

Functional Diversity in Agricultural Field Margins

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Abstract

This report is the final publication (in an electronic version only) of a project investigating species diversity in agricultural field margins in the Nordic countries. Field margins, especially buffer zones were sampled for plant and pollinating insect diversity in Finland. Both conventional and organic farmland was included in the study. In Denmark, remote sensing of margins (windbreaks) that separate adjacent crop fields was developed.

Continuous arable farming of mainly annual crops is least beneficial (or even, harmful) to species diversity in boundaries. Excess or careless use of fertilizers and herbicides results in loading of the boundaries, and in drastic decline of their biodiversity value. Most boundaries in conventional agricultural land still have impoverished plant communities infested with most serious perennial weeds.

Organic farming results in higher species diversity in the boundaries, compared to conventional farming. This result is consistent with previously published studies. Also, the biotic communities in organic margins are markedly dissimilar to the communities in the conventional field margins. The dominant plants are not the weeds of nutrient rich sites as in conventional boundaries, and the abundance of flowers supports high insect diversity. Changes in vegetation composition are slow, and it may take a decade or more before results of good field margin management are visible. All measures to reduce nutrients from the boundaries are beneficial for both biodiversity and protection of waterways.

In conclusion, we found that in the Nordic conditions, field margins are specific semi-natural habitat types supporting characteristic flora and fauna of their own. According to our results, the width of a field boundary should be no less than 5 m. Increase in width from the currently most abundant narrow types effectively improves biodiversity value and value as a buffer strip. Management of the boundaries for general biodiversity enhances beneficial insect diversity and abundance. This should result in improved pollination services and natural biocontrol of pests in agricultural crops. Organic farming should be favored over conventional practice, in order to restore and enhance biological diversity in agricultural field margins. Indicators of landscape quality should include monitoring of the state of the field margin networks. Remote sensing by laser could be developed as a monitoring tool for this purpose.

In Europe, including Nordic and Baltic countries, agricultural management and land use changes rapidly, and at the same time, regulatory measures include requirements for management of the boundaries. We conclude that such measures and schemes should, along with the buffering function to protect waterways, target the biodiversity value of these major semi-natural habitat types in agricultural landscapes.

1 Introduction

Juha Helenius

Agricultural field margins are an important semi-natural habitat type in Fenno-Scandian landscapes. The margins are narrow, typically from less than a meter to a few meters in width, but they form a network of millions of km in aggregated length in the region. They harbor both beneficial and pest organisms that affect crop production, including pollinating insects, natural enemies of crop pests, and food and refuge for the beneficial, but also weeds, pests, and crop diseases. They also harbor a wide diversity of plants and animals which may be insignificant to production, but important from the biodiversity conservation point of view, and contribute to the aesthetic and recreational value of the landscapes.

Unlike in many other parts of Europe, the northern field boundaries usually are not hedgerows. Instead, they are grassy, meadow-type ditch banks or ecotones between field parcels or between a field and some other (often forest or waterway) land use type.

Agro-environmental schemes in the Nordic countries address issues of management of the field margins. Such schemes generally include variable recommendations or requirements concerning the role of the boundaries in reducing nutrient loading from the fields to surface waters, and/or concerning enhancement of biodiversity in agricultural landscapes. For example, the Finnish agro-environmental scheme, based on EC Regulation 2078/92, requires widened buffer zones along waterways, prohibits spreading of fertilizers or pesticides to the boundaries, and recommends management by annual mowing and removal of the phytomass.

A treatise of the ecology of field margins in European farming systems was recently published (Marshall 2002). It includes two articles (Bäckman & Tiainen 2002, Ma et al. 2002) from the research project the summary of which this issue is, and provides an excellent overview as well as details of many case studies into field margin ecology and management.

The project 'Functional Biodiversity in Agricultural Field Margins' (Project No. 65.33.22.00) was funded by the Nordic Council of Ministers and by the host institutions for 1997-2002. A parallel project 'Regionalization of erosion and nitrate losses from agricultural land in Nordic countries' (TemaNord 2002:536) was managed to cover the role of field margins in preventing loading of the waterways. Our project focused on role of field margins in contributing to species diversity in Nordic agricultural landscapes.

2 Flora and vegetation types in agricultural buffer zones in Finland

Sanna Tarmi & Juha Helenius

2.1 Introduction

Field boundaries, especially buffer zones (in Finnish: *pientareet* and *suojakaistat*), are a dominating, semi natural type of habitat in agricultural landscapes. They are essential to agro-ecosystems as well as to the agricultural landscape function. Direct services to agricultural production include the buffering and redirecting the flow of materials, pollination of crop plants, and biological control of pest insects. On the other hand, mismanagement may result in invasion of noxious weeds, and the introduction of pathogens or pests from the boundaries into arable land.

In Finland, these linear habitats run as an irregular network of ca. 0.5 million km around and within arable land. The first Finnish Agri-Environmental Scheme, (1995-1999), created ca. 30,000 km of widened boundaries along water courses alone, which were called buffer zones. The official objective of the field boundary management and the *MAF's* (Ministry of Agriculture and Forestry) second scheme for 2000-2006 is to prevent and reduce nutrients and other pollutants from leaching. Also included is to stop soil erosion from agricultural fields to watercourses, to sponsor biodiversity in agricultural environment and to support game and fisheries (see the resp. www pages of MAF Finland in <http://www.mmm.fi/>).

Vascular plant species diversity is the primary determinant of the ecosystem and biodiversity value of field boundary habitats to other organisms. Plants provide the physical structures and primary resources for feeding, breeding, nesting, resting, over wintering and dispersing for the animals (e.g. *Lagerlöf et al.* 1992, *Aebischer et al.* 1994, *Dover* 1996, *Kromp* 1999).

Surveys providing basic information on plant species diversity in field boundaries are available from many other European countries (e.g. *de Snoo* 1995, *Dramstad & Fry* 1995, *Dramstad* 1996a, 1996b, *Kleijn* 1997, *Bäckman & Tiainen* 2002). Our aims are; 1) to provide knowledge about plant species diversity in agricultural field boundary habitats, especially in buffer zones of Finland, 2) to classify vegetation as ecological groups representing different environmental conditions and agricultural practises, and 3) to observe successional changes in boundary vegetation during the five years.

2.2 Material and Methods

To get the basic knowledge about the current status of plant species composition and vegetation structure in buffer zones, we collected quadrat data from four areas in S, SW, W and NE Finland. These areas were the sampling frame for a larger and a joint project (MYTVAS 1995-1999), which aimed in assessing and monitoring the impact of the first Finnish Agri-Environmental Scheme. A description of biophysical and agricultural characteristics of the study areas is available in *Granlund et al.* (2000).

Boundaries were pre-selected from aerial photographs to facilitate the finding of appropriate sites. The data consisted of approximately 200 buffer zones per year. The exact number of sites designated for width measurements and vegetation sampling varied slightly every year. In the first year some sites had to be rejected because they were too narrow for sampling. A usual reason for rejection in any one season was mowing just before the site visit. Some sites were excluded because the field was no longer in agricultural use; e.g. trees had been planted or houses had been built in the field area.

The first Finnish Agri-Environmental Scheme started in 1995. The first sampling took place between July and mid-August of 1995, when most farmers had not yet established the widening of the buffer zones along the main (gathering) ditches (requirement of 'ca. 1 m' in the scheme), or along natural watercourses like rivers and lake shores (requirement of 'no less than 3 m'). The next sampling round was from July till mid-August of 1997, and the last in July through mid-August of 1999. Thus, our monitoring covered 4 years after the establishment of the buffer zones, as required by the Agri-Environmental Scheme.

In order to meet the requirements of the scheme, farmers, in most cases, had to widen their field boundaries along watercourses. Therefore, a typical boundary in our sample consisted of the original boundary (OB) and the widening of the boundary (WB) on the side of the arable field (Fig. 2.1). In the first year of the scheme it was possible to establish WB by simply leaving it unploughed after the harvest, but more often they were established by sowing grassland seed mixture (*Phleum pratense*-*Festuca pratensis*-*Trifolium pratense*), or by leaving it untouched from the existing sowed grassland.

Each buffer zone was sampled for plant species richness and cover in quadrates of 0.25 m² (0.5 x 0.5 m). Five quadrates were examined in 1995; the first one was no less than 20 m from one end of the buffer zone, and the four others were in 20 m intervals. In 1997 and 1999, parallel quadrates were made to the boundary widening (WB: Fig. 2.1) at 1 m distance from each quadrate in the old-

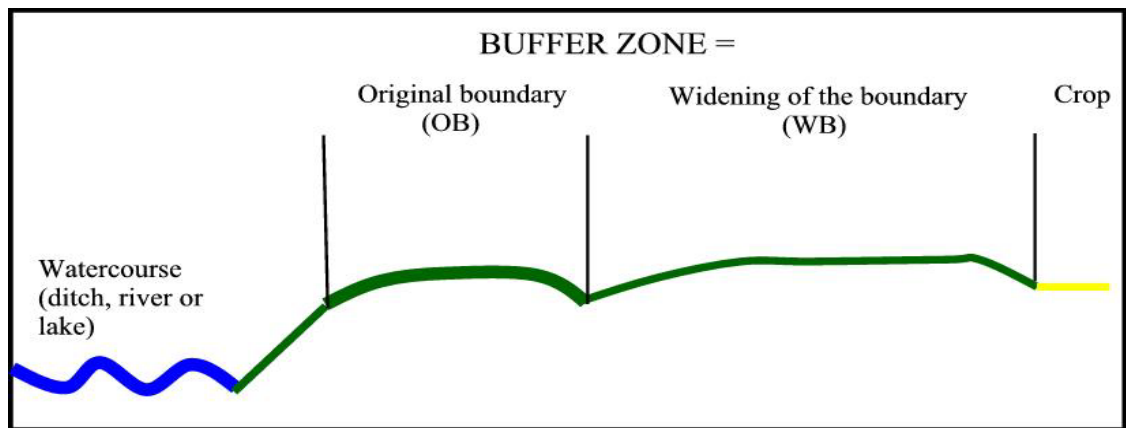


Figure 2.1. Sections of a field boundary include the original boundary (OB), and the widening of the boundary (WB) to ca. 1 m in case of a ditch, and to no less than 3 m in case of a natural water course, to meet the rules of the 1st Finnish Agri-Environmental Scheme 1995-1999.

boundary (OB). As a result, ten quadrates were observed in the buffer zones of natural watercourses. *Oksanen's* nine class scale (1981) was used for the cover values of the plant species. Grasses were identified mainly to genus level in 1995 in order to keep the sampling effort within the time frame, but in the following two sampling years, we had the capacity to identify the grasses also to species level. Width of the buffer zone was measured in the site of every quadrate. The nomenclature follows *Hämet-Ahti et al.* (1998: see Table 2.2 for author names).

We used the 1995 data to get an understanding of the vegetation status in the original boundaries (OB: Fig. 2.1). These were expected to be characteristics of the agro-eco-zones of the four regions, and they were to have predictive value for succession in the newly established widening of the boundaries (WB). The mean cover values were calculated for each plant species as arithmetic mean of all the quadrates in a buffer zone. These mean cover values were then used to obtain unbiased mean class values in the original scale for data analysis (Tarmi et al, manuscript). We used ordination and cluster analysis to explore the data for possible patterns of community variation (*Mazzoleni et al.* 1991). Ordination by correspondence analysis (CA) was carried out by CANOCO programme (*ter Braak & Šmilauer* 1998). The boundaries were then clustered according to their vegetation into ecological groups using Ward's method, via SAS[®].

2.3 Results

With some exceptions, the field boundaries were still in their original width (OB) of 1995. In all regions, except in Taipaleenjoki, the average width of both the ditch bank sites (aim 1 m) and sites along natural watercourses (aim 3 m or more), clearly increased from 1995 through 1999 (Table 1); the means were

Table 2.1. Mean widths (cm) of the buffer zones (mean (Me), S. E., min and max) 1995, 1997 and 1999 in Lepsämäenjoki (Lepsa), Lestijoki (Lesti), Taipaleenjoki (Taipa) and Yläneenjoki (Ylane).

