Restoration of ditch bank plant diversity : the interaction between spatiotemporal patterns and agri-environmental management

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Chapter 5

Synergy between nature reserves and agri-environment schemes in enhancing ditch bank target species plant diversity

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In press, *Biological conservation*

Abstract

The issue of what conservation strategies to apply in agricultural landscape for the most effective protection of biodiversity has been debated for some years. The creation and maintenance of nature reserves is often hampered by both ecological and economic factors, while the ecological effectiveness of agri-environment schemes (AES) still being queried. Our study examined how the spatial pattern of nature reserves and AES affects the diversity of 25 target species of conservation interest in ditch banks and how this information might be used to develop a strategy resulting in synergy between protected areas and enhanced matrix quality. We studied target species plant diversity on 92 ditch banks under AES and on 102 banks not under such a regime; all of them running parallel to nature reserves. We compared the results with those obtained from a previous study which focused on ditch banks running transverse. On non-AES ditch banks running parallel to nature reserves, there was a significant decline in species richness with increasing distance from the nature reserve while this was not the case for AES ditch banks. The effect of AES differed between the two directions, with a significant effect beyond 200 m in the parallel direction and within 200 m in the transverse direction. Our results indicate that synergy between nature reserves and AES can enhance plant diversity and, since the AES effect was different in different direction due to wind direction and nitrogen input to adjacent fields, location of AES should be chosen carefully.

Introduction

In the last few decades there has been a dramatic decline in the biodiversity of agricultural landscapes (Stoate et al., 2001; Gregory et al., 2004), with increasingly intensive agricultural practices leading to substantial losses of natural habitats and species diversity (Benton et al., 2003; Duelli and Obrist, 2003; Tscharntke et al., 2005). In an attempt to conserve diversity, the creation of protected areas has become a fundamental element of conservation strategies (Richardson et al., 2006). One of the key problems faced in all efforts to maintain and enhance biodiversity by establishing such areas is how their spatial arrangement can be designed most cost-effectively (Andelman and Willig, 2002; Drechsler et al., 2007; Wikberg et al., 2009). One important factor in this context is obviously the distance between protected areas. The optimum distance will depend on the quality of the intervening matrix: a landscape with greater permeability for species will allow protected areas to be spaced further apart. In examining the issue of spatial arrangement, this study focused on the potential interplay of the two main conservation strategies employed in modern agricultural landscapes: *nature reserves*, i.e. protected areas, and *agri-environment schemes* designed to improve the quality of the matrix for plant species.

Nature reserves, which in agricultural landscapes harbour a broader range of plant and animal species than the surrounding area (Kremen et al., 2004), are a potential source of biodiversity for the wider matrix (Soons et al., 2005; Kohler et al., 2008; Leng et al., 2009). However, it is obviously out of the question to designate an entire farming region as nature reserves. High land prices and conflicting land user interests are the main issues, especially in densely populated areas. In the Netherlands, for instance, the conservation areas still remain so fragmented that the effectiveness of nature reserves is fairly limited (MNP, 2007). The maintenance and enhancement of biodiversity is still hampered by the small area of many reserves and by the fact that in today's fragmented landscapes many plant dispersal processes have been disrupted (Ehrlen et al., 2006; Kiviniemi, 2008; Ozinga et al., 2009).

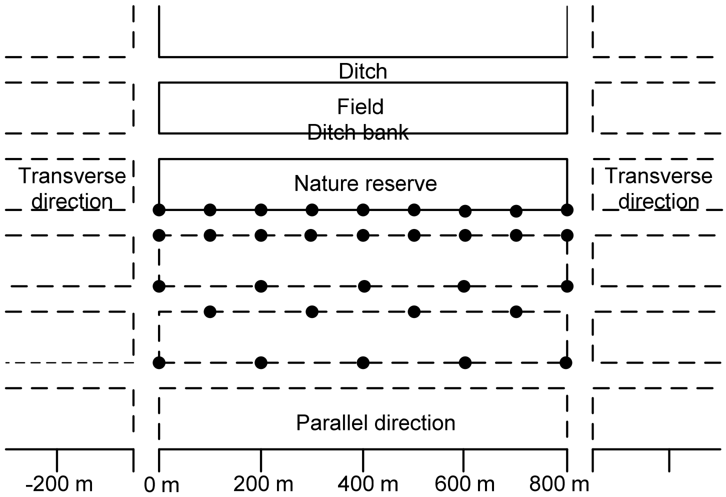
Agri-environment schemes (AES), introduced in many European countries in the 1990s, are to protect the diversity of (farmland) species and habitats by offering farmers financial incentives to use 'nature-friendly' agricultural practices on certain parts of their land (Whittingham, 2007). Their effectiveness is still being debated (Kleijn and Sutherland, 2003; Musters et al., 2009). One important impediment to improve plant diversity on farmland might be seed limitation (Zobel et al., 2000; Blomqvist et al., 2003). At locations where the seeds of many species have been lost from the seed bank (Bissels et al., 2005), seed influx from nearby species-rich source habitats like nature reserves appears to be an essential precondition for restoring plant diversity (Rosenthal, 2006; Kohler et al., 2008; Leng et al., 2009).

