discussion

The study confirms the well-established findings that bumblebees and butterflies are attracted by specific plant species during their food searching (e.g. Fussell & Corbet 1992, Dramsted & Fry 1995, Clausen et al. 2001, Pywell et al. 2005). These plant species belong to certain families including Asteraceae, Laminaceae, Rosaceae, Dipsacaeceae (kurveblomst-, læbeblomst-, rosen- og kartebollefamilien) and for butterflies also Brassicaceae and Violaceae (korsblomst- og violfamilien). However, few of these food plants were found in each hedgerow and their occurrence were scattered and unaffected by establishment of a one-year herbicide-free field margin. Positive relationship between diversity of flower resources and diversity of insects could only be established for butterflies.

The weather conditions during July, August and September were favourable for transect recordings of bumblebees and butterflies and all of the individual recordings met the minimum weather requirements laid out by Pollard (1977) and Pollard & Yates (1993). Despite good conditions, bumblebees were few in both numbers and species. In Denmark, seven species of bumblebees are considered very common and among these we found six species which all were sparsely represented. This indicates that the agricultural landscape investigated holds very few or too far spread resources for bumblebees. Butterflies were more numerous and more than 2,000 individuals were recorded with 20 out of 78 potential species being registered. Two of these butterfly species: ***Lycaerna virgaureae*** and ***Plebeius optilete*** (dukatsommerfugl og bølleblåfugl) are considered "near threatened".

Generally, the study showed that hedgerows at conventional farms were poor localities for bumblebees, butterflies and their food plants. This is in accordance with previous findings that biodiversity in agro-ecosystems is in decline (Tscharntke et al. 2005) and that conventional agricultural practice is among the main drivers for pollinator declines (e.g. Brittain et al. 2010).

The study showed that the activity and diversity of both butterflies and bumblebees in the hedgerows were low despite establishment of 18-24 m herbicide-free field margins next to the hedgerows and that number of these insects was too low to establish any significant effects of the treatment except for butterflies within the field margins on sandy soils. One-year herbicide-free field margins, therefore, seemed to be an inadequate mitigation method for improvements of bumblebee and butterfly diversity. Other mitigation methods need to be used to make significant improvements for bumblebees and butterflies in hedgerows.

In the field margin, the absence of herbicides increased the weed cover visibly but this was not recorded during the project. A few of the weed species were good nectar and pollen resources for bumblebees and butterflies. Bumblebees primarily visited different thistles (***Cirsium*** sp. and ***Carduus crispus***), ***Centaurea cyanus*** (kornblomst), ***Stachys arvensis*** (ager-galtetand) and ***Viola arvensis*** (ager-stedmoder). In addition butterflies also visited ***Brassica rapa*** (raps). Of the weeds in the field it seemed to be mainly ***Viola arvensis*** (ager-stedmoder) that received the most visits by ***B. pascuorum*** (agerhumle). Pywell et al. (2005)

also found that ***V. arvensis*** in conventional cereal field margins accounted for half of the foraging visits by bumblebees.

Butterflies and especially bumblebees require a constant supply of pollen and nectar from spring to autumn. We found that there were gaps without any flowering of the selected food plants within the hedgerows during the activity period of the insects. The hedgerows, therefore, represented a poor forage locality in the agricultural landscape and did not constitute a continuous food resource. A one-year period with herbicide-free field margins is not long enough for establishment of new plant species. Furthermore, the competition from large and well-established clonal plants within the hedgerows make establishment very difficult (Milchunas & Lauenroth 1995).

Six of the 10 fields were sprayed with pesticides that may be harmful to bees (and probably also to other insects). Therefore it is not possible to strictly isolate herbicide effects on activity and diversity of bumblebees and butterflies mediated through herbicide effects on flowering.

In order to estimate general effects of the pesticide treatments on sandy and loamy soils, we tested general activity and diversity of bumblebees and butterflies. The most pronounced result was a markedly higher diversity of butterflies in herbicide-free areas on sandy soils. However, effect of soil may also be confounded with crop species effects, though we are more inclined to believe, that the effect of soil type on the target insects is most likely an indirect effect, mediated through the soil type effect on plant composition and flowering, with higher plant diversity and flowering frequency on sandy soils. This is supported by (Fried et al. 2008), who found that sandy soils may generally hold a higher diversity of wild plants. The results suggest that positive biodiversity effects with reduced chemical inputs are sooner achieved on sandy soils compared to heavier soils.

Earlier large scale studies showing positive biodiversity gains of extensively grown field margins in Denmark have primarily been carried out along old uniform hedgerows on clayish soil (e.g. Hald et al. 1988, Navntoft et al. 2009). An important result of this experiment is, that herbicide exclusion had a positive biodiversity effect on butterflies in field margins on sandy soils. We found no general effects of herbicide exclusions on loamy soils. Positive biodiversity effects on loamy soil requires most likely also the exclusion of fertilisers, because the exclusion of fertilizer may leave relatively more space for wild herbaceous plants to flower due to reduced crop cover.