Ditch	1995					1997					1999				
	n	Me	S.E.	Min	Max	n	Me	S. E.	Min	Max	n	Me	S.E.	Min	Max
Lepsa	29	70	10	0	256	25	91	9	4	210	26	143	24	15	514
Lesti	28	77	9	6	250	25	92	9	7	216	25	93	7	43	175
Taipa	23	86	36	3	860	21	84	13	12	240	19	75	12	0	246
Ylane	27	46	4	23	100	23	132	13	50	330	22	129	11	60	250

River, lake	1995					1997					1999				
	n	Me	S.E.	Min	Max	n	Me	S. E.	Min	Max	n	Me	S. E.	Min	Max
Lepsa	31	136	22	0	510	31	284	21	72	480	32	310	20	64	590
Lesti	31	107	18	0	390	34	225	20	6	390	35	295	22	63	725
Taipa	22	189	46	2	780	22	323	40	10	826	22	354	42	92	826
Ylane	32	56	4	25	100	33	287	18	25	570	33	287	21	50	640

near the aim widths in 1997 and even improved by 1999. Still, in 1999, the width requirement was not met in several sites; but as the scheme allowed for exceptions when the slope was long and gentle towards the watercourse, these cases remained within the restrictions of scheme regulations.

Looking at the habitat types, in the 1995 materials, we had two groups: 1) original buffer zones of ditches and 2) original buffer zones of natural watercourses. In 1997 and 1999 the widening of the buffer zones were included into these original groups.

Table 2.2. Vegetation types in old boundaries, as identified by cluster analysis of plant species cover values of 1995 (*Tarmi et al. 2002*).

Cluster		Number of sites	Plant species richness		Typification
		n	S	S. D.	
1.	<i>Ranunculus repens</i> – <i>Phleum pratense</i>	37	18	5	Dominant type in Lestijoki
2.	<i>Filipendula ulmaria</i> – <i>Ranunculus repens</i>	12	20	8	Northern, diverse type of wet sites
3.	<i>Calamagrostis</i> sp. – <i>Phalaris arundinacea</i>	9	23	8	Most diverse, northern type
4.	<i>Elymus repens</i> – <i>Epilobium angustifolium</i>	3	12	4	Species poor, high N, disturbed
5.	<i>Elymus repens</i> – <i>Anthriscus sylvestris</i>	48	14	5	Species poor, southern type
6.	<i>Elymus repens</i> – <i>Tripl. inodorum</i>	19	18	6	Annual species type, esp. Lepsämä
7.	<i>Elymus repens</i> – <i>Cirsium arvense</i>	19	16	6	Indifferent, poor, southern type

Table 2.3. Most frequent species in boundaries of main ditches, and in boundaries of natural water courses. The 1997 and 1999 data from boundaries of the natural water courses include both the samples of the old boundaries (OB; see Fig. 2.1), and the parallel samples of the widened boundaries (WB).

Boundaries of main ditches					
1995 (N=91)	%	1997 (N=102)	%	1999 (N=101)	%
<i>Elymus repens</i> L.	76	<i>Elymus repens</i>	85	<i>Elymus repens</i>	93
<i>Phleum pratense</i> L.	58	<i>Achillea millefolium</i>	70	<i>Phleum pratense</i>	71
<i>Achillea millefolium</i> L.	57	<i>Phleum pratense</i>	58	<i>Achillea millefolium</i>	66
<i>Ranunculus repens</i> L.	57	<i>Vicia cracca</i>	53	<i>Cirsium arvense</i>	54
<i>Poa</i> L.	50	<i>Cirsium arvense</i> .	51	<i>Vicia cracca</i>	53
<i>Equisetum arvense</i> L.	43	<i>Ranunculus repens</i>	42	<i>Angelica sylvestris</i>	46
<i>Vicia cracca</i> L.	43	<i>Taraxacum</i>	42	<i>Taraxacum</i>	45
<i>Cirsium arvense</i> (L.) Scop.	42	<i>Angelica sylvestris</i>	36	<i>Agrostis capillaris</i>	44
<i>Stellaria media</i> (L.) Vill.	41	<i>Festuca pratensis</i> Huds.	36	<i>Anthriscus sylvestris</i> (L.) Hoffm.	43
<i>Filipendula ulmaria</i> (L.) Maxim.	37	<i>Poa pratensis</i> L.	36	<i>Festuca pratensis</i>	42
<i>Taraxacum</i> Weber	35	<i>Agrostis capillaris</i> L.	34	<i>Lathyrus pratensis</i>	39
<i>Rumex acetosa</i> L.	31	<i>Festuca rubra</i> L.	32	<i>Ranunculus repens</i>	39
<i>Angelica sylvestris</i> L.	30	<i>Lathyrus pratensis</i> L.	32	<i>Filipendula ulmaria</i>	37
<i>Achillea ptarmica</i> L.	28	<i>Rumex acetosa</i> L.	32	<i>Poa pratensis</i>	37
<i>Deschampsia cespitosa</i> (L.) P. Beauv.	28	<i>Deschampsia cespitosa</i>	31	<i>Urtica dioica</i> L.	31
Boundaries of natural water courses					
1995 (N=92)	%	1997 (N=108)	%	1999 (N=114)	%
<i>Elymus repens</i>	76	<i>Elymus repens</i>	87	<i>Elymus repens</i>	93
<i>Ranunculus repens</i>	59	<i>Phleum pratense</i>	80	<i>Phleum pratense</i>	89
<i>Phleum pratense</i>	55	<i>Ranunculus repens</i>	56	<i>Ranunculus repens</i>	73
<i>Alopecurus pratensis</i> L.	51	<i>Taraxacum</i>	56	<i>Cirsium arvense</i>	62
<i>Cirsium arvense</i>	45	<i>Cirsium arvense</i>	52	<i>Vicia cracca</i>	61
<i>Stellaria media</i>	44	<i>Achillea millefolium</i>	51	<i>Anthriscus sylvestris</i>	59
<i>Anthriscus sylvestris</i>	38	<i>Alopecurus pratensis</i>	51	<i>Taraxacum</i>	58
<i>Vicia cracca</i>	36	<i>Festuca pratensis</i>	50	<i>Agrostis capillaris</i>	55
<i>Trifolium repens</i>	35	<i>Vicia cracca</i>	46	<i>Alopecurus pratensis</i>	55
<i>Poa</i>	34	<i>Poa pratensis</i>	45	<i>Festuca pratensis</i>	55
<i>Achillea millefolium</i>	30	<i>Anthriscus sylvestris</i>	44	<i>Lathyrus pratensis</i>	51
<i>Deschampsia cespitosa</i>	29	<i>Lathyrus pratensis</i>	42	<i>Filipendula ulmaria</i>	50
<i>Lathyrus pratensis</i>	28	<i>Trifolium repens</i>	40	<i>Achillea millefolium</i>	48
<i>Taraxacum</i>	28	<i>Angelica sylvestris</i>	34	<i>Trifolium repens</i>	46
<i>Tripleurospermum inodorum</i> Sch.	23	<i>Filipendula ulmaria</i>	33	<i>Poa pratensis</i>	45
Bip.					
For more details, see the text and Table 3. Frequency (%) denotes the proportion of the sites in which the species was found.					

In the ordination, the northern (Lestijoki and Taipaleenjoki) and the southern (Lepsämäenjoki and Yläneenjoki) sites were separated. Furthermore, the two southern regions 'overlapped' in terms of the vegetation patterns of the boundaries, whereas the two northern regions both had their own characteristic patterns. In Taipaleenjoki, there was more regional variability within the sites than in the other regions.

After ordination, we grouped the original buffer zones (OB) of 1995 to ecological groups according to their vegetation composition. Judging from the grouping results, we concluded that seven identifiable clusters would be appropriate for interpreting of the results (Table 2.2). Clusters of the northern agricultural areas (1-3, Table 2.2.) were more species rich than clusters of the

southern areas (5-7, Table 2.2). Cluster four had too few cases for further interpretations. Southern clusters were characterized by *Elymus repens*, a noxious perennial weed, with frequent occurring also in the northern clusters. Another significant perennial weed, *Cirsium arvense*, in addition to several annual herbs typified the southern clusters. In northern clusters, *Ranunculus repens*, *Rumex acetosa*, many perennial herbs, as well as other grassy species were recurrent. Species richness was higher in northern clusters relative to southern clusters.

When comparing the plant species assemblages, using the lists of the 15 most frequent species (Table 2.3), there were no major differences between the years, nor between the boundary types (ditch banks vs. buffer zones of natural water courses). No clear succession changes in vegetation composition were perceivable from this four-year time series. The most significant changes occurred within *Elymus*, in which they became more frequent from 1995 to 1999. Moreover, the rate of recurrence of *Phleum pratense* and *Festuca pratensis* increased in the (widened) boundaries of natural watercourses, increased since 1995. Of the most frequent plant species, the majority of them indicate the existence of lush sites (moist soils and high nitrogen availability; Ellenberg *et al.* 1991).

2.4 Discussion

Clustering analysis revealed two broad vegetation types in field boundaries, namely a northern regional group and a southern regional group. The dissimilarities between regions may best be explained by differences in agricultural land use. Dairy farming and associated leys and pastures, as well as grazing, are typical in central and north-central parts of the country. Leys and pastures are in three to four year rotations, along with mowing or grazing that sometimes extends to the boundaries; which, jointly, they cause the complete turnover and disturbance of the fields by ploughing, tilling and re-sowing to be less often. Herbs like *Ranunculus repens* and *Rumex acetosa* are not eaten by cattle and thus they get an advantage in competition among other species. These species are typical grassland weeds in Finland. Permanent vegetation cover together with mowing or pasturing diminish the occurrence of species which have an advantage on bare soil flora like annual herbs or such perennials as *Cirsium arvense*. In the south, most of the farming is arable, and annual crops are the most common. Nutrient enrichment to these boundaries may take place through passage of the eroded land or by leaching from the field. Herbicide drifts to boundaries are more likely to occur in annual arable agriculture than in mixed dairy farming.

Critical perennial weed species are frequent in boundaries of all the studied regions. However, species such as *Elymus repens* and *Cirsium arvense* are more frequent and typical in boundaries of the southern arable farming regions.

The northern mixed farming regions maintain higher plant species diversity in their boundaries than in the southern regions.

In comparison between years, the increase of *Phleum pratense* and *Festuca pratensis* during the four years of the Agri-Environmental Scheme in boundaries of natural watercourses is probably a consequence of establishing the boundary widening by sowing grassland seed mixture. Further analysis of successional changes at area and site level is necessary. There is also a need to analyse vegetation together with more detailed information about the soil and management practises in each boundary.

3 Plant and bumblebee species diversity in boundaries of organic and conventional agricultural fields

Virpi Aalto, Jan-Peter C. Bäckman & Juha Helenius

3.1 Introduction

In organic farming, manufactured chemical fertilizers and pesticides are not used. Soil fertility is maintained by integrating green-manuring- crops and nitrogen fixing leys into 4-6 year crop rotations. Theoretically, these practices result in a lower nutrient loading to the field boundaries, a lower exposure of the boundary communities to toxic substances, and due to rotations, a higher diversity of crop species adjacent to the boundaries. These differences indicate that field boundaries may be more species diverse in organic farms than in conventional farms by having lower nutrient availability, especially, in nitrogen. This low nutrient accessibility favours plant species diversity in terrestrial ecosystems (*Tilman 1987, Wedin & Tilman 1990*), and the exclusion of herbicide spraying and drift to the boundaries favours diverse flora of perennials, such as annual weeds and ruderal species that are no longer 'selected for', by herbicides (*Kleijn 1997*).

