© 2012 Triveni Enterprises
Vikas Nagar, Lucknow, INDIA
editor@jeb.co.in
Full paper available on: www.jeb.co.in

J. Environ. Biol.
33, 565-572 (2012)
ISSN: 0254-8704
CODEN: JEBIDP

The wild flora biodiversity in pesticide free bufferzones along old hedgerows

Author Details

L.C. Andresen (*Corresponding author*)	Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen, Denmark Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Sciencepark 904, 1098 XH Amsterdam, Netherlands e-mail: l.c.andresen@uva.nl
J. Nothlev	Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen, Denmark
K. Kristensen	Department of Genetics and Biotechnology, University of Aarhus, Blichers Allé 20, DK-8830 Tjele, Denmark
S. Navntoft	Department of Agriculture and Ecology, University of Copenhagen, Thorvaldsensvej 40, DK-1871 Frederiksberg C, Denmark
I. Johnsen	Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen, Denmark

Publication Data

Paper received:
14 September 2010

Revised received:
17 February 2011

Re-revised received:
02 May 2011

Accepted:
25 May 2011

Abstract

The natural field margin ecotone from the field border and into a cropped field hosts a diversity of plant species. In conventional cropped fields, biodiversity suffers from fertilizer and pesticide application. In our study at Danish conventional spring-barley fields, we laid out bufferzones with no pesticide application spraying after sowing, with the widths: 24, 12, 6 and 4 m (and control) to the field edge hedgerow. Through one season: plant species number, biodiversity and evenness for each bufferzone at the distances: 18, 9, 5, 2 and 0 m from the hedgerow were significantly affected by distance to the hedge and by width of bufferzone. The bufferzones affected: species number (total of 92 weed species), species diversity (1.27 to 0.44) and species evenness index (0.63 to 0.87), and revealed that the bufferzone of 24 m gave the largest improvement of the field margin for plants. Decreasing the bufferzone widths provided smaller biodiversity and larger evenness of plants at distances larger than the buffer width: the distance at which diversity (Shannons) was reduced by half the difference between hedge- and field diversity was 1.2, 3.1, 6.7, 10.8 and 10.9 m in bufferwidth treatments of 0, 4, 6, 12 and 24 m; likewise, the half-way distance for Smiths and Wilsons evenness index was 1.2, 1.7, 5.4, 14.0 and 30.2 m in the bufferwidth treatments of 0, 4, 6, 12 and 24 m. Based on modelled diversity and evenness indexes a positive effect of buffer was evident from 6 m bufferzone. The average diversity over the distances from 0 to 18 m was 0.66, 0.75, 0.98, 1.14 and 1.11 in bufferwidth treatments of 0, 4, 6, 12 and 24 m and the average evenness over the distances from 0 to 18 m was 0.82, 0.80, 0.74, 0.66 and 0.63, in bufferwidth treatments of 0, 4, 6, 12 and 24 m. Furthermore, the accumulated number of species revealed that a bufferzone width of at least 6 m was needed to significantly increase the species richness at all distances between 2 and 18 m. At 18 m distance, the accumulated number of species was 37.1, 39.7, 41.2, 42.4 and 42.7 in bufferwidth treatments of 0, 4, 6, 12 and 24 m.

Key words

Bufferstrips, Field margin management, Hedge, Herbicide, Insecticide

Introduction

The importance of high biodiversity in agricultural fields has become widely recognized throughout Europe and with the desire to increase species biodiversity in cropped fields, constraining pesticide and fertilizer use should be included as management precautions near vulnerable, and high biodiversity neighbouring habitats. Recently, a Europe-wide synthesis highlighted the negative effects of intensified conventional agriculture on ecology in the arable land Stoate *et al.* (2009), and the UK countrywide extensive management practices of the field margins through the last two decades, have proved valuable improvements for biodiversity and resource provision for farmland birds (Douglas *et al.,* 2009; Vickery *et al.,* 2009; Woodcock *et al.,* 2009).

The field margin constitutes a more or less wide zone along the edge surrounding the agricultural field, and includes any strip already present along this edge and the semi-natural habitat associated with the field boundary including hedge, fence, wall, ditch *etc*. (Marshall and Moonen, 2002). The natural field margin ecotone from any hedgerow into the cropped field (Willi *et al.,* 2005; Marshall, 1989; Boutin *et al.,* 2002; Wilson and Aebischer, 1995), harbour more plant species of conservation value when the hedgerow is natural than planted (Boutin *et al.,* 2002; Freemark *et al.,* 2002) and when the field margin is left fallow, the natural regeneration of floral diversity directly stimulates arthropod diversity, which again serve as food for farmland birds, *e.g.* grey and red-legged partridge (Vickery *et al.*, 2009), thus increasing the biodiversity.

Through the nineties in England, set-aside and fallow field practices with naturally regenerating vegetation, increased plant biodiversity with dominance of broad-leaved grassland species (Firbank *et al.,* 2003). Contrary, removal of non-cropped areas and field boundaries and intensification of agricultural practice has decreased biodiversity of the arable land (Stoate *et al.,* 2009). Furthermore, the loss of habitat heterogeneity and connectivity has been the main reason for the observed down regulation of biodiversity in the arable land (Benton *et al.,* 2003; Freemark *et al.,* 2002). Careful implementation of habitat connections such as green lanes (United States Department of Agriculture, 2000) and maintenance of field margins with modified management can promote biodiversity in the fields (Marshall and Moonen, 2002; Walker *et al.*, 2006).