In the Netherlands ditch banks with a total length of 300,000-400,000 km are an important feature of the agricultural landscape (Higler, 1994). AES are often implemented on these banks, with mandatory provisions including no fertilizer use, no deposition of ditch sediment or plant remains on the banks, reduced ditch-cleaning frequency, postponed mowing and a grazing regime at the start of the season (Kleijn et al., 2004). Leng et al. (2009) has evaluated the importance of nature reserves for the plant diversity of ditch banks influenced by AES along ditches running transversely from a nature reserve to the farmland, with positive effects being found within the first 200 m. This leaves unanswered question of trends in plant diversity along banks running in other directions, a common feature in the Netherlands, so that there is still no clear picture of the impact of the entire network of nature reserves, AES and ditch banks (Fig. 1a).

In this research we test a set of hypotheses concerning whether there might be synergistic effects of nature reserves and AES on plant species within a network of ditch banks in the Western Peat District of the Netherlands, a country with an extensive network of ditches and one of the most intensively exploited regions in Europe. By focusing on plant diversity on AES and non-AES ditch banks running parallel to the edge of nature reserves and comparing the results with the findings of research on transverse ditch banks (Leng et al., 2009), we attempted to identify the aggregate influence of the entire mixed landscape of nature reserves and AES.

Specifically, we tested the following hypotheses. First, because of its association with seed limitation, we predicted that the plant diversity on successive ditch banks running parallel to a nature reserve might exhibit a declining gradient according to distance from the reserve. Given the effect of lower nutrient input (Blomqvist et al., 2003), we also predicted that ditch banks under AES would have higher plant diversity than those under non-AES. Second, human disturbance and wind direction might be important factors contributing to plant diversity (Leng et al., 2009). In the ditch banks with less human disturbance and suited on the downwind direction of a seed source, the plant diversity is expected to be high. We thus predicted that the association between plant diversity and distance to nature reserve might differ between ditch banks running transverse and parallel to a nature reserve and AES might show different pattern of plant diversity in the two directions. We focused on 25 target species that have been designated as valuable ditch bank plants by the Dutch government.

(a)



(b)

Fig. 1. (a) Landscape of Middelblok Polder in the Western Peat District of the Netherlands, with the nature reserve delineated in black (from Google Earth). **(b)** Sketch of the Middelblok polder, with ditch banks in the reserve and surrounding area depicted as solid and dashed lines, respectively; the sampled plots were ditch bank sections with a length of 10 m and a width depending on ditch bank width.

Methods

Study area

The study area Krimpenerwaard is located in the Western Peat District of the Netherlands. Most of the farmland here is grassland used either for hay-making or as pasture for dairy cattle and sheep. The soils are mainly peat or peat with clay. The fields are long and narrow, varying in width between 30 and 60 m, and are all separated by ditches 1-4 m wide. The field edges (ditch banks) are 0.8-1.5 m wide, with slopes ranging from 15º to 20º. The nature reserves in this region are mainly grassland and have been chose to protect plant diversity and meadow birds in nutrient-poor habitats (Fig. 1a). Ten nature reserves (Table 1) were selected, with a size of 42 ± 48 ha (average ± SE). On the surrounding farmland we investigated ditch banks managed under AES (n = 92) and those that were not (n = 102). The duration of AES management varied, with a mean of 10 ± 3 years. A total of five nature reserves had only AES ditch banks in its surrounding in the parallel direction, four reserves had only non-AES ditch banks, and one reserve had both.

Table 1. Number of ditch banks investigated in Krimpenerwaard in 2007. In the Middelblok, Kattendijksblok and de Nesse polders two nature reserves were selected, in one of which both the downwind and upwind direction were investigated.

Reserves	Parallel to nature		Transverse to nature	
	AES	non-AES	AES	non-AES
Bilwijk	4	11	3	3
Polder Middelblok 1	14			
Polder Middelblok 2, upwind		17	3	3
Polder Middelblok 2, downwind		12		
Polder Kattendijksblok 1	20		3	3
Polder Kattendijksblok 2, upwind	14			
Polder Kattendijksblok 2, downwind	9			
Polder de Nesse 1	15			
Polder de Nesse 2, upwind		16		
Polder de Nesse 2, downwind		12		
Polder Krommer		16		
Polder Berkenwoude		18		
Berkenwoudse Driehoek	16		3	3
Total	92	102	12	12

Study design

Data were collected from the ditch bank boarding the nature reserve and from successive ditch banks parallel to the nature reserve. The sample size we used is commonly applied in ditch bank analysis (Leng et al., 2009): bank width x 10 m long plots. Bank width is on average 1.15 ± 0.07 m. On the ditch bank bordering the nature reserve as well as on the first following ditch bank we marked off nine replicate plots at regular intervals of 100 m from one end (Fig. 1b). From the second ditch, we defined the two ditch banks of the same ditch as one since our previous study indicated that there was no significant effect of the different sides of the ditch on species richness. Therefore, four or five replicate plots on each side of a ditch were investigated at regular intervals of 200 m, marking nine replicate plots per ditch to represent each distance from nature reserves (Fig. 1b). Sampling was carried out from May 15th to July 15th, 2007.