Carduus/Cirsium (tidsler), propagating through rhizomes and as seeds, are problematic for farmers, but very attractive for the bumblebees and butterflies. Other attractive annual weed species for pollinating insects such as ***Centaurea cyanus*** (kornblomst) and ***Viola arvensis*** (ager-stedmoder) however, should pose less of a problem in the hedgerow and field margin. It may therefore be worth allowing some of these annual weeds to flower in order to improve biodiversity in the arable land.

5 Conclusions

It is important to state, that the conclusions below are based on a limited experiment. Furthermore, the effect of herbicides on bumblebee and butterfly activity and diversity cannot be isolated strictly, as one of the 10 field margins received an insecticide treatment.

Conclusions:

- The plant species visited by bumblebees and butterflies were among those known to serve as good food plants, species belonging to the families Asteraceae, Brassicaceae, Laminaceae, Rosaseae (kurveblomst-, korsblomst-, læbeblomst- og rosen-familien). However, good food species of Fabaceae (ærteblomst-familien) were very scarcely represented.
- In all of the hedgerows the abundance of flowers, butterflies and especially bumblebees were few and more than half the hedgerows lacked a continuous flower supply.
- A one-year herbicide-free field margin seems to be an inadequate mitigation method for improvements of bumblebee and butterfly diversity in hedgerows.
- The diversity of selected flowers measured as species richness tended to be positively related to the diversity of butterflies. This indicates that a more divers composition of flowers results in a more divers assemblage of butterfly species.
- For butterflies in the field margins there was a significant positive effect of the exclusion of herbicides on both activity and diversity on sandy soils.
- In the field margins, ***Viola arvensis*** (ager-stedmoder) received through the season the most flower visits by bumblebees and butterflies combined. This weed is less problematic for the farmers and underlines the importance of leaving floral resource in the field margins which may only pose few problems for management.

6 Perspectives

6.1 Perspectives for management

It can be stated, that the current management regime does not provide favourable conditions for flowers in hedgerows and this study may fill some gaps in our knowledge of how to conserve and improve biodiversity in and along arable fields and still combine such aims with modern farming.

Our results indicate, that a more diverse composition of flowering plants results in a more diverse assemblage of butterfly species but also that most hedgerows do not provide many pollen and nectar sources for insects. Furthermore, there is no continuous nectar- and pollen supply during the summer needed for especially bumblebees but probably also for some species of butterflies. Management of hedgerows should leave more space for flowering herbs instead of the predominant shady and grassy edges encroached by the field.

Field margins had a relative high amount of flower visits by butterflies compared to the hedgerows, and may therefore play an important role as foraging area. Therefore more wild flowering plants in the margins should be allowed. High value food sources such as thistles may not be acceptable to farmers but less problematic weed species such as ***Viola avensis*** (ager-stedmoder) should be allowed, because it proved to be a very important nectar source for butterflies, even until late in the season.

Herbicide-free field margins had a positive effect on butterfly activity and diversity on sandy soils only. If the aim is to improve biodiversity in general, it seems most relevant from an applied approach to avoid all chemical treatments.

6.2 Perspectives for future research

In the present project, transect data of bumblebees and butterflies for the entire season were lacking, as the spring and early summer period was not investigated. In order to get the full picture of nectar and pollen resources for the early bumblebee and butterfly species, early samplings should also be included in future investigations. Furthermore, the prospect of measuring activity and diversity of pollinating insects during several years should be considered in order to follow the development of floral resources in response to reduced chemical inputs.

It seems appropriate to investigate further the importance of pesticide-free field margins in terms of:

1. their impact on hedgerows.
2. their impact on the biodiversity within the field margins.

This should be seen in relation to other hedgerow quality parameters such as tree density, diversity of trees and bushes, how dense they are, how much sunlight reaches the bottom vegetation, etc. Currently most of the hedgerows

investigated are managed in a way that makes them very dense so very little light reaches the herbaceous layer. At the same time the fields were in many cases ploughed almost to the tree stems leaving very little room for flowering plants. Floral investigations of flowering plants in the hedgerows should be complimented by floral investigations of flowering plants in the field margins in order to access effects of extensively grown field margins at the ecosystem level.

The indication of a lack of continuous resources of flowers that are useful nectar and pollen sources for butterflies and bumblebees, seems to deserve a more thorough investigation. This may be regarded as one of the hedgerow quality parameters mentioned above. The continuous flower supply seems to be especially important for bumblebees as they have a continuous production of juveniles in the hives and therefore require a coherent food supply, which may not presently be available in most hedgerows.

What is the value in terms of quality and quantity of the nectar/pollen offered by the various plant species for the specific bumblebee and butterfly species? Some plant species may have a higher general value but to our knowledge it has only been investigated indirectly through studies of plant preferences of various flower-dependent insects.