In a Dutch investigation of 2-3 meters wide pesticide free field margins, plant cover emerged either naturally from the soil seed bank or was established by sowing grass. In both cases the plant species richness more than doubled and dragonfly and butterfly species richness increased during the following four years (Musters *et al.*, 2009). Plant species richness in adjacent ditch banks also increased through the five years after establishment (Musters *et al.,* 2009). The species richness of dicotyledons was significantly larger on mown grass ditch banks bordering 3-6 m unsprayed field margins (no herbicides and insecticides) than on banks along sprayed field edges (De Snoo and van der Poll,1999). Furthermore, plant species richness was higher on ditch banks of organic compared to conventional farms (Manhoudt *et al.,* 2007).

In this study the impact on floral diversity of pesticide unsprayed bufferzones with different widths bordering conventionally cultivated fields was studied at increasing distance from old hedges.

Materials and Methods

Bufferzones at the field site: The field site was located at Gjorslev estate (Gjorslev vej 20, Holtug, 4660 Store Heddinge, Denmark, coordinates (wgs84): 55°21'14.34"N, 12°22'51.93"E). The estate covered 1.668 ha of which 753 ha was forest. Four large spring barley fields with long uniform hedgerows with the same type of hedges along one side with the same geographical direction (north-south hedges) and with a hedge bottom of herbs were selected for the study.

Data was collected at the western side of the hedgerows of all fields. Along each hedge, five treatments consisting of areas treated with neither fertilizer nor pesticides after sowing in 2008 were called bufferzones with the widths: 0, 4, 6, 12 or 24 m. These were arranged in chronological order for easier and more reliable management. The bufferzones (treatments) were referred to as buffer 0 (0 m buffer), buffer 4 (4 m buffer) etc.

The four fields (I, II, III and IV) were treated identically with respect to the cultivation procedures, including fertilizing, sowing and pesticide application. The crop (spring Barley cv. Henley) was sown late in April due to wet soils. All fields received three pesticide applications in late May, late June and early July and the bufferzones did not receive pesticide application. The pesticide dosages were normal for conventional farming according to Danish Agricultural Advisory Service (2011). The crop was harvested in mid August. All plants in the field, the hedge bottom and the woody hedgerow were determined to species or, if only at cotyledon developmental stage, to genus.

Vegetation recording and calculation of diversity and evenness indexes: The dimensions of the hedge were measured once with total height, height of bank and total width of the hedges. Furthermore, plant species composition was assessed for all woody species with 1 m resolution on 7th May, 2008.

Starting May 14th (Time one, data not shown) and June 24th (Time 2), vegetation was analysed after the experimental fields were sprayed with herbicides. At the distances 0, 2, 5, 9 and 18 m from the hedge, 10 vegetation frames (40 by 50 cm, divided into 20 sub-squares) were used for plant count by species or by genus, according to Frederiksen et al. (2006). The plant stage, being either flowering or generative, was noted. Additionally, at about 40 m distance from the hedge, 12 vegetation frames were analyzed as control plots.

Shannon's biodiversity index (H) and evenness index *(*E) was calculated for each frame by the method of Magurran.A.E. (2004). At Time 1, spring barley plants were counted in all vegetation frames in 4 of the 20 sub-squares. In Time 1 and 2, the growth stage of spring barley was assessed according to the BBCH scale Tottman and Broad (1987), furthermore the height and percentage cover of spring barley was recorded, in managed and non-managed spring barley for each of the four fields. Data from Time 1 is not presented, as the phenological development only allowed for identification to genus level for most plant individuals.

Data analysis: The number of counted plants at each sampling time was analyzed using generalised linear mixed models. The analyses were carried out for groups of plant species (all species, type (monocot or dicot) and family) at sampling Time 2. The fixed effects in the model depended on the source of the data: hedge or field. For data from the hedge the model included the fixed effect of field and buffer width. For data from the field the model included the fixed effect of field, buffer width, distance to hedge and the interaction between buffer width and distance. The percentage of flowering plants at sampling Time 2 were analyzed using a generalised linear mixed model including the effect of field, buffer width, distance to hedge and the interaction between buffer width and distance as fixed effects.

The number of species (after log-transformation), Shannon's biodiversity index and Smith and Wilsons evenness index were analysed with a linear mixed model with: distance to hedge, width of bufferzone and the interaction between distance to hedge and width of bufferzone. The model also included the effect of sampling time and interactions with sampling time as fixed effects.

To evaluate the distance at which Shannon's index and Smith and Wilsons index was changed to half of the difference between its value in the hedge and its value in "the middle" of the field the logistic function was applied. The model included a common effect for all bufferzones describing the decrease per unit (log distance) and an individual effect for each bufferzone describing the halving distances.

The linear mixed models for data from the field included random effects in order to take into account the structure of the design. For data from the hedge a block design (with repeated measurements in each plot) was applied and for data from the field or field and hedge a split-block design was applied. For analyses involving both sampling times, a repeated measurement design was applied following McCulloch and Searle (2001) and West *et al.* (2007). The analyses were carried out using the procedures MIXED, GLIMMIX and NLMIXED of SAS (2008).

Results and Discussion

The number of weed plants decreased with increasing distance to the hedgerow (Fig. 1,2 and Table 1) and increasing width of the bufferzone increased the number of weeds and flowering percentage of the weeds. For the total number of weed plants and for monocots, the effects of field, distance to the hedgerow (termed 'distance'), bufferzone width (termed 'buffer') and the interaction between distance and buffer, were significant (Table 1).