Sampling the plant diversity was the most obvious solution to testing the hypothesis of higher species diversity in organic boundaries versus the conventional ones. Amongst the high number of herbivores and predators that are supported by plants in the consumer food web, we chose to study the species diversity of bumblebees. The species pool of bumblebees is manageable, they are relatively easy to observe, and they belong to an important functional group of pollinators of plants, including crop plants outside the boundaries. Bumblebees use nectar and pollen of dicotyledonous flowers as their food. Conventional field boundaries in Finland are frequently dominated by monocotyledonous (grass) species (*Bäckman & Tiainen 2002* and *Tarmi & Helenius, 2002*), and if organic farming increases dicotyledonous plants, it would, consequently, favour the bumblebee population as well.

Our preliminary data from south Savo in Finland suggests that organic farming increases plant species diversity in field boundaries (*Holme 1996, Helenius 1996*). Quadrature sampling (0.25 m² quadrates) yielded 3 more species of dicotyledonous plants in organic boundaries than in the conventional boundaries. According to *Shannon-Wiener* alpha-diversity, index H', organic boundaries do have a higher value than the conventional ones. The communities were found to be dissimilar, sharing only 49% of all the species. Modified *Sørensen's* index showed only 35% similarity between the two communities (Table 3.1).

Table 3.1. Diversity of dicotyledonous plant species in quadrature sampling (four quadrates per boundary) data from boundaries of organic vs. conventional fields in 1995, South Savo, Finland (Holme 1996, Helenius 1996).

	Organic farms (n=5 boundaries)	Comparison	Conventional farms (n=5 boundaries)
Number of species	59		56
Number of specimens	4 301		2 846
Specimens of the most common species	700		818
Species found only once or twice	10		15
Shannon-Wiever, H'	3.08		2.88
Number of shared species		38	
Proportion of shared species		49%	
Modified Sørensen C _N		0.35	

The aim of this study was to test the hypothesis of higher species diversity in organic than in conventional field boundaries. The methods and results concerning the plant surveys were presented in detail by *Aalto* (1999). The original results of line-transect surveys of bumblebees and their forage plants in field boundaries are provided by *Bäckman* (in prep.).

3.2 Material and Methods

Sampling for plant species diversity

The data were collected in summer of 1997 in Häme and Uusimaa districts in South Finland. The sampling frames were six field areas in which both conventional and organic farms were operating. From each field area, three boundaries of organic farms and three of conventional farms were sampled. All organic farms were past the transition phase, having practised organic farming for five years or more. The criteria for all boundaries were that they had to be naturally vegetated, perennially, throughout bordering spring cereal crop, in the year of sampling. Boundaries that had been tilled and established less than two seasons earlier were rejected. In one field area the organic boundaries were mown just before sampling and thus, they were excluded. Altogether, the sample consisted of 18 conventional boundaries and 15 organic boundaries. To be able to compare the species diversity in the symmetric data of the five areas with full samples in three boundaries of both types (n=15), the field area in which organic boundaries were excluded was removed from the data. Length of the boundaries varied from 50m to 600 m, each having a typical width of only 0.5 m or less.

Each margin was sampled by percentage coverage method for dicotyledonous plant species diversity, in four quadrates of 0.25 m², dispersed in 15-100 m distances depending on the length of the boundary. In addition, species number (richness) was assessed by line transect counting. Above ground biomass of each species from each quadrate was measured. After the

coverage estimation, the quadrat was cut, species were sorted in lab and oven dried in 80 °C for 20 h, and weighted.

Boundaries' soils were sampled for pH and nutrient analysis by drilling to the depth of 0.20 m. For soil analysis, 12 drill cores, three around each quadrat, were mixed to form one collective sample to represent the whole boundary. Grouping of the species to agro-ecological guilds was based on their reproductive traits, agronomic significance (common and noxious weeds), and pollination biology (*Knuth* 1898-1905, *Teräs* 1985, *Raatikainen* 1991, *Hämet-Ahti et al.* 1998).

Sampling for pollinators and their forage plants

The first set of data was collected in summer 1997 in the same farmland areas as the plant species diversity data. From each area, boundaries of 2-5 cereal fields were sampled in which line-transect counting method was used (*Teräs* 1983). A line-transect block was set to two meters in width, and to the full length of the field boundary. At least one third of every boundary in each field was included into the sample. Thus, a study frame was a field, around which the boundaries were sampled. Field margins were selected from 13 organic cereal and 8 conventional cereal fields. Bumblebee individuals were identified to species, sexes and castes and butterflies were specified to their species.

The abundance of dicotyledonous plants in flower was assessed into 5 classes: $1 \geq 0.5\%$, $2 \geq 1\%$, $3 \geq 10\%$, $4 \geq 25\%$, and $5 \geq 50\%$ throughout the boundary. The species were divided into ecological and morphological groups according to flower type (*Knuth* 1898-1905, *Teräs* 1985), availability of pollen, type of nectar source in the flower (open, half-concealed, or fully-concealed), morphology (composite flowers), and visitor or pollinator taxa (honeybee, bumblebee and dipteran flowers). Another type of classification was based on 'desirability to bees' as 'good' (very often or often visited) vs. 'poor' (never or seldom visited) flowers (divided by prior knowledge of foraging plants of bees; see *Elfving* 1968, *Teräs* 1985, *Dramstad* 1996b, *Bäckman & Tiainen* 2002). In addition, observations of species of all flowers visited by any pollinator were registered. Unlike the sampling of plant species diversity, in these measurements, only plants in flower during the bumblebee sampling were included into the data.

3.3 Results

Plant species diversity

Within each farmland area, soil types of the organic and conventional boundaries were the same, varying from silty clay to fine sandy soils. Soils of the organic boundaries had a significant, 33% lower levels of Phosphorus P, 25% lower levels of Potassium K, and 10% lower Specific Conductivity in soil water suspension (referring to ion content) than soils of the conventional boundaries. Levels of Nitrogen N (nitrate nor ammonium), Calcium Ca, Magnesium Mg, soil pH, organic Carbon C content, or organic matter content (SOM) did not differ significantly between the organic and conventional boundaries (Aalto 1999).

In all, 117 plant species (or higher taxa: *Taraxacum* Weber and *Achillea* L. at genus level, *Pilosella officinarum* coll. F.W.Sch.Bip as a collective group) were found. In the organic boundaries, species richness was higher than in the conventional boundaries (Table 3.2). The two types shared 62% of the species. Number of species occurring in organic boundaries was 27, whereas only 15 species occurred in conventional boundaries. The species of the organic boundaries were characteristically species of dry meadows, like *Fragaria vesca* L., *Potentilla anserina* L., *P. argentea* L. and *Trifolium aureum* Pollich, the last being listed as a declined species in Finnish Red Data Book. The species of the

Table 3.2. Number of dicotyledonous plant species in boundaries of organic and conventional agricultural fields.

1. Richness (line transect counts)	Organic (n=15)	Conventional (n=15)	All boundaries (n=30)
Cumulative number of species	102	87	117
Average number $\pm$ S. D.	30.0 $\pm$ 6.6	22.8 $\pm$ 7.1	26.4 $\pm$ 7.6
Maximum number	44	38	44
Minimum number	15	12	12
2. Species in quadrat samples			
Cumulative number of species	65	52	80
Average number $\pm$ S. D.	16.5 $\pm$ 4.0	12.3 $\pm$ 5.1	14.7 $\pm$ 4.8
Maximum number	22	20	22
Minimum number	9	1	1

conventional boundaries were mainly road verge and ditch bank species favouring lush sites, like *Anthoxanthum odoratum* L., *Phragmites australis* (Cav.) Trin., and *Valeriana officinalis* L., or annual weeds like *Erysimum cheiranthoides* L., *Senecio viscosus* L., *Spergula arvensis* L., and *Galeopsis bifida* Boenn.

The three most frequent species in the organic boundaries were *Phleum pratense* L., *Taraxacum*, and *Achillea millefolium* L., which are not among significant weeds. In the conventional boundaries, the three most frequent species were *Phleum pratense*, *Elymus repens* (L. Gould), and *Cirsium arvense* (L. Gould), in which the two latter are considered amongst vital perennial weeds

(Table 3.3). Rank-frequency plots from the line transect ('all the species') show smoother dominance pattern and higher richness, i.e. higher plant species diversity in the organic boundaries than in the conventional boundaries (Fig. 3.1).

The observed proportions of broad leaved species (vs. grass species), non-weed species (vs. weed species), and of species requiring specific pollinators

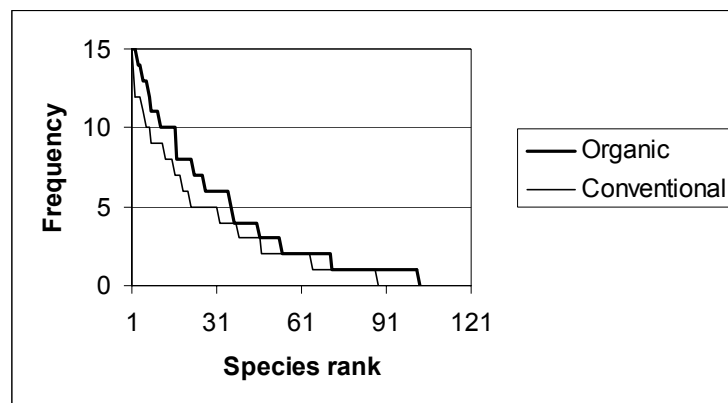


Figure 3.1. Rank-frequency patterns for plant species encountered in organic (n=15) and conventional (n=15) field boundaries in line transect counting.

(such as bumblebees; vs. species pollinated by any visitors, such as flies), were higher in organic boundaries than in conventional boundaries. (The 'bumblebee pollinated species' were here defined as those with long corollas, whereas species grouped into 'pollinated by all visitors' are the ones with short corollas, such as Umbelliferae, e.g. *Aegopodium podagraria* L.). In relative frequencies, however, none of these differences were significant (Table 3.3).

Bumblebee diversity, density and forage flowers

Total number of bumblebee species in the data was 12. All these species occurred in the organic boundaries, whereas only 8 species were found in the conventional boundaries (Table 3.5). The species assemblages of both types of boundaries resemble bumblebee assemblages found in forest edge habitats. However, the species that enrich the diversity of the organic boundaries represent the species pool of open (meadow) habitats. For example, the mean abundance of an open habitat species *B. veteranus* (F.), was lower; and the two others, namely *B. distinguendus* Mor. and *B. ruderarius* (Müll.), were not even found in the conventional boundaries.

Table 3.3. The ten most frequent plant species in organic and conventional field boundaries.

Organic boundaries (n=15)	Frequency %	Conventional boundaries (n=15)	Frequency %
<i>Phleum pratense</i> L.	100	<i>Elymus repens</i>	100
<i>Taraxacum</i> Weber	100	<i>Phleum pratense</i>	80
<i>Achillea millefolium</i> L.	93	<i>Cirsium arvense</i>	80
<i>Elymus repens</i> (L.) Gould	93	<i>Taraxacum</i>	80
<i>Equisetum arvense</i> L.	86	<i>Vicia cracca</i>	73
<i>Vicia cracca</i> L.	86	<i>Achillea millefolium</i>	66
<i>Cirsium arvense</i> (L.) Scop.	80	<i>Agrostis capillaris</i> L.	66
<i>Campanula patula</i> L.	73	<i>Alopecurus pratensis</i> L.	60
<i>Galium album</i> Miller	66	<i>Artemisia vulgaris</i> L.	60
<i>Lathyrus pratensis</i> L.	66	<i>Festuca rubra</i> L.	60

Line transect counts. The two most harmful perennial weed species are bold.