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Detailed results of the statistical analyses

Table A.1. Schematic summary of the statistical analyses on relationships between density/diversity of flowers and activity/diversity of bumblebees and butterflies in hedgerows. For model description see section 2.6.1.

Taxa	Measure	Test results $F_{(ndf,ddf)}{}^{P1}$		
		Soil[2]	Flowers[3]	
			Density	Species richness
Bumblebees	Activity	$0.29_{(1, 6.4)}{}^{NS}$	$3.05_{(1, 7)}{}^{NS}$	-
	Species richness	$0.69_{(1, 7)}{}^{NS}$	-	$0.71_{(1, 7)}{}^{NS}$
Butterflies	Activity	$0.51_{(1, 7)}{}^{NS}$	$0.17_{(1, 7)}{}^{NS}$	-
	Species richness	$0.83_{(1, 7)}{}^{NS}$	-	$3.58_{(1, 7)}{}^{P=0.100}$

[1] ^{NS} not significant ($P > 0.05$), P- values at the 10% level ($0.05 < P \leq 0.1$) indicating a tendency are shown F is the F-value, ndf and ddf is the numerator and denominator degree of freedom used for testing the significance.
[2] Effect of soil (sandy or loamy).
[3] Effect of flowering (flower density and flower species richness, respectively).

Table A.2. Activity of flower visiting butterflies. Schematic summary of the statistical analyses.

Area[2]	Test results $F_{(ndf,ddf)}{}^{P1}$						
	Soil[3]	Period[4]	Soil × Period[5]	Treatment[6]	Soil × Treatment[7]	Period × Treatment[8]	Soil × Period × Treatment[9]
Field margin	$14.80_{(1,34)}{}^{***}$	$2.54_{(2,22)}{}^{NS}$	$1.22_{(2,22)}{}^{**}$	$5.81_{(1,19)}{}^{*}$	$0.57_{(1,19)}{}^{NS}$	$0.74_{(2,48)}{}^{NS}$	$2.53_{(2,48)}{}^{0.09}$
Hedgerow+ Field margin	$5.16_{(1,8)}{}^{0.05}$	$4.28_{(2,16)}{}^{*}$	$4.86_{(2,16)}{}^{*}$	$1.05_{(1,10)}{}^{NS}$	$4.40_{(1,10)}{}^{0.06}$	$1.15_{(2,48)}{}^{NS}$	$3.61_{(2,48)}{}^{*}$

[1] ^{NS} not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, P-values at the 10% level ($0.05 \leq P \leq 0.1$) indicating a tendency are shown. F is the F-value, ndf and ddf is the numerator and denominator degree of freedom used for testing the significance.
[2] Sampling area (hedgerow, field margin or combined).
[3] Effect of soil (sandy or loamy)
[4] Effect of sampling period (transects were carried out in July, August and September).
[5] Effect of the combination of soil and period.
[6] Effect of treatment (treated with herbicides or untreated).
[7] Effect of the combination of soil and treatment.
[8] Effect of the combination of period and treatment.
[9] Effect of the combination of soil, period and treatment.

Table A.3. Species richness of flower visiting butterflies. Schematic summary of the statistical analyses.

Area[2]	Test results $F_{(ndf,ddf)}{}^{P}$[1]						
	Soil[3]	Period[4]	Soil x Period[5]	Treatment[6]	Soil x Treatment[7]	Period × Treatment[8]	Soil x Period × Treatment[9]
Field margin	$21.38_{(1,24)}{}^{***}$	$1.50_{(2,24)}{}^{NS}$	$0.46_{(2,24)}{}^{NS}$	$7.36_{(1,24)}{}^{*}$	$4.01_{(1,24)}{}^{0.06}$	$1.49_{(2,24)}{}^{NS}$	$2.12_{(2,24)}{}^{NS}$
Hedgerow + Field margin	$10.32_{(1,8)}{}^{*}$	$2.25_{(2,16)}{}^{NS}$	$0.40_{(2,16)}{}^{NS}$	$2.95_{(1,8)}{}^{NS}$	$6.64_{(1,8)}{}^{*}$	$1.09_{(2,16)}{}^{NS}$	$5.12_{(2,16)}{}^{*}$

[1] ^{NS} not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, P-values at the 10% level ($0.05 \leq P \leq 0.1$) indicating a tendency are shown. F is the F-value, ndf and ddf is the numerator and denominator degree of freedom used for testing the significance.
[2] Sampling area (hedgerow, field margin or combined).
[3] Effect of soil (sandy or loamy)
[4] Effect of sampling period (transects were carried out in July, August and September).
[5] Effect of the combination of soil and period.
[6] Effect of treatment (treated with herbicides or untreated).
[7] Effect of the combination of soil and treatment.
[8] Effect of the combination of period and treatment.
[9] Effect of the combination of soil, period and treatment.