Table 1: Abundance of the wild flora. Monocots are all individuals of monocotyledonous species. Dicots are all individuals of dicotyledonous species or by family

Order	Family	Test results: F (degrees of freedom) P[1]			
		Field[2]	**Distance[3]**	**Buffer[4]**	**Buffer × distance[5]**
All weeds	All weeds	30.14(3,13)***	9.86(4,14)***	14.48(4,62)***	3.61(16,62)***
Monocots	All (Poaceae)	21.31(3,14)***	5.52(4,11)*	5.05(4,12)*	1.99(16,52)*
Dicots	All	13.36(3,12)***	6.77(4,11)**	8.08(4,16)***	5.16(16,43)***
	Apiaceae	51.15(3,16)***	4.49(4,7)*	0.76(4,8) ns	6.85(16,52)***
	Asteraceae	4.57(3,11)*	15.54(4,15)***	3.08(4,55)*	2.63(16,47)**
	Brassicaceae	2.83(3.20) ns	2.45(4,13) ns	3.49(4,16)*	3.90(16,51)***
	Chenopodiaceae	20.66(3,9)***	3.26(4,7)ns	7.20(4,11)**	4.99(16,55)***
	Lamiaceae	3.83(3,16)*	7.93(4,13)**	2.88(4,26)*	1.55(16,51) ns
	Scrophulariaceae	0.67(3,14) ns	3.07(4,11) ns	0.86(4,19) ns	3.63(16,47)***
	Violaceae	9.94(3,16)***	0.91(4,11) ns	2.06(4,11) ns	3.33(16,45)***

[1]The F-values (based on Type III tests) are sown with degrees of freedom in brackets and P values indicated as: 'ns' is not significant, * is P < 0.05, ** is P < 0.01, *** is P < 0.001. [2]Effect of field (four fields were included in the experiment). [3]Effect of distance from field edge (sampling was carried out 2, 5, 9 and 18 m from the field edge). [4]Effect of buffer width (0, 4, 6, 12 and 24 m). [5]Effect of the combination of distance and buffer width

Table - 2: Number of species, Shannon's biodiversity index (H), Smith and Wilsons evenness index (E).

	Number of species	**H**	**E**
Bufferzone-'Centre' of field	29.17 (1,75) ***	14.71 (1,75)***	7.10 (1,75)**
Time	3.27 (1,78) ns	4.69 (1,78)*	0.19 (1,78) ns
('Bufferzone'-'Centre' of field)´Time	1.23 (1,78) ns	0.95 (1,78) ns	1.73 (1,78) ns
In field margin			
Distance to hedge	33.89 (4,75) ***	29.15 (4,75) ***	8.90 (4,75) ***
Buffer zone	13.74 (4,75) ***	9.22 (4,75) ***	5.40 (4,75) ***
Distance´Buffer zone	3.22 (16,75) ***	2.69 (16,75) **	0.91 (16,75) ns
Distance´Time	1.29 (4,78) ns	2.77 (4,78) *	0.70 (4,78) ns
Buffer zone´Time	3.63 (4,78) **	3.74 (4,78) **	4.99 (4,78) **
Distance´Buffer zone´Time	1.73 (16,78) ns	2.02 (16,78) *	1.87 (16,78) *

The F-values (based on Type III tests) are shown with degrees of freedom in brackets and P values indicated as: 'ns' is not significant, * is P < 0.05, ** is P < 0.01, *** is P < 0.001

Fig. 1: Number of weeds for each of the families: *Apiaceae* (a), *Asteraceae* (b), *Brassicaceae* (c), *Chenopodiaceae* (d), *Lamiaceae* (e), *Poaceae* (f), *Scrophulariaceae* (g) and *Violaceae* (h). Within each bufferzone (width in m) figures with the same capital letter are not significantly different (P=0.05). Within each distance (m) figures with the same lower case letter are not significantly different (P=0.05). Non-treated plots are hatched from upper left to lower right, and plots treated with pesticides are hatched from lower left to upper right