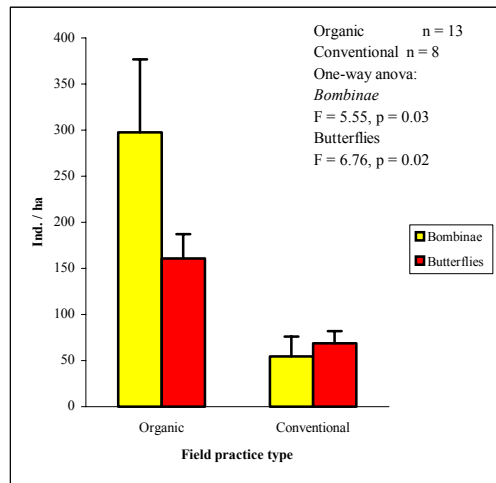
Table 3.4. Proportions of species in agro-ecological guilds in organic (n=15) and in conventional field boundaries (n=15).

	Organic boundaries % (n=102 species)	Conventional boundaries % (n=87 species)	Chi-squared (df=1)
Grasses (monocot.)	13.7	16.1	0.208 n. s.
Broad leaved (dicot.) species	86.3	83.9	0.208 n. s.
Weed species	21.6	28.7	1.290 n. s.
* Annual or biennial weeds	16.7	23.0	1.192 n. s.
* Perennial weeds	4.9	5.7	0.067 n. s.
Species pollinated by specialists	34.3	29.9	0.421 n. s.
Species pollinated by all visitors	16.7	17.2	0.011 n. s.

Mean number of species was higher in the organic than in the conventional boundaries (Fig. 3.2). Also the mean densities of the bumblebees (all species) and day active butterflies were higher in the organic boundaries. Mean *Shannon-Weaver* diversity H' calculated for bumblebees was higher (1.1) in the organic than in the conventional boundaries (0.6). Bumblebee assemblages were only 33% (*Renkonen* similarity index) similar.

Altogether 68 plant species were flowering during the time of bumblebee sampling, 62 species in the organic and 55 species in the conventional margins. Proportion of shared species was 74%. The four most abundant species in the organic margins were *Trifolium medium* L. (found in all boundaries; frequency 100%), *Cirsium arvense* (77%), *Epilobium angustifolium* L. (69%), and *Vicia cracca* L. (92%) (Table 3.6). In the conventional margins these were *E. angustifolium* (88%), *C. arvense* (88%), *Tripleurospermum inodorum* Sch. Bip. (75%), and *Achillea millefolium* (88%).

A.



B.

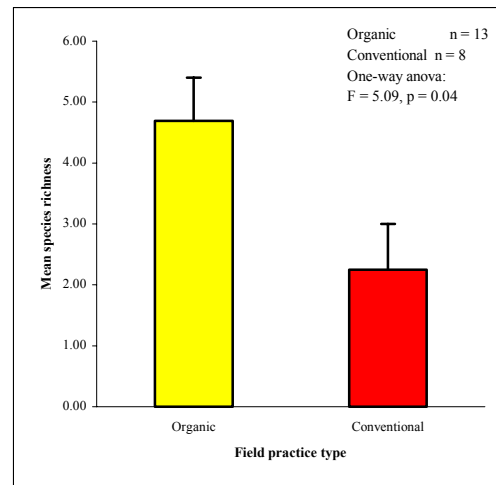


Figure 3.2. Mean number of bumblebee (*Bombus* and *Psithyrus* = *Bombinae*) and butterfly densities (A), and mean species numbers of bumblebees in organic and conventional field margins in 1997 (B).

Table 3.5. Bumblebee species in organic and in conventional cereal field boundaries (in order of mean abundance) in 1997. Frequency included.

Organic			Conventional		
Species	Density	Freq. % (freq.)	Species	Density	Freq. % (freq.)
<i>Bombus pascuorum</i> (Scop.)	66	69 (9)	<i>Bombus lucorum</i> –group	15	63 (5)
<i>Bombus lucorum</i> –group	64	85 (11)	<i>Bombus pratorum</i>	11	38 (3)
<i>Bombus veteranus</i> (F.)	43	62 (8)	<i>Bombus lapidarius</i>	10	25 (2)
<i>Bombus lapidarius</i> (L.)	35	46 (6)	<i>Bombus pascuorum</i>	8	38 (3)
<i>Bombus hortorum</i> (L.)	23	38 (5)	<i>Bombus hortorum</i>	4	13 (1)
<i>Bombus distinguendus</i> Mor.	21	23 (3)	<i>Bombus subterraneus</i>	3	13 (1)
<i>Bombus pratorum</i> (L.)	14	38 (5)	<i>Bombus veteranus</i>	2	25 (2)
<i>Bombus soroeensis</i> (F.)	10	31 (4)	<i>Bombus soroeensis</i>	2	13 (1)
<i>Psithyrus bohemicus</i> (Seidl.)	8	15 (2)			
<i>Bombus hypnorum</i> (L.)	7	31 (4)			
<i>Bombus rudericus</i> (Müll.)	4	15 (2)			
<i>Bombus subterraneus</i> (L.)	3	15 (2)			

Density = Individuals / hectares / field

Table 3.6. Ten most abundant plant species in flower, and species found in only organic cereal field boundaries, and in only conventional cereal field boundaries in 1997.

The ten most abundant species			
Rank	Organic boundaries	Rank	Conventional boundaries
1.	<i>Cirsium arvense</i> (L.) Scop.	1.	<i>Epilobium angustifolium</i> L.
2.	<i>Trifolium medium</i> L.	2.	<i>Cirsium arvense</i> (L.) Scop.
3.	<i>Epilobium angustifolium</i> L.	3.	<i>Tripleurospermum inodorum</i> Sch. Bip.
4.	<i>Vicia cracca</i> L.	4.	<i>Achillea millefolium</i> L.
5.	<i>Tripleurospermum inodorum</i> Sch. Bip.	5.	<i>Tanacetum vulgare</i> L.
6.	<i>Galeopsis bifida</i> Boenn.	6.	<i>Galeopsis speciosa</i> Miller
7.	<i>Galeopsis speciosa</i> Miller	7.	<i>Vicia cracca</i> L.
8.	<i>Achillea millefolium</i> L.	8.	<i>Persicaria lapathifolia</i> (L.) Gray
9.	<i>Persicaria lapathifolia</i> (L.) Gray	9.	<i>Sonchus arvensis</i> L.
10.	<i>Lathyrus pratensis</i> L.	10.	<i>Trifolium medium</i> L.
Species founded exclusively:			
	In organic boundaries		In conventional boundaries
1.	<i>Centaurea cyanus</i> L.	1.	<i>Arctium tomentosum</i> Mill.
2.	<i>Centaurea jacea</i> L.	2.	<i>Galium verum</i> L.
3.	<i>Heracleum sphondylium</i> L.	3.	<i>Prunella vulgaris</i> L.
4.	<i>Mentha arvensis</i> L.	4.	<i>Rorippa sylvestris</i> (L.) Besser
5.	<i>Pilosella</i> Hill.	5.	<i>Thlaspi arvense</i> L.
6.	<i>Rhinanthus minor</i> L.	6.	<i>Vicia sepium</i> L.
7.	<i>Rosa</i> L.		
8.	<i>Stellaria media</i> (L.) Vill.		
9.	<i>Trifolium aureum</i> Pollich		
10.	<i>Valeriana officinalis</i> L.		
11.	<i>Veronica longifolia</i> L.		
12.	<i>Vicia sativa</i> L.		

`Good bee plant' = rank number bolded!

51 of all species found were `good' and 29 were `poor'. The ratio of `good' to `poor' plant species was 1.85 in the organic boundaries, and it was 1.62 in the conventional boundaries. Out of the 12 species found in the organic field boundaries, ten were `good' (Table 3.6). Flower assemblages were not any more similar than bumblebee assemblages between these two types of field margins; only 44% (*Renkonen* similarity). In the organic boundaries, majority of flowering dicot species (79%), represented the most suitable groups of flower types for bumblebees (by *Knuth* 1898-1905), i.e. pollen flowers, flowers with fully concealed nectar source, composite flowers, honeybee flowers, and bumblebee flowers. The rest of them were flowers with open or half-concealed nectar source, as well as dipterous flowers. In the conventional boundaries 75% of the species were of the first group. The two biggest types of flower groups in the data pool of both boundaries were composite flowers (ca. one third) and honeybee flowers (ca. a quarter).

3.4 Discussion

It is concluded that organic agriculture works in favour of species diversity of plants and pollinators in agricultural field boundaries. Our data suggests not only increased species richness of plants but also a stronger dependence of some pollinating insect groups on the plants in organic field boundaries. Even though in these relatively small sets of data, no single comparisons were statistically significant (Table 3.4), mean pollinator density and species richness due to organic practise, proves our original hypothesis of increased diversity in organic farms.

Conclusions concerning the bumblebee diversities and their forage plant availabilities should be drawn bearing in mind the bigger sampling size for organic than for conventional types (13 vs. 8 boundaries). The inferences yield higher number of species found in the organic boundaries even if their richness were the same. However, the nearly six time (552 %) higher mean for the abundance of bumblebees in the organic boundaries strongly points towards the conclusion that organic farming supports higher bumblebee diversities than conventional farming. Although not conclusive, due to small sample size, our tentative rarefaction analysis (describing how fast new species are added to the list when increasing sample size), indicated a genuine higher species richness in the organic than in the conventional boundaries.

An additional advantage of having organic farms sharing farmland areas with conventional farms is that these two types are dissimilar; organic agriculture increases the 'regional' species richness by supporting not just higher number of species, but also partially different flora and fauna in the boundaries.

4 The impact of landscape structure of field margins on floral richness in a semi-natural habitat

Maohua Ma, Sanna Tarmi & Juha Helenius

4.1 Introduction

Buffer zones along watercourses are used to maintain water fitness for agricultural ecosystems. Buffer zones are vegetated filter strips between agricultural fields and banks of a watercourse. The vegetation diversity (for example, species richness, vertical structure, species composition), in buffer zones, plays an important role in protecting water from being contaminated by agro-chemicals and eroded soil (*Jenssen et al.* 1994, *Daniels & Gilliam* 1996), as well as providing habitats for natural species (*Sotherton* 1984, *Dennis et al.* 1994).

One objective to study field margin-strips in agro-ecological systems was to understand the relationship between management activities and biodiversity; thus enabling the possibility to implement new practises through agricultural management services to increase production in the fields. This can be accomplished while the adjacent areas such as field margins, ditches, and hedges remain as habitats for diverse flora and fauna (*Kiss et al.* 1997, *Marrs & Frost* 1997, *Baines et al.* 1998, *de Snoo et al.* 1998, *Tsiouris & Marshall* 1998).

This study was conducted based on three motives: 1) to examine primary spatial determinant for species richness in the buffer zone context; 2) to propose a modified model to fit the observational data; and finally (*Ma et al.* 2002), 3) to understand the relationship between spatial structure of buffer zones and floral species richness (*Ma et al.* in prep.).

4.2 Material and Methods

Lepsämäenjoki was selected as the study area. It is situated in Nurmijärvi commune, 30 km to the north of Helsinki, Finland. The upper course of the Lepsämäenjoki River flows through the study area and has created broad and flat plains. The total number of plant species was 130. Field data was collected during a two-week period, starting from July 14 through July 27, 1998.

The key process in this study was finding out which factor is the primary determinant to predict species richness from potential spatial indicators. Patch size (area, width and length), patch connectivity, and the distance between patch and the nearest neighbouring woodlands are considered potential spatial indicators. GIS was used in displaying the results.

Patch size: species-area relationship

It has been observed that species richness in plant communities has to do with the species-area relationship. Patch area is an important indicator for species richness. Plant ecologists first attempted to elucidate the exact form of the curvilinear relationship, early in the present century (*Jaccard*, 1908, 1912). The botanist, *Arrhenius* (1921) and the zoologist, *Preston* (1962) assumed that the species-area relationship was expressed as a power function:

$$(1) \quad S = c A^z$$

which is often presented in a linear form after logarithmic transformation:

$$(2) \quad \log S = \log c + z \log A$$

Because the buffer zones were narrow strip patches, their area was approximated as the product of width and length. Therefore, the original species-area model was transformed:

$$(3) \quad \log S = \log c + z(\log L + \log W)$$

where S is species richness, and A is area L is length, and W is width. The parameter c and z are constants. The relationship between the dependent variable ($\log S$) and independent variables ($\log A$, $\log L$ and $\log W$) were examined. Using modelling approach, the best-fit model was proposed (for more, see *Ma et al.* 2002).