Target species surveys and habitat variables

As stated, we focused on all 25 target species that based on a list of valuable plants used by the Dutch government. These species are easy to recognize and their presence is used in rewarding farmers for AES implementation. On each plot the vegetation variables recorded were the presence of each individual target species and the total number of target species (species richness). Of the 25 target species, 19 species were found in our study. Nine of them are water-dispersed species: *Caltha palustris*, *Filipendula ulmaria*, *Galium palustre*, *Hydrocotyle vulgaris*, *Iris pseudacorus*, *Lysimachia thyrsiflora*, *Lythrum salicaria*, *Mentha arvensis*, *Ranunculus flammula*; three are wind-dispersed species: *Cirsium palustre*, *Lychnis flos-cuculi*, *Pedicularis palustris*; four are animal-dispersed species: *Lycopus europaeus*, *Myosotis* (*Myosotis arvensis* and *Myosotis discolor* were lumped), *Prunella vulgaris*, *Rhinanthus angustifolium* and the last three are unassisted-dispersed species: *Lathyrus pratensis*, *Lotus uliginosus*, *Vicia cracca* (Grime et al., 1988; Van Dorp, 1996).

A large amount of habitat variables relative to habitat parameters and management which potential influence on plot vegetation were measured (Van Strien et al., 1989; Geertsema and Sprangers, 2002). Habitat parameters include ditch bank width, ditch water level below the field surface and ditch bank slope. On non-AES ditch banks, farmers were free to choose the kind of management adopted, while on all types of AES ditch banks a similar management regime is recommended or applied, as described in the Introduction. Management indicators such as mowing time and nitrogen supply to adjacent fields were established in interviews with farmers. The distances to the roads where the farm houses are located were also measured due to possible human disturbance. As plant diversity is possibly influenced by wind direction, which in the Netherlands is mainly from south-west to north-east, we categorised nature reserves as being either on the south-west side (upwind location) or north-east side (downwind location) of the plot under consideration. Beside nature reserves, the other seed sources such as woodlots were also considered.

Statistical analysis

The relationships between the vegetation variables per plot (species richness and the presence or absence of individual species) and possible variables affecting plot vegetation were tested by HGLM (Hierarchical Generalized Linear Model; GENSTAT 10.0). HGLM was used in our study since the vegetation variables are assumed to have a Poisson (richness) or Binominal (individual species) distribution, and our ditch banks and neighbouring nature reserves were assumed to be a random sample of all possible locations (Lee and Nelder, 2001). In all HGLM analyses, ditch bank nested within reserve was thus added as a random factor.

For each plot on the successive ditch bank parallel to the nature reserve, the variables and factors listed in Table 2 were used in a HGLM (analysis 1) to test changes in species richness as a function of distance from the reserve. Species richness was taken as the dependent variable, while distance, management, their interaction, and other variables of potential influence on species richness were taken as independent variables and included in the fixed part of the model. To detect non-linear relation, quadratic terms of each distance variable were also included. Because of inability of resolving the models, only the independent variables that were found to be significant in the previous analysis of species richness was tested on presence of individual species using HGLM (analysis 2). For that, the presence or absence of each species was regarded as response variable and the fixed model consisted of the independent variables mentioned above. Because *C. palustris*, *H. vulgaris*, *P. vulgaris* and *R. angustifolium* were rare in our study area, they were not analysed in the model, so that finally 15 individual species were tested. Wald test in HGLM was used to test a fixed effect on individual species by leaving out this fixed variable from the HGLM. The results of these two analyses enable us to test whether plant diversity decreased with increasing distance from nature reserves, to what extent plan diversity was higher under AES, and whether individual species differed in these aspects (Hypothesis 1). We further used Mann-Whitney U-test to investigate whether species richness was significantly different in different distance categories (we defined each 100 m from nature reserve as a category).

Whether plant diversity differs between AES and non-AES ditch banks running transverse and parallel to the nature reserve (Hypothesis 2) were also tested in HGLM. To avoid the influence of time as well as regional differences, we used only the 2007 data of the Krimpenerwaard from our previous study on 'transverse' ditch banks (Table 1). For species richness (analysis 3), the variables found to significantly affect species richness in the transverse and parallel direction individually were added as fixed factors. As ditch water level might also potentially affect ditch bank biodiversity (Van Strien et al., 1989), this was also included as a fixed factor. For the presence or absence of species (analysis 4), the variables found to significantly affect species richness in analysis 3 were added as fixed factors. The Mann-Whitney U-test was again used to compare the species richness per distance category and independent variables between transverse and parallel direction.

Results

Species diversity pattern on parallel ditch banks

Of the 25 target species considered, 19 were observed on the ditch bank bordering nature reserves and 18 on the surrounding ditch banks. *P. vulgaris* was found only bordering nature reserves. The mean species richness bordering reserves was 6.95 (SE = 0.28). The mean species richness on AES ditch banks was found to be 6% lower (6.57 ± 0.18) and on non-AES banks 11% lower (6.16 ± 0.23) than the ditch bank bordering nature reserves.

On non-AES ditch banks parallel to the nature reserve, species richness declined significantly with distance from the reserve, over and against no significant relationship for AES banks (Fig. 2, analysis 1, significant management x distance interaction in Table 2). Presence of most individual species also declined with distance (data not show, analysis 2). The differences between AES and non-AES ditch banks tended to increase with distance from the reserve. On AES ditch banks considerably higher species richness was found at distances of 200-300 m and 300-400 m.