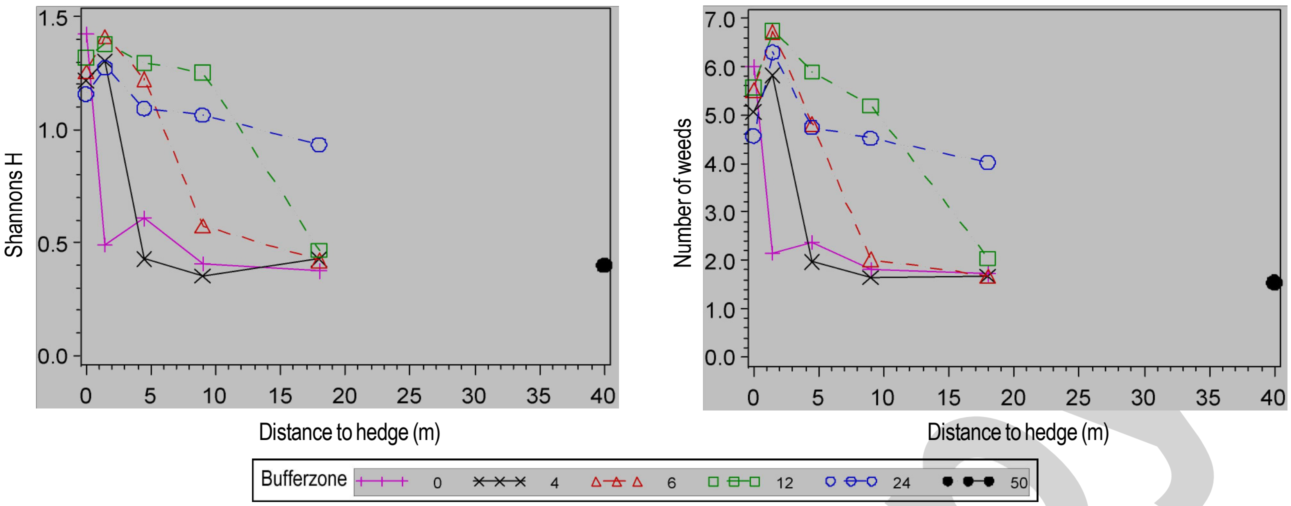

Fig. 2: (A) Shannon's biodiversity index (H) and (B) Number of weed species versus distance to hedge (m) for each bufferzone width (m) at sampling time 2.

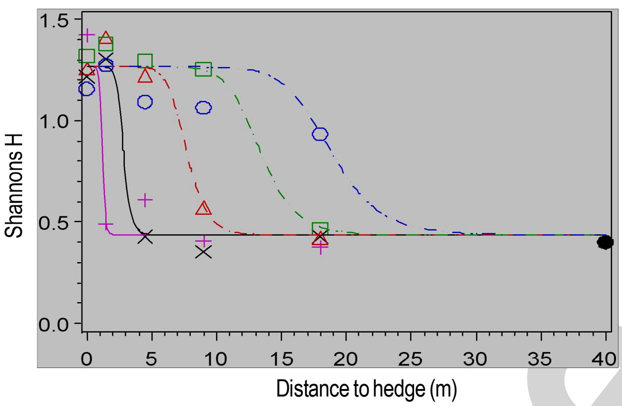

Fig. 3: Shannon's biodiversity index (H) against distance to hedge (m) for each bufferzone width (m). The fitted curves are based on the logistic model with common slope for all bufferzones using observations at distance 0-18 m and the control in 40 m for sampling time 2.

In surveys of weed abundance and seed banks in arable fields in S. England, the number of weed seedlings and number of species decreased as long as 4 m away from the hedgerow in conventionally managed fields. Beyond the 4 m distance to the hedge, the abundance was constant (Wilson and Aebischer, 1995). Furthermore, in accordance with our findings, plant abundance of *Viola arvensis* (*Violaceae*) did not decrease away from the hedge (Wilson and Aebischer, 1995). In parallel to Marshall (1989), we found that 21 species (59% of all species in the hedge-bottom) were limited to the hedge-bottom and absent from the field (*Achillea millefolium, Anisantha sterilis, Arabidopsis thaliana, Arrhenatherum elatius, Chaerophyllum temulum, Cirsium vulgare, Dactylis glomerata, Erodium cicutarium, Geum rivale, Glechoma hederacea, Heracleum sphondylium, Lamium album, Mercurialis perennis, Myosotis discolor, Plantago major, Poa trivialis, Senecio vulgaris, Sonchus oleraceus, Triticum, Rubus sect. Rubus, Rumex crispus*), and 19 species (37% of all species in the field) were limited to the field and absent the hedge-bottom (*Anchusa arvensis, Atriplex patula, Daucus carota, Euphorbia exigua, Euphorbia helioscopia, Galeopsis spp., Geranium pusillum, Lamium amplexicaule, Papaver rhoeas, Persicaria lapathifolia ssp. pallida, Persicaria maculosa, Silene noctiflora, Sinapis arvensis, Stellaria media, Tripleurospermum maritimum, Veronica persica, Veronica hederifolia, Viola tricolor, Urtica urens*).

Seven individual families were represented in more than 25% of the plots, and six of these showed a significant interaction between distance and buffer (Fig. 1 and Table 1). In *Asteraceae*, *Brassicaceae* and *Chenopodiaceae*, the interaction was caused by the specific effects of buffer at individual distances, *i.e.* a larger number of plants in the untreated plots than in the treated plots. The number of individual plants of species belonging to the families: *Apiaceae, Asteraceae, Lamiaceae* and *Poaceae* decreased significantly with distance to hedge, whereas no significant relation to hedge distance was found for plants in *Brassicaceae, Chenopodiaceae, Scrophulariaceae* and *Violaceae*.

At least 50% of the plots were carrying flowers, with regard to the total number of all individual plants, the number of dicots as well as the number of individuals of the family *Violaceae*. The flowering percentage of all plants (Fig. 5) was significantly related to buffer, distance and their interaction (P-values: buffer: 0.0035, distance: <0.0001, buffer*distance: 0.0001). The dicot flowers had significant effect of distance and the interaction between distance and buffer (P-value: buffer: 0.1716, distance: <0.001, buffer*distance: < 0.001). The *Violaceae* family showed a significant effect of the interaction between distance and buffer (P-value: buffer: 0.1051, distance: 0.1641 and buffer*distance: < 0.001, data not shown). For all three groups the interaction was mainly due to a larger percent of flowering plants in the untreated areas than in the treated areas.