Patch connectivity: proximity index

Proximity index quantifies the spatial context of a habitat patch in relation to its neighbours. To figure out the relationships between the indices and species richness, we calculated patch proximity indices based on seed dispersal process from source to sink patch. In this analysis, species richness and the natural logarithm of species richness were related to the six proximity indices whose values were based on the distance (d) between patches and area of sink patches (A) (Table C.1). *MacArthur & Wilson* (1967) and *Riebesell* (1982) introduced these indices in their studies. Based on the analysis of species-area relationship, these models were modified to fit our case study.

Distance between margin and nearest neighbouring woodlands

In ArcView®, we measured the distances between patches and nearest neighbouring woodlands. Using statistical method, the relationships between the distances and species richness in field margins were studied and compared with former results.

GIS and spatial analysis

ArcView® version 3.1 and ArcView® Spatial Analyst version 1.0 (ArcView is registered trademarks of Environmental System Research Institute, Inc.) were used in this procedure. Spatial analysis is the process of looking at characteristics from a number of layers for each location to solve a problem. ArcView Spatial Analysis imposes a rectangular mesh or grid on selected layers. Each grid cell represents a location and has a value for each map layer, describing many attributes of each location (*ESRI 1996*). Some extensions are useful tools to establish dispersal model in GIS (*Huber 1999* and *Zhou 2000*).

Table 4.1. Proximity indices used in this study.

Model 1	$I_i = \sum_{j=1}^n A_j \exp(-d_{ij}^2)$
Model 2	$I_i = \sum_{j=1}^n A_j d_{ij}^{-1}$
Model 3	$I_i = \sum_{j=1}^n A_j \exp(-d_{ij}) (2\pi d_{ij})^{-1}$
Model 4	$I_i = \sum_{j=1}^n A_j \exp(-d_{ij}^2) (2\pi d_{ij})^{-1}$
Model 5	$I_i = \sum_{j=1}^n A_j d_{ij}^{-2}$
Model 6	$I_i = \sum_{j=1}^n A_j \exp(-d_{ij}) (0.5\pi d_{ij}^{-1})^{1/2}$

4.3 Results

Original species-area model

The sample data were used to demonstrate the relationship between species richness and patch area. Table 4.2 shows that there was no statistically significant relationship ($\rho = 0.1062$) between $\log S$ and $\log A$ in the original species-area model (Equation (2)) in our field data. Therefore, it was concluded that the original species-area model is unsatisfactory for buffer zones. Obviously, a modification of the model must be considered.

Modified species-area model

The modified model to describe the relationship between log S and the two independent variables, log L and log W, produced a statistically significant ($P=0.0990^*$) fit. Multiple regression analysis (Table 4.3) showed a higher and significant estimate for width than for length.

Table 4.2. Analysis of variance for the fitted model of original species-area relationship (*Ma et al.* 2002).

Source	Sum of Squares	d. f.	Mean Square	F-ratio	P-value
Model	0.0145	1	0.0147	2.79	0.1062
Residual	0.1420	27	0.0053		
Total (Corr.)	0.1567	28			

Correlation Coefficient = 0.3062
R-squared = 9.3744%
Standard Error of Est. = 0.0725

Therefore, it was accepted that area increment in the cross sectional direction is more valuable for plant species diversity than a similar area increment in length of a buffer zone. Based on these analyses, the modified species-area model was determined as:

$$(4) \quad S = cL^{z_L}W^{z_W}$$

Because of its insignificance, length (L) can be removed from this equation when it is applied.

Table 4.3. Analysis of variance of a fitted modified species-area model with log S the dependent variable and the independent variables log L and log W (S = plant species richness; L = buffer strip length; W = buffer strip width) (*Ma et al.* 2002).

Source	Sum of Squares	d. f.	Mean Square	F-ratio	P-value
Model	0.0255	2	0.0128	2.53	0.0990
Residual	0.1312	26	0.0051		
Total (Corr.)	0.1567	28			

R-squared = 16.2984
R-squared (adjusted for d. f.) = 9.8599%
Standard Error of Est. = 0.0710

Patch proximity indices and distances with woodlands

Due to the important role of width to predict species richness, six patch proximity indices were weighted by width of field margin. Regression relationships between species number (S) or $\ln(S)$ and the variables were calculated. Ten linear and ten non-linear regression relationship analyses were carried out to study the associations between species richness, six width-weighted patch proximate indices, and distances between patch and nearest woodlands. It was found that there is no significant relationship between them,

statistically (Ma et al. in preparation). As a result, width is a primary spatial indicator to describe the species richness in field margins in this study area.

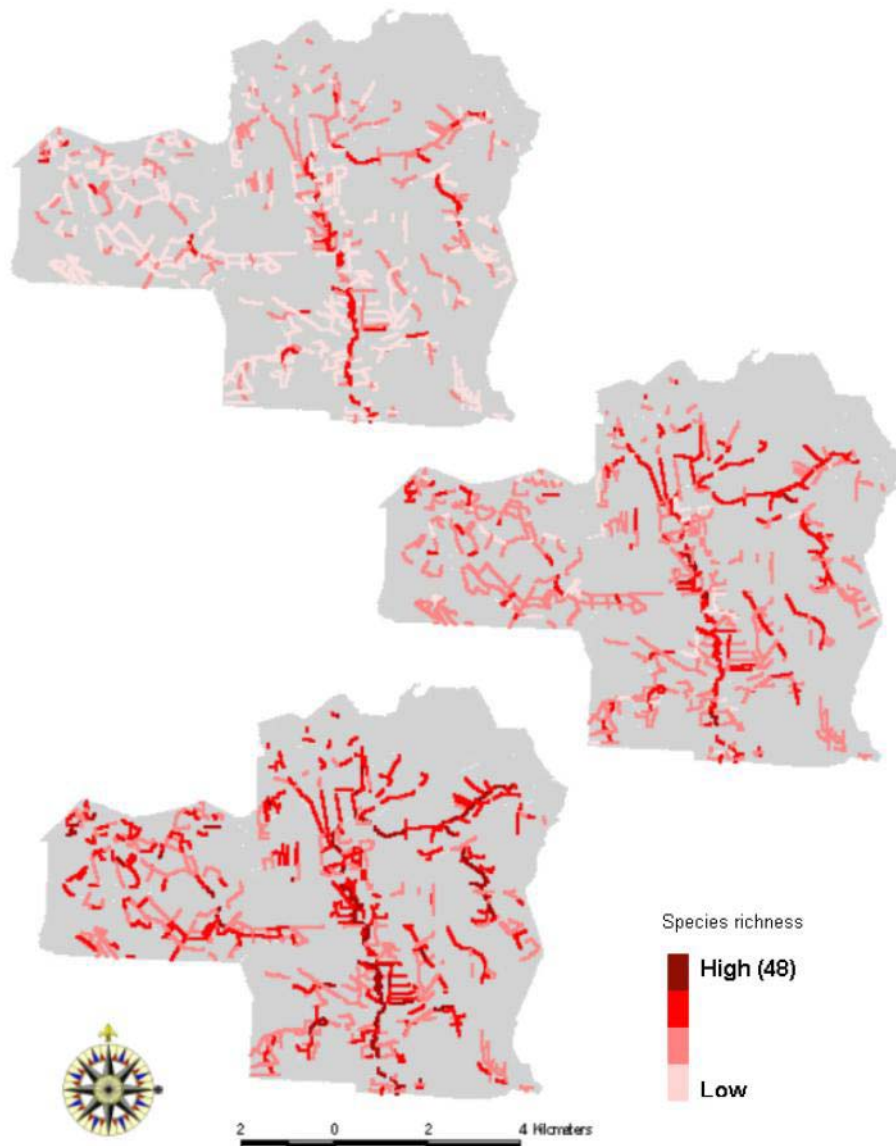


Figure C.1. GIS scenario: impact of width on species richness in buffer zone (top: width reduced by half; middle: current situation; bottom: width doubled) (Ma et al. in prep.)

GIS scenario

Using ArcView Spatial Analyst, Equation (4) was loaded into ArcView. A GIS spatial scenario of the effect of patch width of buffer zone on floral diversity provides a visual representation (Fig. 4.1) of the interaction between landscape structure and floral diversity. As shown in the figure, plant species richness increased in all buffer zones if the width is doubled from its original size. Floral

diversity in buffer zone demonstrated three levels when the width was reduced by half: 7% of total buffer zones represented the lower level (11-17 species lost) of floral diversity; 52%, the middle level (5-10 species lost), and 41%, the higher level (0-4 species lost). Clearly, the latter spatial arrangement is unacceptable because of the highest loss of species diversity. Widening of some buffer zones in the current situation is necessary.

Risk assessment of decline of floral diversity

A risk assessment diagram of the decline of floral diversity in buffer zone based on the developed model was produced (Fig. 4.2). The curve showed an about 3% risk of decline in floral diversity at the width of 5 meters, which meant one or two plant species, would be lost. If, however, one of the two vanished species was of special significance, for instance, it offered a habitat for some insects, or was an endemic species in danger, losing it would not be acceptable. In this case, a patch width of up to 6.5 meters could provide a satisfactory, 2% risk of decline in floral diversity (*Ma et al.* in prep.).

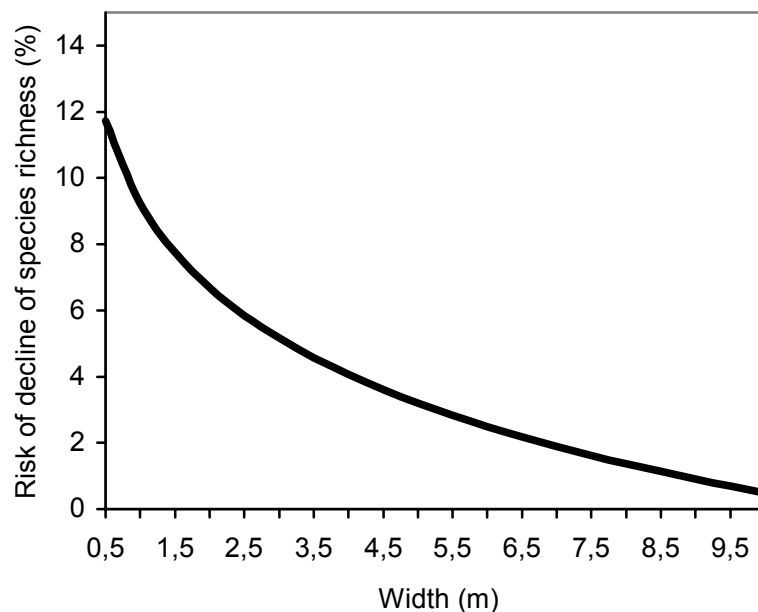


Figure 4.2. Risk of decline in species richness against width of buffer zone (*Ma et al.* in prep.).

4.4 Discussion

Our results showed that width is a spatial indicator for species richness in this study area. There is no statistical relationship between patch proximity indices, distances between patch, nearest woodlands, and species richness. This indicated that, either dispersal processes are not critical to plant species diversity, or connectedness is not a critical factor for dispersal, at this spatial scale. Or that neither is true. Furthermore, Width carries more significance in maintaining species richness in field margin than other spatial indicators.

Considering buffer strips as corridors in agricultural mosaics, the indicated result for the importance of width in landscape elements is in accordance with the key role of corridor width (*Forman* 1995). It was believed that in a landscape mosaic, the widths of corridors were closely related to their connectivity in terms of five functions: habitat, conduit, filter, source, and sink (*Forman* 1983, *Forman & Godron* 1986, *Henien & Merriam* 1990, *Merriam & Lanoue* 1990, *Bennett* 1991, *Forman* 1995, *Andreassen et al.* 1996, *van Dorp et al.* 1997, *Haddad* 1999).