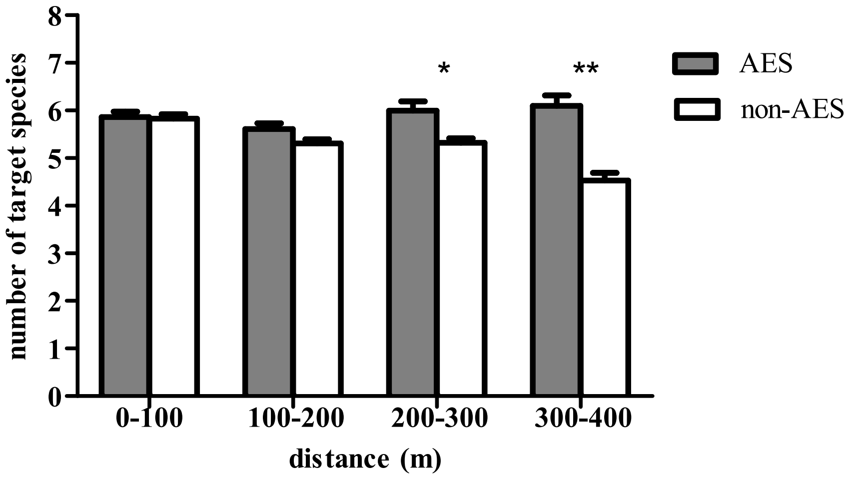


Fig. 2. Relationship between distance and species richness on AES (closed bars) and non-AES (open bars) ditch banks running parallel to a nature reserve. Bars indicate mean values ± SE; * = p<0.05; ** = p<0.01 (Mann-Whitney U-test).

Table 2. Results of HGLM analysis for the effect of distance, management and habitat variables on ditch banks running parallel to a nature reserve. Management (class 1: AES; class 2: non-AES); Nitrogen supply on the adjacent field (class 1: 0-200 kg $ha^{-1}year^{-1}$; 2: 200-300 kg $ha^{-1}year^{-1}$; 3: 300-400 kg $ha^{-1}year^{-1}$; 4: 400-500 kg $ha^{-1}year^{-1}$); Reserve location (class 1: nature reserve suits on the south-west side of parallel ditch banks (downwind parallel direction); class 2: nature reserve suits on the north-east side of parallel ditch banks (upwind parallel direction)); Other seed source (class1: no other seed source; class 2: seed source such as woodlots). Lambda estimates represent the random part of the model. * p<0.05; *** p<0.001.

	Species richness		
	estimate	SE	t
Constant	2.54	0.65	3.92***
Distance from nature reserve	0.005	0.0052	1.05
Square distance	0.0001	0.0001	-0.22
Management	0.039	0.049	0.78
Management*Distance	-0.012	0.003	-3.59***
Distance from farmhouse	0.0003	0.0008	-0.34
Square distance from farmhouse	0.0001	0.0001	0.23
Ditch bank width	0.81	1.06	0.76
Ditch bank slope	-0.096	0.11	-0.91
Ditch water level below field surface	0.23	0.14	1.75
Mowing time	0.031	0.044	0.71
Nitrogen supply	-0.069	0.015	-4.67***
Reserve location	-0.11	0.042	-2.37*
Other seed sources	0.048	0.045	1.07
Estimates from the dispersal models:			
phi	-1.23	0.045	-27.57***
Lambda reserve	-5.78	0.55	-10.51***
Lambda reserve*ditch bank	-5.45	0.18	-30.48***

Higher species richness was correlated to lower nitrogen input to the field adjacent to the ditch bank (analysis 1, Table 2), while mean species richness was significantly higher within 100 m when the nature reserve was on upwind location compared to downwind location (Fig. 3, analysis 1, Table 2). A significantly positive effect of upwind nature reserves location was found on two water-dispersed species *F. ulmaria* and *L. salicaria* (p = 0.009 and p = 0.03, respectively; Wald test) and one wind-dispersed species *L. flos-cuculi* (p = 0.03; Wald test) (analysis 2).

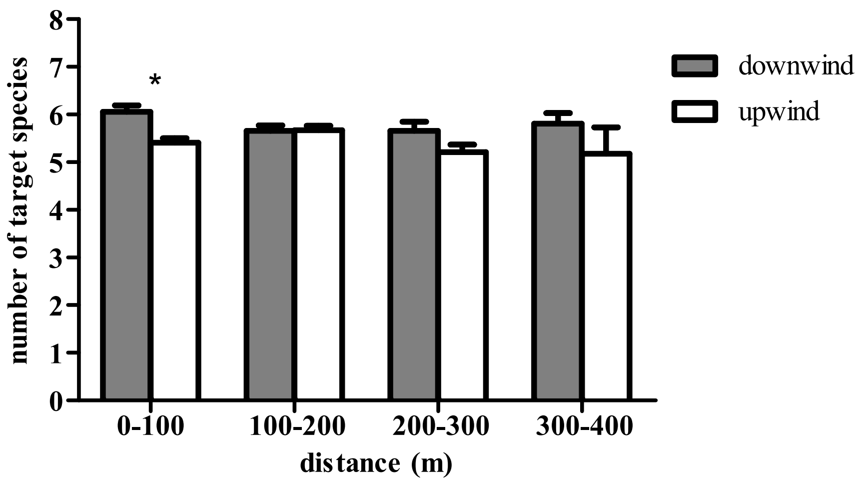


Fig. 3. Relationship between distance and species richness in the downwind (closed bars) and upwind (open bars) parallel direction. Bars indicate mean values ± SE. Differences between) downwind and upwind parallel direction were tested with Mann-Whitney U-test; * = $p<0.05$.