Species number, species diversity as well as species evenness index revealed that a field margin bufferzone of 24 m gave the largest improvement in plant biodiversity. For monocots,

Table - 3: Estimated parameters of the logistic model for Shannon's biodiversity index at each sampling time separately. At the bottom the halving distances d_b in m, (and its 95% confidence intervals) at which Shannon's index has decreased by half the difference between its value form at the hedge bottom and in the fielsd for each bufferzone width. SE = Standard error of estimate. Halving distances followed by the same letter are not significantly different (*Pe'*0.05 using t-tests). The Greek letters refers to the fixed effect parameters

	Sampling time 1		Sampling time 2	
Parameter	**Estimate**	**SE**	**Estimate**	**SE**
Slope, b	2.02	1.50[1]	9.96	13.09[1]
Biodiversity, g_{field}	0.46	0.12	0.43	0.06
Biodiversity, g_{hedge}	1.12	0.09	1.27	0.04
Buffer effect, d_0	0.17	0.45	0.15	0.38
Buffer effect, d_4	1.13	0.52	1.03	0.80
Buffer effect, d_6	1.91	0.39	2.04	0.23
Buffer effect, d_{12}	2.38	0.31	2.59	0.34
Buffer effect, d_{24}	2.39	0.46	2.93	0.08
Estimated halving distances with 95% confidence limits				
d_0	1.2 a (0.4-3.4)		1.2 a (0.5-2.9)	
d_4	3.1 ab (0.9-10.5)		2.8 abc (0.4-18.7)	
d_6	6.7 ab (2.7-16.9)		7.7 bd (4.4-13.3)	
d_{12}	10.8 b (5.2-22.3)		13.4 cd (6.0-29.9)	
d_{24}	10.9 b (3.7-32.7)		18.8 c (15.6-22.6)	

[1)] The large uncertainty of the slope parameter is mainly caused by different profile of the index in the individual fields. However, the relative effect of buffer widths (as measured by d_i, a function of the distance at which effect were halved) were much more constant over the fields

these effects were not seen, as the herbicide mainly targeted dicots. The weed biodiversity gain from the buffer zone was relatively higher at the shorter distances from the hedge (0, 3 and 6 m) than at the longer distances (12 and 24). Furthermore, the relative rate of decrease in diversity diminished with larger buffer width. For the model based on the logistic function for Shannon's *H* (Fig. 3), the estimates (Shannon's *H* at the distance 0 (hedge) and 40 ("the middle of the field")) and the distances at which Shannon's *H* decreased by half the difference between its value in the hedge and in the field (the d parameters, Table 3), for bufferzone width 6 m was significantly different from the halving distance at both 0 and 24 m bufferzone, furthermore, the halving distance of the Shannon's biodiversity (H) decreased as the bufferzones became narrower.

As biodiversity decreased, evenness increased accordingly with increasing distance to the hedgerow. For the Smith & Wilson evenness index (E) (Fig. 4) there were significant effects of buffer, distance, and the interactions of buffer and time and buffer distance and time, with the inverse relation of highest evenness (40 m) consequently being the least diverse with lowest *H* (Fig. 3). During the growing season, plant biodiversity increased and evenness decreased with larger bufferzone widths at distances to the hedge larger than any given bufferzone (Table 2,3). Based on the modelled *H* and *E*, a positive plant biodiversity effect of bufferzone width was evident for 6 m and larger bufferzone widths. In the survey by Marshall (1989), the dicotyledonous species were dispersed with a logistically decreasing distribution pattern for the individual species away from the hedge. Here in our study, the overall biodiversity index (H) (which was comparable for all distances 0 to 18), fitted by the logistic model, also revealed this pattern and the halving distance of (H) for all species increased with increasing bufferzone width.

The use of herbicides significantly decreased the floral biodiversity, supporting what was found in a survey of 20 years of pesticide use on Danish fields (Andreasen *et al.,* 1996) and the overall ecological impacts from conventional farming throughout Europe (Stoate *et al.,* 2009). The effects of reduced dosages of herbicides and insecticides on conventional fields were found to increase wild flora density, wild flora flowering and wild flora species richness at quarter dosage and (more limited) at half dosage (eds. Esbjerg and Petersen, 2002). Likewise, at ditch banks with 3-6 m unsprayed field margins (no herbicides and insecticides) presence and abundance of plant species increased compared to control (De Snoo and van der Poll, 1999; Manhoudt *et al.,* 2007).

This experiment revealed effect on the wild flora of different bufferzone widths to hedges, when the farming practice at the main field was compared to these bufferzones (with reduced fertilizer use as well as no pesticide application). It is thus not possible in this study to distinguish between effects due to no pesticide application, reduced fertilization or a combination of the two. The observed effects on monocotyledonous species being insensitive to the applied herbicides may be due to the reduced fertilization and possibly natural selection for herbicide resistance.

The survey conducted was a one-season study of the effects of bufferzones along hedges. The conclusions concerning effects on species diversity, species richness and number of individuals in this study may differ after long-term absence of fertilization and pesticide application. In the short term, fertilization may increase biomass of weeds and crops (Andreasen *et al.,* 2006), but also decrease the number of weed species (Marshall and Moonen, 2002). Herbicide application will decrease biomass and species richness of the wild flora (Marshall and Moonen, 2002; Sonderskov *et al.* 2006; Kudsk and Streibig, 2003).