In semi-natural ecosystems, especially in agricultural ecosystems, the internal structure of buffer zone is disturbed by agricultural activities. As a result, cross-sectional habitat gradients are generated because of the function of buffer zones as filters for eroding soil, leaching nutrients and drifting pesticides from agricultural field towards the watercourse (*Yates & Sheridan* 1983, *Peterjohn & Correll* 1984, *Lowrance et al.* 1985). The boundary edge differences between the two sides reflect different land uses. *Forman* (1995) observed that the overriding result of the filter effect was to separate patches on opposite sides of a corridor, where species composition often differs. Therefore, the width and the presence of an interior environment are key spatial variables controlling the function of buffer zones.

Policy makers can use the important results obtained in this study as a reference, and it has application value in agricultural management. Management for conservation in agro-ecological systems should aim to establish an optimal spatial arrangement. Our result suggested that managers of buffer zones should consider width not only for its buffering function, but also as an important factor for biodiversity management plans at the landscape level. We suggest application of the modified model for optimising buffer zones to meet the needs of biodiversity conservation.

5. Using airborne, laser scanner data and GIS for the automatic detection of windbreaks.

Preben Olsen and Mette Balslev Greve

5.1 Introduction

Field windbreaks (hedgerows) contain one to several rows of trees or bushes and are located along crop field borders or within the field itself. Originally, the windbreaks were to serve as boundaries between fields, they were to reduce wind erosion, protect young crops and control the snowdrift. Nowadays, shelterbelts are highly regarded for their cultural and ecological values. Windbreaks provide protection from the elements of wildlife and act as refuges for native plant and wildlife species. Furthermore, they are corridors for dispersion of plants and animals.

Due to their high societal, as well as their natural values, the Ministry of Agriculture subsidizes windbreaks in Denmark. According to the regulations, subsidised windbreaks need to contain no less than 75 % of deciduous trees or bushes; they must be positioned in 1 to 7 rows, they are required to be up to 10 meters wide, and they should be kept for at least 15 years. Law does not protect, however, older windbreaks or those established without a subsidy. From an agricultural point of view, the importance of windbreaks has diminished in many parts of Denmark. Due to the intensification and mechanisation of the agricultural sector, numerous windbreaks have been removed to increase field sizes. The spacing of windbreaks as well as their physical constitution and connectivity, however, still maintain an important function for the wildlife that is unable to exist elsewhere in the agricultural landscapes.

In order to make an inventory of windbreaks in a larger area, we examined the usefulness of visual interpretation of orthophotos in scale of 1:25,000. The outcome of this study showed, that it was meaningful to use the orthophotos as background information when detecting windbreaks. However, the visual classification of the hedgerows was time consuming. Furthermore, the physical parameters such as the width and height of the hedgerows could not be gathered by such a procedure. Therefore, we started the development of a method for automatic detection of windbreaks. The data was collected via an airborne laser scanner.

The preliminary analysis indicates that both the signal strength and the height information are useful for detecting hedgerows. It also shows that it is possible to improve the orthophoto based visual interpretation and classification of hedgerows, if the laser signal is used.

5.2 Materials and methods

Laser data

The laser scanner used was an ALTM 1210 from the Canadian company, Optech (<http://www.optech.on.ca>). The wavelength of the instrument was 1064 nm and the repetition rate was at 10.000 Hz. When flying at an altitude of 850-meters, the resulting point density was 1 pr. 6 m². The digital terrain model produced had accuracy in the vertical direction (z) at a range of between 3 and 6 cm, whereas in the horizontal direction, the accuracy was better than 20 cm (RMS). The laser, simultaneously, sends out two pulses (first/last), which enables the detection of the trees as well as the ground beneath them in a single pass. Thereby, it is possible to distinguish between vegetation cover and the terrain. The data collected with the laser hold two sorts of information: the elevation of the surface and the intensity of the reflected laser signal. Through the use of this information, combined with vector and raster based GIS analyses, windbreaks were localized.

Orthophotos

The orthophotos that were used were taken in the summer of 1999 in the scale of 1:25.000. The pixel resolution was 40 cm and pictures were in 24-bit RGB colour (<http://www.kampsax-gis.dk/default.asp?ID=216>) (Fig. 5.1).



Figure 5.1. Orthophoto of the test area located in the vicinity of Research Centre Foulum, DK.

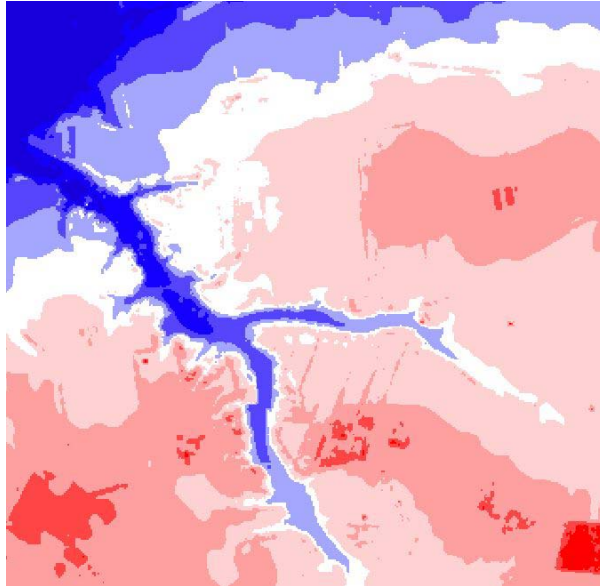


Figure 5.2. The resulting signal from the first laser pulse, Z1.

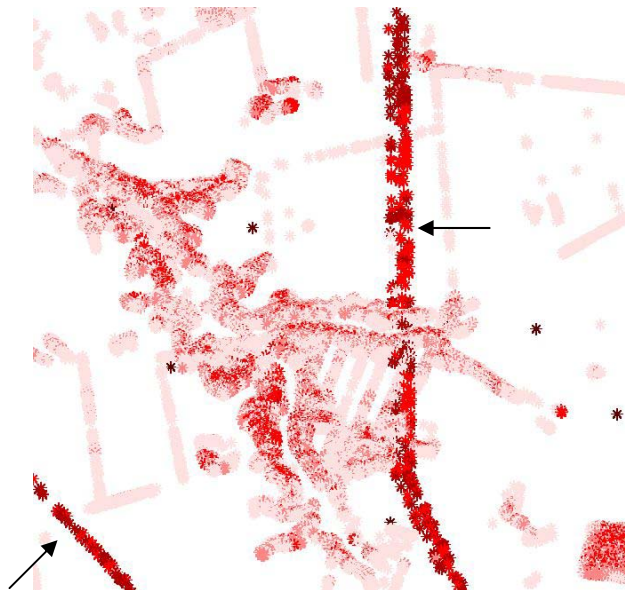


Figure 5.3. Height difference between first laser pulse, Z1 and second, Z2. Dark red "fuzzy" lines indicated with black arrows are high-voltage lines passing through the area.

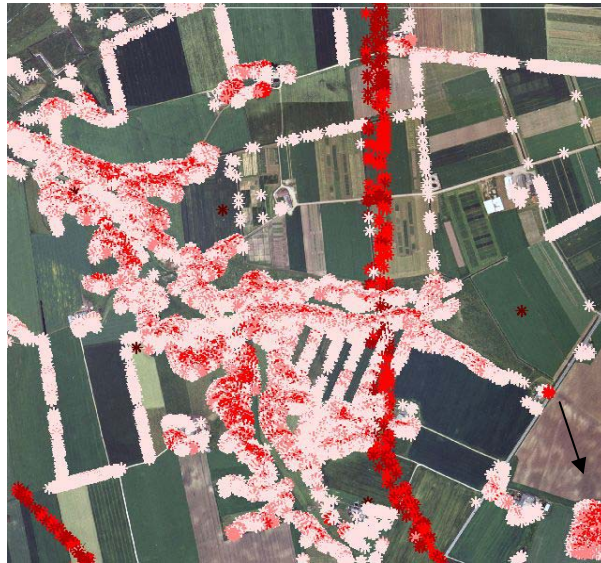


Figure 5.4. Figure 3 super-imposed upon an orthophoto. The “fuzzy” reddish/white areas are woody areas along permanent grassland, whereas the reddish indicated with a black arrow is a Christmas tree planting.



Figure 5.5. Signal strength –the difference between the initial signal and the reflected one. The denser the canopy, the weaker the reflected signal will be. The brighter the colours are the denser canopies.

In order to distinguish a windbreak from the surrounding fields and also to avoid “forested areas” from being included as windbreaks, several criteria were set. The first was that the Z_{diff} being the height difference between the first and second pulse should be > 6 meters within a 3 meter buffer zone (Fig. 5.6).

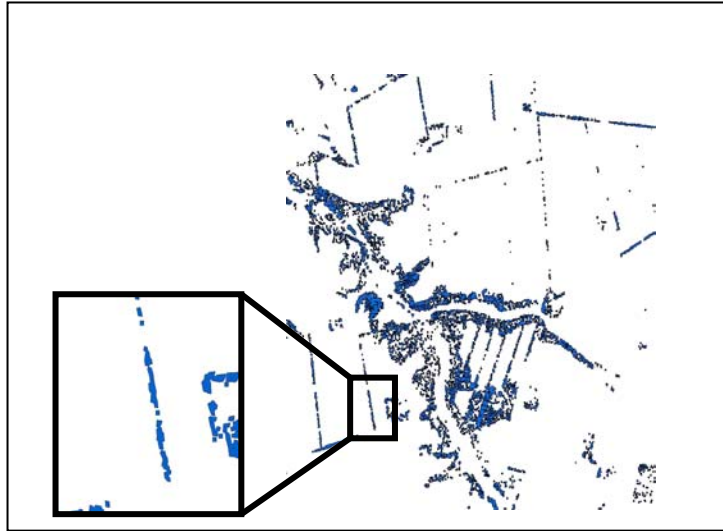


Figure 6. Height difference as a criteria to distinguish windbreaks from the surrounding fields.

The second criteria concerned with the strength of the signal. A signal value < 20 was chosen and again with a buffer of 3 meters (Fig. 5.7).



Figure 7. Signal value as a criteria to distinguish windbreaks from the surrounding fields.

A processing of the formed polygons was conducted on the basis that polygons should be longer rather than being wider. Polygons narrower than 0.5 meters and wider than 2.0 metres were excluded. Donuts were rejected. This meant

that the polygon marked B would be included, whereas A would be excluded (Fig. 5.8).

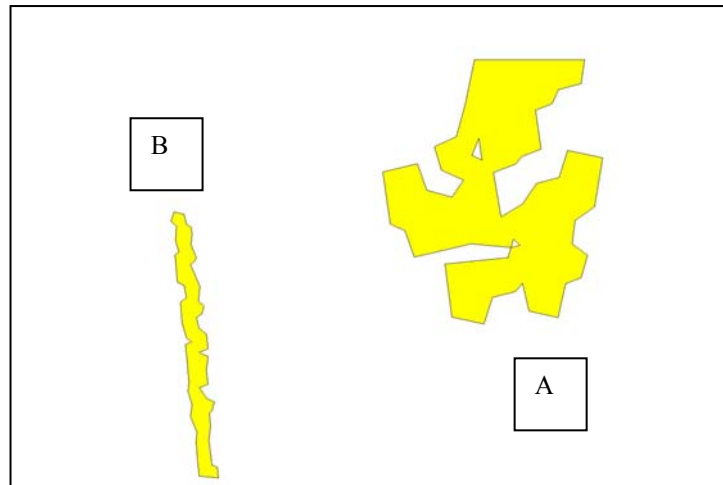


Figure 5.8. Processing of the formed polygons was based on shape.

Finally, a windbreak should have a minimum size. In our study a minimum area of 150 m² was chosen. To delineate the windbreak from the surrounding field we used the point density outside the windbreak polygons. This was arbitrarily selected so that the outside area was < windbreak polygon/4 (Fig. 5.9).