Species diversity on parallel and transverse ditch banks

The transverse ditch banks showed a significantly greater number of species between 0 and 100 m from the reserve than parallel ditch banks. From 100 m onwards, however, species richness was lower, becoming significantly lower at a distance of 200 m. In the parallel direction, the decline in species richness was far less pronounced than along ditches extending in the transverse direction (Fig. 4). Both AES and non-AES ditch banks showed a significantly different change of species richness with distance from nature reserve according to whether they were transverse or parallel (analysis 3, Table 3).

A significant difference in correlation between species richness and distance from the farmhouse between the transverse and parallel direction was found: in the transverse direction the correlation was lower than in the parallel direction (analysis 3, Table 3). Nitrogen input, which showed no change along the transverse ditch banks but a significant change along the parallel banks, was found to have a significant effect on species richness. The level of the ditch water below the field surface, which showed no changes in either the transverse or parallel ditches, had a significant effect on species richness when the two directions were included in the model. In the parallel ditches the distance between ditch water level and field surface was found to be significantly greater (0.58 ± 0.07) than in the transverse ditches (0.49 ± 0.11) ($p < 0.01$, Mann-Whitney U-test). Moreover, 8 of 15 species had significant effects of ditch water level, two were positive (*Myosotis* and *P. palustris*) and six were negative (*C. palustre*, *I. pseudacorus*, *L. pratensis*, *L. uliginosus*, *M. arvensis* and *R. flammula*) (data not show, analysis 4).

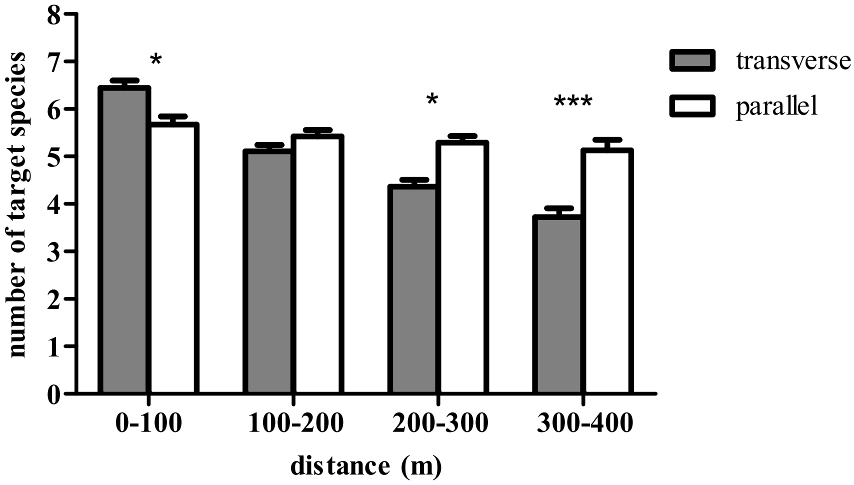


Fig. 4. Relationship between distance and species richness on ditch banks transverse (closed bars) and parallel (open bars) to a nature reserve. Bars indicate mean values ± SE. Differences between transverse and parallel direction were tested with Mann-Whitney U-test; * = p<0.05; *** = p< 0.001.

Table 3. Results of HGLM analysis for the effect of distance, management and potential habitat variables on ditch banks transverse and parallel to a nature reserve. Management (class 1: AES; class 2: non-AES); Nitrogen supply on the adjacent field (class 1: 0-200 kg $ha^{-1}year^{-1}$; 2: 200-300 kg $ha^{-1}year^{-1}$; 3: 300-400 kg $ha^{-1}year^{-1}$; 4: 400-500 kg $ha^{-1}year^{-1}$). Lambda estimates represent the random part of the model. * = p<0.05; ** = p<0.01; *** = p<0.001.

	species richness		
	estimate	SE	t
Constant	2.22	0.08	26.37***
Distance from nature reserve	-0.01	0.004	-3.15**
Square distance	0.0002	0.00005	4.57***
Distance*Management	-0.009	0.0038	-2.49*
Distance*non-AES* upwind parallel	0.008	0.0044	1.74
Distance*non-AES*transverse	-0.02	0.0039	-4.44***
Distance*AES* upwind parallel	0.01	0.0031	4.43***
Distance*AES*transverse	-0.005	0.0025	-2.02*
Distance from farmhouse	0.002	0.00049	-4.22***
Distance from farmhouse*direction	0.0017	0.00041	4.09***
Ditch water level blow field surface	-0.18	0.075	-2.37*
Nitrogen supply	-0.063	0.011	-5.68***
Estimates from the dispersal models:			
phi	-1.31	0.039	-32.91***
Lambda reserve	-4.61	0.45	-10.31***
Lambda reserve*ditch bank	-5.29	0.15	-34.94***

Predicted species diversity on parallel and transverse ditch banks

With respect to the predicted species richness indicated by HGLM, for non-AES ditch banks we found a different pattern of species diversity on the surrounding of nature reserves (Fig. 5; Fig. 6a). In particular, species richness was greater in the downwind parallel direction. For example, six species were predicted up to 425 m in the downwind parallel direction. The same number of species was found up to 87 m in the transverse direction and up to 186 m in the upwind parallel direction. Figure 6b shows the difference in species pattern between AES and non-AES ditch banks running transverse and parallel to the nature reserve. In the transverse direction this difference between AES and non-AES ditch banks becomes smaller further from the reserve, while in the parallel direction it increases. Comparison of species richness downwind and upwind parallel direction indicated that the effects of differences in management regime extended further in the downwind direction.