In conversion from conventional to organic farming a differentiation was found after three to four years in plant communities, with stress-tolerant plant species being more abundant in hedge bottom vegetation bordering organic farms and ruderal and nutrient demanding plant species being more abundant in hedge bottoms at conventional farms (Petersen *et al.* 2006). A comparison of vegetation in hedgerows bordering fields with or without pesticide application through 10-14 years, revealed more species (weed, ruderal and semi-natural) in hedges without pesticide drift (Aude *et al.,* 2003), and the species composition was more similar to semi-natural communities than for conventional hedges (Aude *et al.,* 2004). Countrywide in Denmark, species diversity of plants in Danish fields have increased through the last 15 years, due to new management practices (Andreasen and Stryhn, 2008). Hence, in accordance

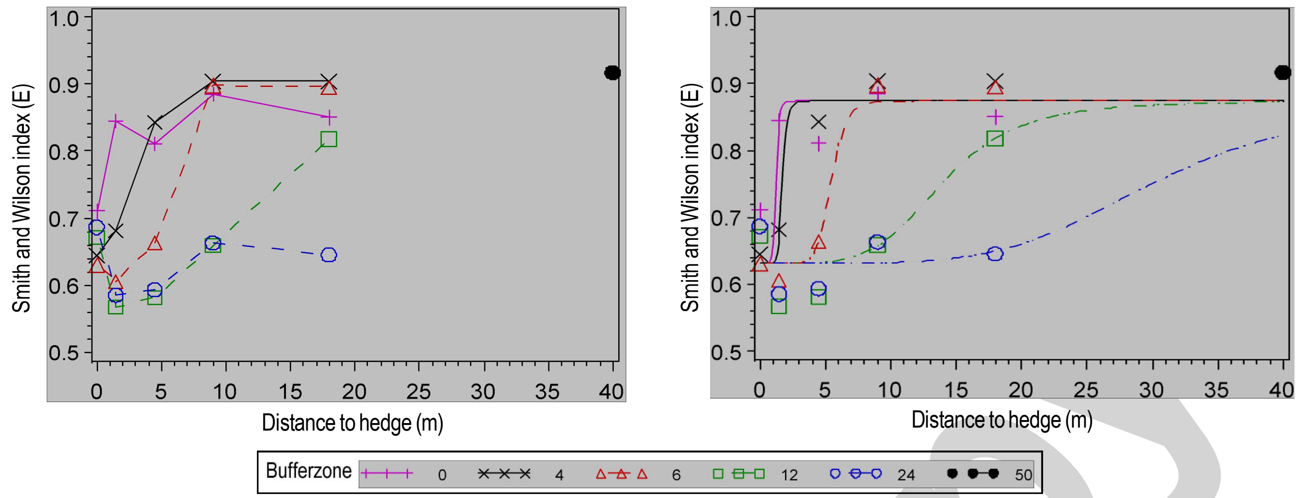

Fig. 4: (A) Evenness index (E) against distance to hedge (m) for each bufferzone width (m), (B) Model of Smith and Wilsons index (E) against distance to hedge (m) for each bufferzone width (m). The fitted curves are based on the logistic model using observations at distance 0-18 m for sampling time 2

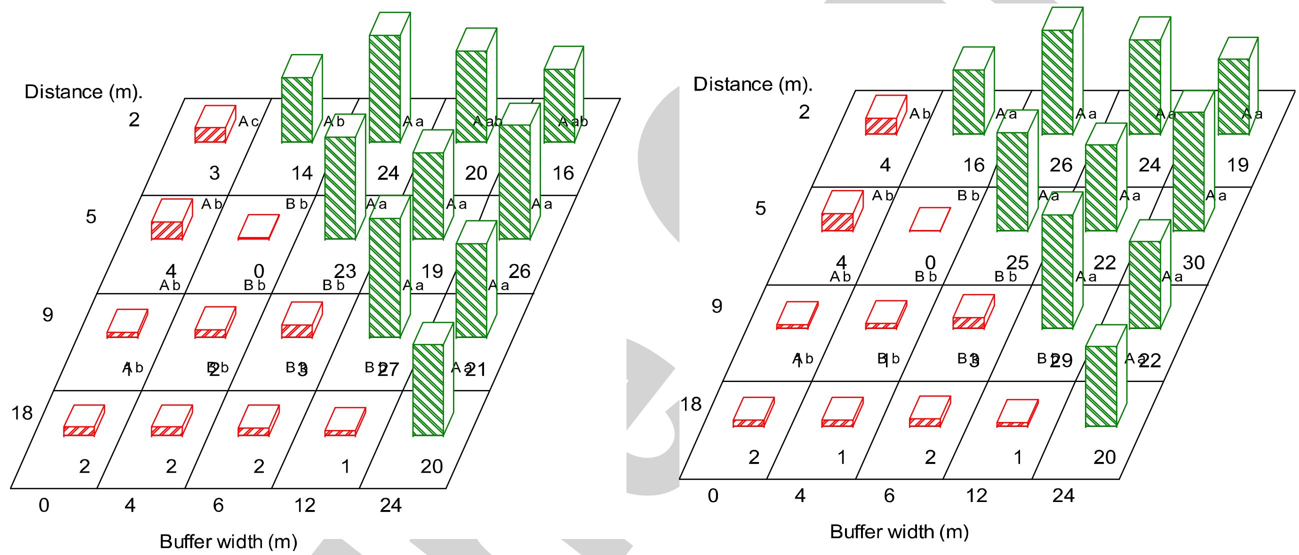

Fig. 5: Flowering percentage for all species (a) and dicotyledoneous species (b), for each combination of buffer width (m) and distance from hedge (m). Non-treated plots are hatched from upper left to lower right, and plots treated with pesticides are hatched from lower left to upper right

with impacts of conversion to organic farming throughout Europe, plant biodiversity in the arable land benefits from abolishment of fertilizer and pesticide use (Stoate *et al.*, 2009; Hole *et al.,* 2005, Bengtsson *et al.*, 2005).