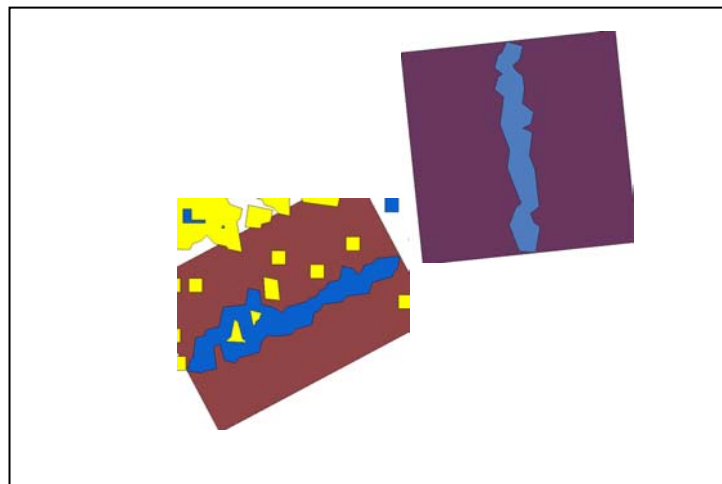


Figure 9. Point density outside the windbreak polygons was used to delineate the windbreak from the surrounding field.

When using the above stated criteria we could detect the windbreaks as indicated by a purple colour on Figure 5.10.

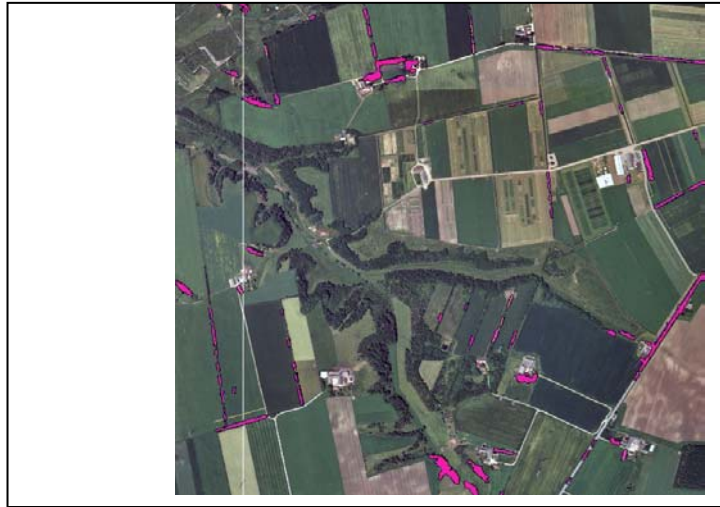


Figure 5.10. The detected windbreaks (purple).

The method, however, has to be further refined since inspection on location showed that undetected windbreaks remained (Fig. 5.11).



Figure 5.11. Undetected windbreaks (yellow).

5.3 Conclusion

There seems to be a possibility of using data obtained by laser scanning in an automatic detection of windbreaks. However, some of the criteria used may need refinements. For instance, where the windbreaks were kept very slim by trimming/cutting on both of its sides, like hedges surrounding a garden, the criteria of a minimum size of 150 m² was too restrictive. Another problem that was observed was with the leaps/holes in a windbreak. For example, dead trees were removed without new ones being planted.

6 General conclusions and recommendations

In Europe, including Nordic and Baltic countries, agricultural management and land use changes rapidly, and at the same time, regulatory measures (e.g. national applications as environmental schemes of the regulation EC 2078/92 for sustainable agriculture) include requirements for placement, width and management of agricultural field boundaries. We conclude that such measures and schemes should, along with the buffering function to protect waterways, target the biodiversity value of these major semi-natural habitat types in agricultural landscapes.

Regional variation of vegetation composition seems to be connected into typical farming type of certain region. Continuous arable farming of mainly annual crops is least beneficial (or even, harmful) to species diversity in boundaries of agricultural fields. Excess or careless use of fertilizers and herbicides results in loading of the boundaries, and in drastic decline of their biodiversity value. Most boundaries in conventional agricultural land still have impoverished plant communities infested with most serious perennial weeds. For example, before the 1st agro-environmental scheme (1995-1999) prohibited the practice in Finland, spraying of boundaries with cereal herbicides was allowed, even recommended. As a result, couch grass, one of the most serious cereal weeds, was selected for and given an advantage over annual dicotyledonous flowers.

Organic farming results in higher species diversity in the boundaries, compared to conventional farming. This result is consistent in our, as well as in previously published studies. Also, the biotic communities in organic margins are markedly dissimilar to the communities in the conventional field margins. The dominant plants are not the weeds of nutrient rich sites as in conventional boundaries, and the abundance of flowers supports high insect diversity.

Changes in vegetation composition are slow, and it may take a decade or more before results of good field margin management are visible. All measures to reduce nutrients from the boundaries are beneficial for both biodiversity and protection of waterways.

Specific conclusions and recommendations:

- 1) In the Nordic conditions, typical field boundaries are grassy banks in between field parcels or between a field and some other land use type.
- 2) These serve as ecotones (ecological transition zones) for organisms and communities of the adjacent ecosystems. At the same time, these are specific semi-natural habitat types supporting characteristic flora and fauna of their own.
- 3) Boundaries in between field and waterways serve in buffering ('buffer zones') surface waters from nutrient loading. Good buffering ability of a

boundary depends on being wide enough and having a dense vegetation cover.

- 4) Recommended width for a field boundary is 5 m. Increase in width from the currently most abundant narrow types effectively improves biodiversity value and value as a buffer strip. Increasing the width even further above the 5 m gives a decreasing return in terms of these services. (However, in specific cases wide buffer zones should be established instead of continuing the arable use: these were not dealt with in this project.)
- 5) Management of the boundaries for general biodiversity enhances beneficial insect diversity and abundance. This should result in improved pollination services and natural biocontrol of pests in agricultural crops.
- 6) Organic farming should be favored over conventional practice, in order to restore and enhance biological diversity in agricultural field margins.
- 7) Any further decline in quality and quantity of field margins in the Nordic countries should be prevented, in order to maintain the biodiversity value of the landscapes.
- 8) Indicators of landscape quality should include monitoring of the state of the field margin networks. Remote sensing by laser could be developed as a monitoring tool for this purpose.

References

- Aalto, V. 1999.** Luomu- ja tavanomaisten pellonpientareiden kasviston monimuotoisuus ja kasvillisuuden rakenne. — MSc-thesis, Department of Ecology and Systematics, University of Helsinki. 37 p. (In Finnish).
- Aebischer, N. J., Blake, K. A. & Boatman, N. D. 1994.** Field margins as habitats for game. — In: **Boatman, N.D. (ed.)**. Field margins: Integrating agriculture and conservation. — BCPC Monograph 58, 95-104.
- Andreassen, H. P., Halle, S. & Anker, I.R. 1996.** Optimal width of movement corridors for root voles: Not too narrow and not too wide. — *Journal of Applied Ecology* 33, 63-70.
- Arrhenius, O. 1921.** Species and area. — *Journal of Ecology* 9, 95-99.
- Baines, M., Hambler, C., Johnson, P. J., MacDonald, D. W. & Smith, H. 1998.** The effects of arable field margin management on the abundance and species richness of Araneae (spiders). — *Ecography* 21, 74-86.
- Bäckman, J. P. C. & Tiainen, J. 2002.** Habitat quality of field boundaries in a farmland area of Finland for bumblebees (Hymenoptera: *Bombus* and *Psithyrus*). — *Agriculture, Ecosystems & Environment* 89, 53-68.
- Bennett, A. F. 1991.** Roads, roadsides and wildlife conservation: a review.— In: **Saunders, D. A. & Hobbs, R. J. (eds.)**. — *Nature Conservation 2: The Role of Corridors*. Surrey Beatty, Chipping Norton, Australia. pp. 99-117.
- Braak, C. J. F. ter & Šmilauer, P. 1998.** CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power (Ithaca, NY, USA), 352 pp.
- Daniels, R. B. & Gilliam, J. W. 1996.** Sediment and chemical load reduction by grass and riparian filters. — *Soil Science Society of American Journal* 60, 246-251.
- Dennis, P., Thomas, M. B. & Sotherton, N. W. 1994.** Structural features of field boundaries which influence the overwintering densities of beneficial arthropod predators. — *Journal of Applied Ecology* 31, 361-370.
- Dorp, D. van, Schippers, P. & Groenendaal, J. M. van 1997.** Migration rates of grassland plants along corridors in fragmented landscapes assessed with a cellular automation model. — *Landscape Ecology* 12, 39-50.
- Dover, J. W. 1996.** Factors affecting the distribution of satyrid butterflies on arable farmland. — *Journal of Applied Ecology* 33, 723-734.
- Dramstad, W. E. & Fry, G. 1995.** Foraging activity of bumblebees (*Bombus*) in relation to flower resources on arable land. — *Agriculture, Ecosystems & Environment* 53, 123-135.
- Dramstad, W. E. 1996a.** Do bumblebees (Hymenoptera: Apidae) really forage close to their nests? — *Journal of Insect Behavior* 9, 163-182.
- Dramstad, W. E. 1996b.** The landscape ecology of bumblebees; Importance of the spatial distribution of resources. — *Norges Landbrukshøgskole, Agricultural University of Norway. Doctor Scientiarum Theses 1996: 10.*
- Elfving, R. 1968.** Die Bienen Finnlands. — *Fauna Fennica* 21. Pp. 69. (In German).

- Ellenberg, H., Weber, H. E., Düll, R., Wirth, V., Werner, W. & Paulißen, D. 1991.** Zeigerwerte von Pflanzen in Mitteleuropa. — Scripta Geobotanica 18, 1-248. (In German).
- ESRI (1996).** ArcView 3.1 -computer software. — Environmental Systems Research Institute, Inc., Redlands, California.
- Forman, R. T. T. 1983.** Corridors in a landscape: Their ecological structure and function. — Ekologia-CSSR 2, 375-388.
- Forman, R. T. T. 1995.** Land Mosaics. The Ecology of Landscapes and Regions. — Cambridge University Press. Cambridge, pp. 54-58, 146-157 and 208-252.
- Forman, R. T. T. & Godron, M. 1986.** Landscape Ecology. — John Wiley, New York.
- Granlund, K., Rekolainen, S., Grönroos, J. Nikander, A. & Laine, Y. 2000.** Estimation of the impact of fertilization rate on nitrate leaching in Finland using a mathematical simulation model. — Agriculture, Ecosystems and Environment 80, 1-13.
- Haddad, N. M. 1999.** Corridor Use Predicted from Behaviors at Habitat Boundaries. — American Naturalist 153, 215-227.
- Hämet-Ahti, L., Suominen, J., Ulvinen, T. & Uotila, P. (eds.) 1998.** Retkeilykasvio. Luonnontieteellinen keskusmuseo, Kasvimuseo. 656 s. Helsinki. (In Finnish).
- Helenius, J. 1996.** Piennarkasvien monimuotoisuutta tulee suosia. — Koetoiminta ja Käytäntö 53: 25. Maaseudun tulevaisuuden liite 18.6.1996. (In Finnish).
- Henien, K. M. & Merriam, G. 1990.** The elements of connectivity where corridor quality is variable. — Landscape Ecology 4, 157-170.
- Holme, T. 1996.** Viljelymenetelmien vaikutus pellon ja pientareen kasviston monimuotoisuuteen. — MSc-thesis, Department of Limnology and Environmental Science, University of Helsinki. 54 p. (In Finnish).
- Huber, W. 1999.** Connect the dots-convert shapes to points. Quantitative Decisions. ArcView extension.
- Jaccard, P. 1908.** Nouvelles recherches sur la distribution florale. — Bulletin de la Société Vaudoise des Sciences Naturelles 44, 223-270.
- Jaccard, P. 1912.** The distribution of the flora in the alpine zone. — New Phytology 11, 37-50.
- Jenssen, P. D., Maehlum, T., Roseth, R., Braskerud, B., Syersen, N., Njos, A. & Krogstad, T. 1994.** The potential of natural ecosystem self-purifying measures for controlling nutrient inputs. — Marine Pollution Bulletin 29, 6-12.
- Kiss, J., Penksza, K., Toth, F. & Kadar, F. 1997.** Evaluation of fields and field margins in nature production capacity with special regard to plant protection. — Agriculture Ecosystems and Environment 63, 227-232.
- Kleijn, D. 1997.** Species richness and weed abundance in the vegetation of arable field boundaries. — PhD thesis. Wageningen Agricultural University, Wageningen. 177 pp.
- Knuth, P. 1898-1905.** Handbuch der Blütenbiologie I, II_{a, b} & III_{a, b}. — Engelman, Leipzig 2973 pp. (In German).