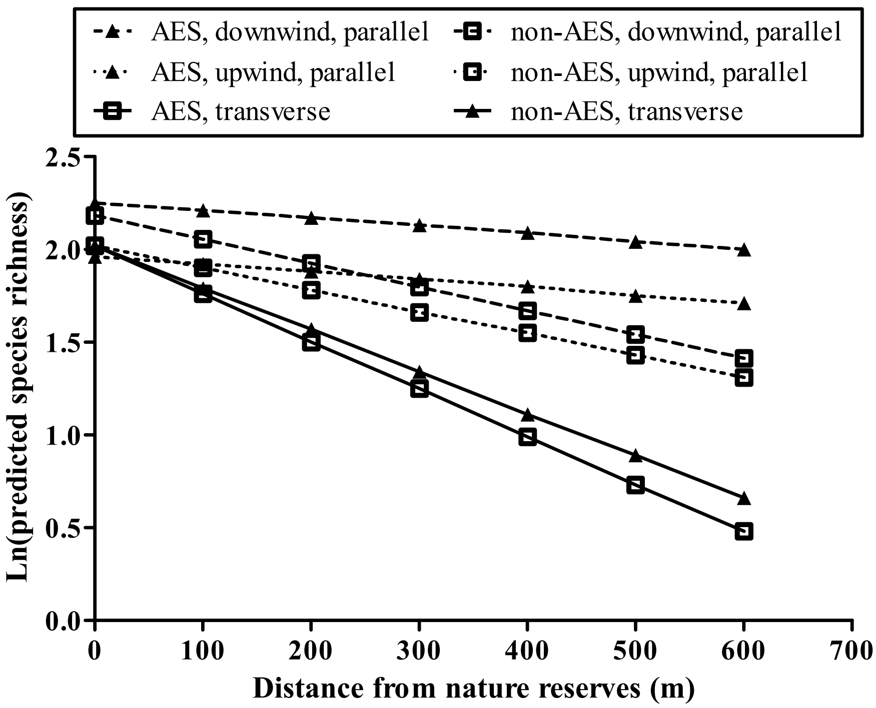


Fig. 5. Relationship between distance from nature reserve and species richness as predicted by HGLM.