Long-term application of bufferzones along hedges may provide new habitats for plant and arthropod species, due to direct species interactions and to structural diversity and landscape heterogeneity (Maudsley, 2000; Rundlöf et al., 2008; Benton *et al.,* 2003). This larger biodiversity of the biotope may better support regeneration after environmental stressors such as drought (Van Ruijven and Berendse, 2010). In UK, the countrywide management practices of the field margins through the last two decades, has resulted in valuable effects on biodiversity and resource provision for farmland birds (Douglas *et al.,* 2009; Vickery *et al.,* 2009; Woodcock *et al.,* 2009). In the field margin management that resemble our suggested bufferzone model (with natural regeneration), higher conservation value of the zone was obtainable depending on the local flora and seed bank, as this provided habitat for invertebrates at - or just below the soil surface or in the canopy. Furthermore, this obtained biotope complexity provided increased prey accessibility and especially provided key winter resources for seed eating birds (Vickery *et al.*, 2009). Not least, increased landscape heterogeneity and habitat connectivity provided basis for increased biodiversity of both animal and plant species in the arable land (Freemark *et al.,* 2002; Ozinga *et al.,* 2009; Brudvig *et al.,* 2009).

In absence of pesticide application in bufferzones along hedgerows, the biodiversity of weed plants increased, and this effect was particularly evident for a bufferzone width of 6 m and higher. The biodiversity of weed plants increased, however, always with increasing bufferzone width. There are qualitative differences in this response at family, genus and species level, which should be studied further. Bufferzones along hedges and indeed all field margins should be encouraged from a biodiversity point of view.

Acknowledgments

We wish to acknowledge Andreas Kelager and Niels Bruun for assistance with flora count and identification. The economic support from the Danish EPA Pesticide Research Program is highly appreciated.

References

Andreasen, C., A.S. Litz and J.C. Streibig: Growth response of six weed species and spring barley (*Hordeum vulgare*) to increasing levels of nitrogen and phosphorus. *European Weed Res. Soc.*, **46**, 503-512 (2006).

Andreasen, C. and H. Stryhn: Increasing weed flora in Danish arable fields and its importance for biodiversity. *Weed Res.*, **48** 1-9 (2008).

Andreasen, C., H. Stryhn and J.C. Streibig: Decline of the flora in Danish arable fields. *J. Appl. Ecol.*, **33** 619-626 (1996).

Aude, E., K. Tybirk, A. Michelsen, R. Ejernæs, A.B. Hald and S. Mark: Conservation value of the herbaceous vegetation in hedgerows - Does organic farming make a difference. *Biol. Cont.,* **118,** 467-478 (2004).

Aude, E., K. Tybirk and M.B. Pedersen: Vegetation diversity of conventional and organic hedgerows in Denmark. *Agric. Ecosys. Environ.,* **99** 135-147 (2003).

Bengtsson, J., J. Ahnström and A.C. Weibull: The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *J. Appl. Ecol.*, **42**, 261-269 (2005).

Benton, T.G., J.A. Vickery and J.D. Wilson: Farmland biodiversity: Is habitat heterogenity the key? Trends in Ecology and Evolution **18** 182-188 (2003).

Boutin, C., B. Jobin, L. Bélanger and L. Choinère: Plant diversity in three types of hedgerows adjacent to cropfields. *Biodiversity and Conservation,* **11** 1-25 (2002).

Brudvig, L.A., E.I. Damschen, J.J. Tewksbury, N.M. Haddad and D.J. Levey: Landscape connectivity promotes plant biodiversity spillover into non-target habitats. *PNAS*, **106**, 9328-9332 (2009).

Danish Agricultural Advisory Service (Videncentret for landbrug): Product selection and dose by control of weeds in winter cereals in spring. *Plantenyt,* **297**, pp. 1 (2011)

De Snoo, G.R. and R.J. Van Der Poll: Effect of herbicide drift on adjacent boundary vegetation. *Agric., Ecosys. Environ.,* **73,** 1-6 (1999).

Douglas, D.J.T., J.A. Vickery and T.G. Benton: Improving the value of field margins as foraging habitat for farmland birds. *J. Appl. Ecol.*, **46**, 353-362 (2009).

Esbjerg, P. and B.S. Petersen: Effects of reduced pesticide use on flora and fauna in agricultural fields. *Pesti. Res.,* **58**, 1-203 (2002).

Firbank, L.G., S.M. Smart, J. Crabb, C.N.R. Critchley, J.W. Fowbert, R.J. Fuller, P. Gladders, D.B. Green, I. Henderson and M.O. Hill: Agronomic and ecological costs and benefits of set-aside in England. *Agric. Ecosys. Environ.,* **95,** 73-85 (2003).

Frederiksen, S., F.N. Rasmussen and O. Seberg: Dansk flora (Danish Flora). Gyldendal, Copenhagen, Denmark (2006).

Freemark, K.E., C. Boutin and C.J. Keddy: Importance of farmland habitats for conservation of plant species. *Conserv. Biol.*, **16,** 399-412 (2002).