- Kromp, B. 1999.** Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. — *Agriculture, Ecosystems & Environment* 74, 187-228.
- Lagerlöf, J., Stark, J. & Svensson, B. 1992.** Margins of agricultural fields as habitats for pollinating insects. — *Agriculture, Ecosystems & Environment* 40, 117-124.
- Lowrance, R., Leonard, P. & Sheridan, J. M. 1985.** Managing riparian ecosystems to control nonpoint pollution. — *Journal of Soil and Water Conservation* 40, 87-91.
- Ma, M., Tarmi, S. & Helenius, J. 2002.** Revisited species-area relationship in a semi-natural habitat: floral richness in agricultural buffer zones. — *Agriculture, Ecosystems & Environment* 89, 137-148.
- MacArthur, R. H. & Wilson, E. O. 1967.** *The Theory of Island Biogeography*. — Princeton Monographs in Population Biology. Princeton University Press, Princeton NJ.
- MAF 1999.** Proposal for an Agri-Environmental Scheme for 2000-2006. — Työryhmämuistio MMM 1999: 13. Helsinki, Ministry of Agriculture and Forestry. 66+4 p. (In Finnish).
- Marrs, R. H. & Frost, A. J. 1997.** A microcosm approach to the detection of the effects of herbicide spray drift in plant communities. — *Journal of Environmental Management* 50, 369-388.
- Marshall, E.J.P. (ed.) 2002.** The Ecology of Field Margins in the European Farming Systems. *Agriculture, Ecosystems & Environment* 89 (1-2), 148 p.
- Mazzoleni S., French D.D. & Miles J. 1991.** A comparative study of classification and ordination methods on successional data. — *COENOSIS* 6, 91-101.
- Merriam, G. & Lanoue, A. 1990.** Corridor use by small mammals: field measurement for three experimental types of *Peromyscus leucopus*. — *Landscape Ecology* 4, 123-131.
- Oksanen, J. 1981.** Reindeer lichen (Cladina) vegetation of rock outcrops on a coast-inland transect in South Finland. — *Annales Botanici Fennici* 18, 133-154.
- Peterjohn, W. T. & Correll, D. L. 1984.** Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. — *Ecology* 65, 1466-1475.
- Preston, F. W. 1962.** The canonical distribution of commonness and rarity. Parts I-II. — I: *Ecology* 43, 185-215, II: *Ecology* 43, 410-432.
- Raatikainen, M. 1991.** Rikkakasvikuvasto. — Kasvinsuojeluseuran julkaisuja No. 82. 136 s. Vesanpaino OY. Helsinki. (In Finnish)
- Riebesell, J. F. 1982.** Arctic-Alpine plants on mountaintops: agreement with island biogeography theory. — *The American Naturalist* 119, 657-674.
- Snoo, G. R. de 1995.** Unsprayed field margins: implications for environment, biodiversity and agricultural practice. The Dutch Field Margin Project in the Haarlemmermeerpolder. — PhD Thesis Rijksuniversiteit Leiden. Ponsen & Looijen BV, Wageningen, 205 pp.

- Snoo, G. R. de, Poll, R. J. van der & Bertels, J. 1998.** Butterflies in sprayed and unsprayed field margins. — *Journal of Applied Entomology* 122, 157-161.
- Sotherton, N. W. 1984.** The distribution and abundance of predatory arthropods overwintering on farmland. — *Annals of Applied Biology* 105, 423-429.
- Tarmi, S. & Helenius, J. 2002.** Maatalouden ympäristöohjelman mukaisten piennarten ja suojakaistojen toteutuminen sekä niiden kasviyhteisöjen monimuotoisuus. — Helsingin Yliopisto, Soveltavan biologian laitos, Julkaisuja 9. 35 s. + 18 liites.
- Tarmi, S., Tuuri, H. & Helenius, J. 2002.** Plant communities of field boundaries in Finnish farmland. — *Agricultural and Food Science in Finland* 11, 121-135.
- Teräs, I. 1983.** Estimation of bumblebee densities (*Bombus*: Hymenoptera, Apidae). — *Acta Entomologica Fennica* 42, 103-113.
- Teräs, I. 1985.** Food plants and flower visits of bumblebees (*Bombus*: Hymenoptera, Apidae) in Southern Finland — *Acta Zoologica Fennica*. No 179, PhD thesis.
- Tilman, D. 1987.** Secondary succession and the pattern of plant dominance along experimental nitrogen gradient. — *Ecological Monographs* 57, 189-214.
- Tsiouris, S. & Marshall, E. J. P. 1998.** Observations on patterns of granular fertilizer deposition beside hedges and its likely effects on the botanical composition of field margins. — *Annals of Applied Biology* 132, 115-127.
- Wedin, D. & Tilman, D. 1990.** Species effects on nitrogen cycling: a test with perennial grasses. — *Oecologia* 84, 433-441.
- Yates, P. & Sheridan, J. M. 1983.** Estimating the effectiveness of vegetated flood-plains/wetlands as nitrate-nitrite and orthophosphorus filters. — *Agriculture, Ecosystems & Environment* 9, 303-31.
- Zhou, Y. M. 2000.** Bearing & distance extension. — University of South Carolina. ArcView extension.

Appendix: Project's publication list

Note:

Papers with 100% contribution from the project funding.

*Papers over 50% contribution.

**Papers 15% - 50% contribution.

- Aalto, V., Bäckman, J. P. C. & Helenius, J.** 2003. Floral species diversity in organic and conventional agricultural field boundaries. — (this issue)
- * **Bäckman, J. P. C., Aalto, V., Hyvönen, T., Pitkänen, M.** 1999. Ökar ekoodlingen biodiversiteten i ett vårsädesfält? — *Forskningsnytt om økologisk landbruk i Norden*. 2, 12-13.
- * **Bäckman, J. P. C., Helenius, J., Maohua, M., Tarmi, S.** 1999. Mitkä tekijät vaikuttavat lajien esiintymiseen peltoympäristön pientareilla ja suojakaistoilla? — *Agro-Food '99*, Tampere 2.-4.2. Poster abstract, P26 (ISBN 951-96301-2-0).
- ** **Bäckman, J. P. C. & Tiainen, J.** 2002. Habitat quality of Finnish field margins in a farmland area for bumblebees (Hymenoptera: *Bombus* and *Psithyrus*). — *Agriculture, Ecosystems & Environment* 89, 53-68.
- ** **Helenius, J.** 1996. Piennarkasvien monimuotoisuutta tulee suosia. — *Koetoiminta ja käytäntö* 53: 25. Maaseudun tulevaisuuden liite 18.6.1996.
- ** **Helenius, J.** 1997. Creating ecologically sustainable agricultural landscapes. — In: *S. E. Olesen* (ed.), *Alternative use of agricultural land*, Proc. NJF- (Nordisk Jordbrukforskarnas Förbund) Seminar 270, 9-10 June, Foulum, Denmark. SP report 18: 43-48. (Danish Institute of Agricultural Sciences) (Invited Keynote Paper).
- ** **Helenius, J.** 1998. Suojakaistat jo useimmilla tiloilla. — *Helsingin Sanomat*, Mielipide 5.9.
- ** **Helenius, J.** 1998. Ympäristötuki ja biologinen monimuotoisuus. — *Agro-Food '98*, Tampere 3.-5.2. Poster abstract, E50 (ISBN 951-9485-12-0).
- ** **Helenius, J.** 1999. Kasvintuotannon ja biologisen monimuotoisuuden positiivinen vuorosuhde. — In: *J. Hiedanpää* (ed.), *Lehmiä ja lintuja - Luonnon monimuotoisuuden hoito maataloudessa*. Sykesarja C3, pp. 23-30. Turun yliopisto / Satakunnan ympäristöntutkimuskeskus.
- * **Hyvönen, T., Aalto, V., Bäckman, J. P. C., Pitkänen, M.** 1999. Luomupelloilla on runsaasti elämää. — *Maaseudun Tulevaisuus; Koetoiminta ja Käytäntö*, 56(1), 3.
- Ma, M., Tarmi, S. & Helenius, J.** 2002. Revisited species-area relationship in a semi-natural habitat: floral richness in agricultural buffer zones. — *Agriculture, Ecosystems & Environment* 89, 137-148
- Ma, M., Tarmi, S., Luoto, M. & Helenius, J.** 1999. A case study of a GIS-based model: impact of landscape structure of buffer zones on floral diversity in a watershed. — *EurEco '99 Conference, Workshop The ecology of field margins in European farming systems*, Halkidiki, Crece 19 Sept. 1999. Poster abstract.

- Ma, M., Luoto, M., Tarmi, S. & J. Helenius** 2003. The impact of landscape structure of field boundary on floral richness in a semi-natural habitat. — (this issue)
- * **Partanen, H., Turtola, A., Heikkilä, T. & Helenius, J.** (eds.) 1997. Viljelyalueiden luonto. 23 s. — Maa- ja metsätalousministeriö, Helsinki.
- * **Tarmi, S.** 1998. Pientareiden ja suojakaistojen kasvilajisto - näkökulmia kasvinsuojelun ja lajimonimuotoisuuden kannalta. — Kasvinsuojelulehti. 2, 52-54.
- * **Tarmi, S.** 1999. Suojakaistojen perustaminen lisää kasvilajistoa. — Koetoiminta ja käytäntö 56, 8. Maaseudun tulevaisuuden liite 17.8.1999.
- * **Tarmi, S. & Helenius, J.** 1998. Miten suojakaistoja tulisi hoitaa. — In: *Markkula, I.* (Ed.), Ajankohtaisia kasvinsuojeluohjeita. Kasvinsuojeluseuran julkaisuja 91, pp. 24-26.
- * **Tarmi, S. & Helenius, J.** 1998. Botanical diversity in agricultural buffer zones. — INTECOL, VII International Congress of Ecology, Florence, Italy 19-25 July.
- * **Tarmi, S. & Helenius, J.** 2002. Maatalouden ympäristöohjelman mukaisten piennarten ja suojakaistojen toteutuminen sekä niiden kasviyhteisöjen monimuotoisuus. — Helsingin Yliopisto, Soveltavan biologian laitos, Julkaisuja 9. 35 s. + 18 liites.
- * **Tarmi, S., Tuuri, H. & Helenius, J.** 2002. Plant communities of field boundaries in Finnish farmland. — *Agricultural and Food Science in Finland* 11: 121-135.
- * **Tarmi, S., Tuuri, H. & Helenius, J.** 1999. The vegetation types of field boundaries along watercourses in four different geographical areas in Finland. — Euroco '99 Conference, Workshop The ecology of field margins in European farming systems, Halkidiki, Greece 19 Sept. 1999. Poster abstract.
- * **Tarmi, S. & Helenius, J.** 2003. Flora and vegetation types in agricultural buffer zones in Finland. — (this issue).
- * **Tiainen, J., Helenius, J., Kurppa, S., Rekolainen, S., & Salonen, J.** 1999. Maatalousympäristön monimuotoisuus: alueellinen ja ajallinen vaihtelu ja merkitys viljelysysteemille. — Agro-Food '99, Tampere 2.-4.2. Poster abstract, (*) (ISBN 951-96301-2-0).