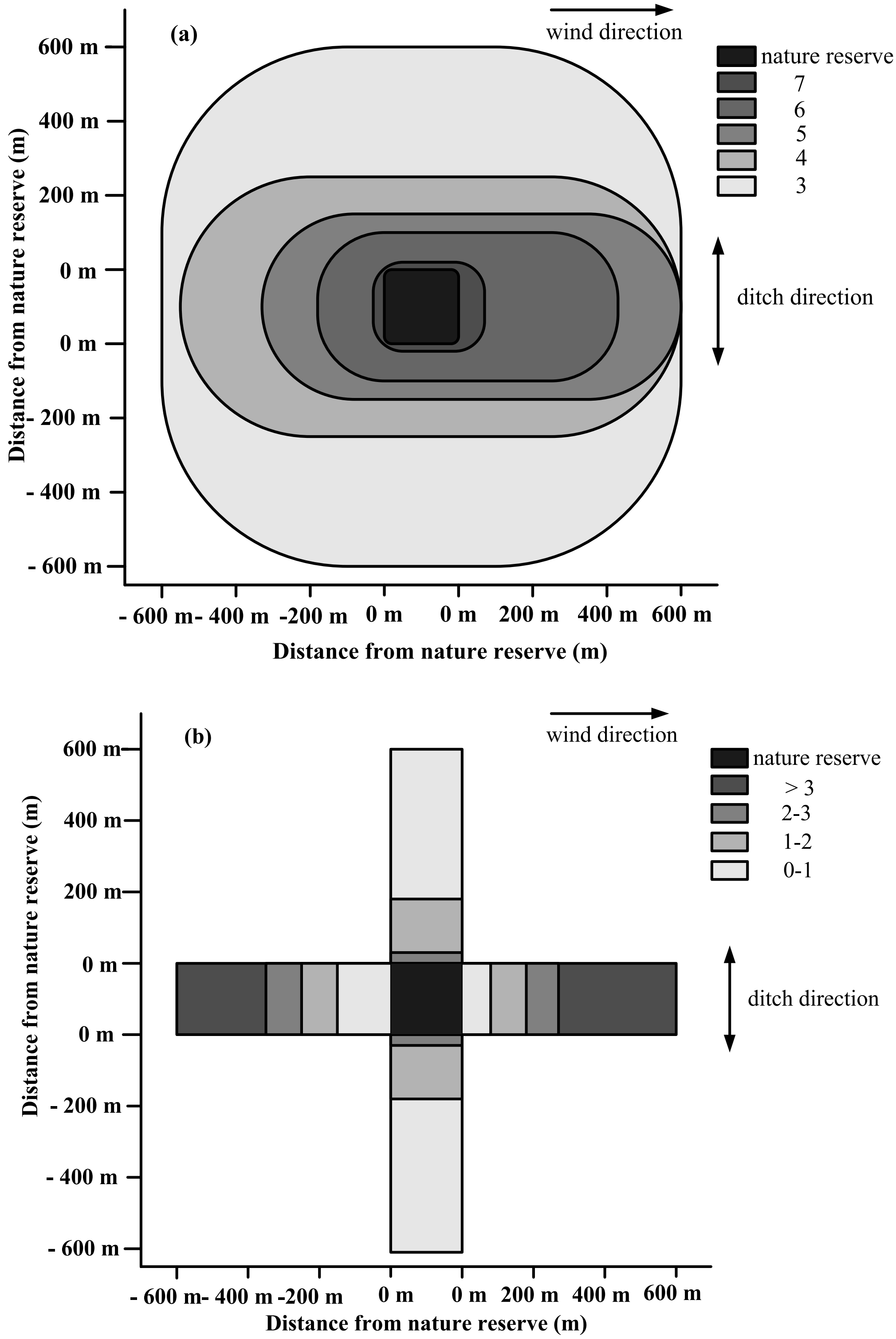


Fig. 6. (a) Relationship between distance and HGLM-predicted species richness on non-AES ditch banks; numbers in legend = number of target species. **(b)** Relationship between distance and HGLM-predicted difference in species richness between AES and non-AES ditch banks transverse and parallel to a nature reserve; numbers in legend = difference in number of target species between AES and non-AES ditch banks.

Discussion

Pattern of plant diversity parallel to a nature reserve

In the Western Peat District of the Netherlands within nature reserves, lower nutrient levels and limited grazing intensity are being applied in order to enhance plant diversity. Our results show that species richness on the ditch bank bordering nature reserves is higher than on the other ditch banks, whether these are under an AES regime or not, and that a species like *P. vulgaris* was found only bordering nature reserves. Nature reserves might therefore act as a source of plant diversity for nearby ditch banks. The precise contribution of nature reserves to regional plant diversity is generally hard to assess, however, as little is known about the dispersal capacities of individual plant species (Duelli and Obrist, 2003). We, therefore, further investigated plant diversity on AES and non-AES ditch banks parallel to the nature reserves to test for possible effects in this respect. As we hypothesized, on non-AES ditch banks species richness declined significantly with increasing distance from the reserve, thus confirming that species-rich sites (nature reserves) can serve as a source for the surrounding area. This is in agreement with the results of Kohler et al. (2008) and Leng et al. (2009), who demonstrated that distance from species-rich sites is an important determinant of species diversity in linear landscape features like ditch banks.

However, Geertsema (2005) suggested that colonization distances of most of the target species considered here is no more than 150 m from source (e.g. *G. palustre*, *I. pseudacorus*, *L. vulgaris* and *L. flos-cuculi*). The ditch banks parallel to the nature reserves are separated by fields with a width of 30-60 m, and species growing on the bank directly bordering the reserve may have difficulty moving to the next bank. Even if nature reserves can function as a seed source for the immediate surroundings, then, these seeds may fail to reach locations further away. Our results indicate that upwind nature reserve location has a distinctly positive impact on plant diversity. The parallel ditch banks situated downwind of a nature reserve were richer in species than those upwind, especially within the first 100 m. This might suggest that wind direction amplifies the effect of a nature reserve, by increasing seed dispersal distances. However, the positive effect of the downwind direction was not only found in wind-dispersed species. Two water-dispersed species showed the same positive relation to the wind direction. One possible explanation is that the downwind direction helped water flow and thus increasing dispersal distance of water-dispersed species. Nitrogen supply to adjacent fields had a negative impact on plant richness, confirming the results of several previous studies (Melman and van

Strien, 1993; Manhoudt et al., 2007; Blomqvist et al., 2009). Lower nitrogen inputs on these fields induce greater plant diversity by reducing site limitation pressure on certain species. On the ditch banks parallel to the nature reserve, other key habitat variables such as ditch bank width and slope were found to have no significant impact on plant diversity.

An effect of ditch bank management on the correlation between species richness and distance from nature reserves was found. At distances of over 200 m from the nature reserve, species richness was higher on AES than on non-AES ditch banks. In other words, the positive effects of agri-environment schemes appear to be relatively pronounced in the parallel direction, even at a considerable distance from the nature reserve. However, the higher diversity under AES observed in our study might also be due to a 'selection effect', for several studies report that some farmers may opt to apply AES management on fields with a high species diversity (Kleijn and van Langevelde, 2006; Matzdorf et al., 2008; Blomqvist et al., 2009).