Hole, D.G., A.J. Perkins, J.D. Wilson, I.H. Alexander, P.V. Grice and A.D. Evans: Does organic farming benefit biodiversity. *Biol. Conserv.*, **122,** 113-130 (2005).

Kudsk, P. and J.C. Streibig: Herbicides - a two edged sword. *Weed Res.*, **43**, 90-102 (2003).

Magurran, A.E.: Measuring biological diversity. Blackwell Science Ltd., Oxford, UK (2004).

Manhoudt, A.G.E., A.J. Visser and G.R. De Snoo: Management regimes and farming practices enhancing plant species richness on ditch banks. Agric. *Ecosys. Environ.*, **119,** 353-358 (2007).

Marshall, E.J.P.: Distribution patterns of plants associated with arable field edges. *J. Appl. Ecol.*, **26,** 247-257 (1989).

Marshall, E.J.P. and A.C. Moonen: Field margins in northern Europe: Their functions and interactions with agriculture. *Agric. Ecosys. Environ.,* **89,** 5-21 (2002).

Maudsley, M.J.: A review of the ecology and conservation of hedgerow invertebrates in Britain. *J. Environ. Manage.*, **60**, 65-76 (2000).

McCulloch, C.E. and S.R. Searle: Generalized, linear and mixed models. John Wiley and Sons, Inc., New York (2001).

Musters, C.J.M., F. Van Alebeek, R.H.E.M. Geers, H. Korevaar, A. Visser and G.R. De Snoo: Development of biodiversity in field margins recently taken out of production and adjacent ditch banks in arable areas. *Agric., Ecosys. Environ.*, **129**, 131-139 (2009).

Navntoft, S., K. Kristensen, L.C. Andresen, L. Sigsgaard, R. Nimgaard, I. Johnsen and P. Esbjerg: Buffer zones for biodiversity of plants and arthropods: Is there a compromise on width ? *Pest. Res.*, **127**, 1-103 (2009).

Ozinga, W.A., C. Romermann, R.M. Bekker, A. Prinzing, W.L.M. Tamis, J.H.J. Schaminée, S.M. Hennekens, K. Thompson, P. Poschlod, M. Kleyer, J.P. Bakker and J.M. Van: Groenendael Dispersal failure contributes to plant losses in NW Europe. *Ecol. Lett.*, **12**, 66-74 (2009).

Petersen, S., J.A. Axelsen, E. Tybirk, E. Aude and P. Vestergaard: Effects of organic farming on field boundary vegetation in Denmark. *Agric. Ecosys. Environ.*, **113**, 302-306 (2006).

Rundlöf, M., H. Nilsson and H.G. Smith: Interacting effects of farming practice and landscape context on bumble bees. *Biol. Conserv.*, **141**, 17-426 (2008).

SAS: Base SAS (R) 9.2 Procedures guide: Statistical Procedures. SAS Institute Inc., Cary, NC, USA.492 pp (online access: http://support.sas.com/documentation/cdl/en/procstat/59629/PDF/default/procstat.pdf. (2008).

Sonderskov, M., J.A. Axelsen, M.B. Pedersen and K. Tybirk: Assessment of the effects of reduced herbicide applications on selected arable weeds by a simulation model. *Agric. Ecosys. Environ.*, **116**, 16-224 (2006).

Stoate, C., A. Báldi, P. Beja, N.D. Boatman, I. Herzon, A. Van Doorn, G.R. De Snoo, L. Rakosy and C. Ramwell: Ecological impacts of early 21st century agricultural change in Europe - A review. *J. Environ. Manage.*, **91,** 2-46 (2009).

Tottman, D.R. and H. Broad: The decimal code for the growth stages of cereals, with illustrations. *Annals Appl. Biol.*, **110**, 41-454 (1987).

United States Department of Agriculture Natural Resources Conservation Service and National Conservation Buffer Team: Conservation buffers work economically and environmentally *Program Aid,* **1615**, 1 (2000)

Van Ruijven, J. and F. Berendse: Diversity enhances community recovery, but not resistance, after drought. *J. Ecol.*, **98**, 81-86 (2010).

Vickery, J.A., R.E. Feber and R.J. Fuller: Arable field margins managed for biodiversity conservation: A review of food resource provision for farmland birds. *Agric. Ecosys. Environ.,* **133,** 1-13 (2009).

Walker, M.P., J.W. Dover and T.H. Sparks: Hinsley SA Hedges and green lanes: vegetation composition and structure. *Biodiv. Conserv.*, **15,** 2595-2610 (2006).

West, B.T., K.B. Welch and A.T. Galecki: Linear mixed models - A practical guide using statistical software. Chapman & Hall/CRC, Boca Raton (2007).

Willi, J.C., J.O. Mountford and T.H. Sparks: The modification of ancient woodland ground flora at arable edges. *Biodiv. Conserv.,* **14**, 3215-3233 (2005).

Wilson, P.J. and N.J. Aebischer: The distribution of dicotyledonous arable weeds in relation to distance from the field edge. *J. Appl. Ecol*., **32,** 295-310 (1995).

Woodcock, B.A., S.G. Potts, T. Tscheulin, E. Pilgrim, A.J. Ramsey, J. Harrison-Cripps, V.K. Brown and J.R. Tallowin: Responses of invertebrate trophic level, feeding guild and body size to the management of improved grassland field margins. *J. Appl. Ecol*., **46**, 920-929 (2009).