Pattern of plant diversity parallel and transverse to a nature reserve

On the parallel ditch banks, a lower decline in species richness with distance from the nature reserve than on the transverse banks was observed, which supports our second hypothesis. Plant diversity in the parallel direction was influenced by distance to the reserve, while in the transverse direction it was also related to distance to the farmhouse (Leng et al., 2009). In the latter case, human disturbance around the farmhouse may be the cause of lower species richness. Ditch water level below the field surface was different for the parallel and transverse ditches. Ditch banks with a greater distance between water and surface level tended to have more species, which contrasts with the findings of Van Strien et al. (1989). Their study investigated the whole vegetation while our study only focused on 25 target species, which might also explain the discrepancy. Furthermore, in Van Strien's paper, ditch water level was categorized according to a wider scale as 15-40 cm, 40-50 cm and 50-80 cm. In our study, the difference in ditch water level between the two directions was only 10 cm on average, however, falling within 50-80 cm category of Van Strien et al. in both cases. Our differences in water level are thus on a completely different scale to those studied by Van Strien et al. The effect of ditch water level differed among species and was not depending on dispersal strategy. It has been demonstrated in numerous studies that seed dispersal is related to water levels in certain types of vegetation (Andersson and Nilsson, 2002; Boedeltje et al., 2004). Whether our results indicate a causal relationship between water level and species richness is an issue requiring further study.

The effect of AES management was markedly different in the transverse and parallel direction. In the transverse direction it is limited to 200 m, while in the parallel direction it was significant at this distance. The effect of AES appears to be greater in the parallel direction. If the 'selection effect' is indeed the cause of the AES effects, this would still mean that parallel ditch banks differ more markedly in species richness than transverse banks. These two directions showed different effects of nitrogen input to the adjacent field. Nitrogen supply had no effect on species richness on the transverse ditch banks but a significantly negative effect on the parallel banks, suggesting greater differences in land use intensity in the parallel direction. Although the ditch banks themselves were not fertilized directly and relatively lower fertilizer inputs were applied in the field under AES, it is unclear to what extent nutrients applied by neighbours could have an impact through joint use of drainage ditches (Kleijn et al., 2004; Smits et al., 2008). In our study it was observed that the areas with AES ditch banks in the transverse direction were seriously fragmented, generally involving clusters of 5-6 together, while all the AES ditch banks parallel to the nature reserve were in clusters of at least 14-15, except in Bilwijk. The relatively greater fragmentation of AES management may impede its efficacy (Geertsema, 2005; Soons et al., 2005; Donald and Evans, 2006; Gabriel et al., 2006; Smits et al., 2008). Several studies have shown that application of AES cannot alleviate the pressure of seed limitation, which plays an important role in species richness (Zobel et al., 2000; Blomqvist et al., 2003; Leng et al., 2009). Further studies on the process of seed dispersal would help elucidate the process behind the patterns of species diversity observed in our study.

Implications for management

The results of this study provide new insights of relevance for the design and implementation of conservation networks for plant diversity on ditch banks. First, our results suggest that plant diversity may be enhanced by the synergy between species-rich grasslands and AES. On the ditch banks running transverse to a reserve the impact was relatively minor and limited to a distance of 200 m, while on the banks running parallel the effect appears to be greater at distances of over 200 m. Priority should therefore be given to implementing AES on the banks of parallel ditches at some distance from a nature reserve. Second, species richness also appears to be affected by several other factors, such as location relative to wind direction and nitrogen input on adjacent fields. Downwind parallel direction as well as fewer nitrogen fertilizer applications on adjacent fields may consequently lead to conservation of a wider diversity of plant species by means of AES. Third, we observed that AES ditches running parallel to a nature reserve had greatly enhanced plant diversity even 400 m from the reserve. The underlying ecological mechanism requires further study. It is worth investigating whether the effects of AES adjacent to nature reserves would be enhanced by expanding the size of the AES area, as several studies have demonstrated that fragmentation would be a problem for nature reserves and our study found greater species diversity in larger stretches of AES areas (Geertsema, 2005; Gabriel et al., 2006; Smits et al., 2008). In our view, then, farmers implementing AES would be more successful if they selected ditch banks adjacent to those where a similar management regime is already in force.

Figure 6a shows the species diversity pattern around nature reserves based on our predicted species richness, while Figure 6b shows the effect of AES on ditch banks transverse and parallel to a nature reserve. Together, these figures provide an impression of species diversity in a network of nature reserves and AES areas. For spatial planning purposes we recommend that AES be preferentially implemented in the parallel direction, especially downwind of nature reserves. Since the impact of AES in this direction was greater beyond a distance of 200 m from the reserve, we suggest management plans should target ditch banks beyond this distance.

Acknowledgements

We are grateful to the farmers J.M. Oudenes, J.P. Verkaik, Th.A. Holierhoek, M. Verzuilen, G. de Groot, D. Leede, J. Anker, G. de Jong, M. Verkaik, M.C.M. Gille, P.G. Blanden, I. Halling, H. Hogendijk, A. Hogendijk, V. Noordergraaf, K.A. Anker, J. Rehorst and V. Erk and nature reserve manager R. Terlouw from Zuid-Hollands Landschap for granting access to their land. We thank the regional water boards of Schieland en Krimpenerwaard for providing information on changes in water tables and L. van Hoven of the 'Weidehof' farmers' collective for data on AES. We gratefully acknowledge the help of E.R.Gertenaar in carrying out the experiments. We thank Nigel Harle for revising our English.

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