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Enhancing biodiversity on arable farms in the context of environmental certification schemes

Manhoudt, A.G.E.

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AN INDICATOR OF PLANT SPECIES RICHNESS OF SEMI-NATURAL HABITATS AND CROPS ON ARABLE FARMS

Astrid Manhoudt, Helias Udo de Haes and Geert de Snoo

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Summary

As a straightforward method of assessing on-farm biodiversity, plant species numbers were compared in a fixed sampling area for each type of habitat distinguished independent of farm size and applicable for comparing different farm strategies. Using the species-area relationship, the minimum sampling areas were determined. For ditch banks, crops and field margin strips sampling areas of 400 m² (independent of the ditch bank width), 100 m² and 25 m² respectively were proposed. Indicator threshold values for conventional farms were defined based on the best 10% of the variation in species richness among farms. With appropriate farm management these targets could be achieved. In comparison to ditch banks, crops and sown field margin strips were relatively poor in plant species. The respective numbers of naturally occurring plant species found in crops and field margin strips were both significantly smaller than those found in ditch banks. In contrast, ecological management of ditch banks appeared to be a promising means of increasing species richness.

4.1 Introduction

To improve biodiversity and environmental quality, several amendments have been introduced by the European Union, under the terms of the CAP and Agenda 2000, for example (European Commission, 1992 and 1999). In several individual countries, including the United Kingdom (MAFF, 1994), and the Netherlands (LNV, 1997; LASER, 2004), agri-environmental schemes (European Commission, 1998) have been introduced for this purpose. Retailers, the food industry and farmers have also taken initiatives to encourage more sustainable agriculture down the agro-production chain by introducing environmental labelling of arable farms and agricultural produce (European Council, 1997; EUREP, 2001;

SAI, 2002). The principal focus of this labelling is currently on nutrient and pesticide use, with criteria for on-farm biodiversity generally lacking. Indeed, little attention is paid to on-farm biodiversity at all, despite it being deemed an important issue (de Snoo and van de Ven, 1999; Manhoudt *et al.*, 2002). Environmental labelling of agricultural farms can in principle provide a useful instrument for remedying this situation.

A methodology for assessing and comparing on-farm biodiversity in the context of environmental certification of conventional arable farms was recently proposed by Manhoudt *et al.* (2002). This method starts by determining the area of semi-natural habitat on the farm, defined as the total area that is non-productive, viz. undisturbed aquatic, herbaceous and woody habitats with no intentional inputs of pesticides or nutrients (Manhoudt and de Snoo, 2003). On average, 2% of the area of a Dutch arable farm is non-productive, the greater part of which generally consists of ditches and ditch banks. This yardstick has the advantage that the results are strictly quantitative and permit straightforward comparison among farms. However, it provides no information about the species richness or the ecological quality of the semi-natural habitats, nor of the cropland.

The next step, then, is to develop an indicator for assessing plant species richness of both semi-natural habitats and cropland. This implies choices regarding 1) the appropriate sampling area, 2) the indicator itself and 3) the threshold to be adopted as a criterion for certification. The method proposed here is to measure and assess plant species numbers in a fixed sampling area per habitat or crop, independent of farm size or total area of semi-natural habitat.

The sampling area for any given habitat should be large enough to allow for the detection of important differences in plant species numbers related to management regimes, farming strategies or regional differences. Indicators for measuring plant species diversity are generally based on the presence of selected plant species such as threatened species (cf. the Red List of threatened species: www.iucn.com; de Iongh *et al.*, 2003) or other selections of species (Albrecht, 2003; Walldhardt *et al.*, 2003). In all cases there is a need to analyse the composition of the respective vegetations. Therefore, the total plant species richness of semi-natural habitats and crops will be considered. Lastly, appropriate indicator threshold values must be defined per habitat type and crop. There are two options here: thresholds based on variation in plant species numbers among conventional farms; and based on the variation when the habitats are optimally ecologically managed. Whichever option is adopted, thresholds should be determined for the most commonly occurring type of habitat, viz. ditch banks, and for crops (Manhoudt and de Snoo, 2003).

The goal of this study is to develop an indicator for measuring and assessing the plant species richness of semi-natural habitats and cropland, independent of farming strategy and farm size, for the purpose of environmental certification or benchmarking. The following research questions will be answered: 1) for a given habitat or crop, what is the minimum sampling area required for comparing farm management regimes, crops or regions based on species numbers, and 2) what indicator thresholds are suitable for certification purposes, based on variation in plant species numbers of habitats and crops among conventional farms and among ecologically managed habitats? Also, plant species inventories are evaluated with respect to the presence of Red List species and species rarity on a national scale.

4.2 Methodology

Thirty conventional arable farms were selected in three regions in the Netherlands: the Haarlemmermeer polder (12 farms on young marine clay), Zeeland (12 farms on old marine clay) and Noord-Brabant (six farms on sand). All farms had an intensive crop rotation scheme, including ware-potatoes, sugar beet, winter wheat and most often also onions. Adjacent to these crops, all farmers had cultivation-free zones to prevent pesticide and nutrient drift to ditch banks: a 0.25 m wide zone next to winter wheat, 0.50 m next to sugar beet and 0.5 m next to ware-potatoes depending on the type of pesticide application (V & W *et al.*, 2000). Also, (inverted) off-centre caps and low-drift nozzles were used for pesticide application. In winter wheat, herbicides were generally applied twice: once in March and in the beginning of May. In sugar beet, farmers usually sprayed herbicides three times (down row) in the period March to May in combination with mechanical weed control between rows. In ware-potatoes, there was, in general, one herbicide spraying in May and one mechanical weed control when building up the potatoes ridges.

The most common habitats selected as non-productive areas on which no pesticide and nutrient use was allowed were field related ditch banks and sown field margin strips. The ditch banks had an average width of 1.9 ± 0.3 m in the Haarlemmermeer Polder, 2.0 ± 0.4 m in Zeeland and 1.6 ± 0.3 m in Noord-Brabant. Ditch bank management on conventional farms differed in terms of mowing frequency and earliest mowing date. On none of the farms was the mown grass removed from the ditch banks. To determine the variation among conventional farms the two most common ditch bank management regimes were taken: 1) early mowing: first cut in May and $\geq$ three cuts a year and 2) late mowing: first cut in June and $\leq$ two cuts a year. Six farms were selected per management regime, except in Noord-Brabant where the early mowing regime was not present. Also, an ecological management regime was selected aimed at reducing nutrient input and vegetation biomass by mowing and removal of the cuttings at least once a year. Ditch banks were selected where this form of management had been applied for at least five years. Such references were only found in Zeeland: two ditch banks owned by the provincial authority and two on organic farms. In the other regions no references were available.

Field margin strips sown with grasses and herbaceous plant species based on Dutch agri-environmental schemes for improving fauna diversity (LNV, 1997) were available in the Haarlemmermeer Polder (annual sown) and Zeeland (perennial). For assessing the plant species diversity in the productive areas of the farms, the Netherlands' three most common arable crops were selected: ware potatoes, sugar beet and winter wheat under current conventional practice (five farms per region). References for crops and field margins were not available in all study areas.

On each farm the presence of vascular plant species (Nomenclature: van der Meijden, 1996) was determined on ditch banks (in May and June 2001 and 2003 before the first cut), in field margins and in crops after the last herbicide application (the end of June and begin July 2001). In the sown field margins only naturally occurring plant species were recorded. The first 10 m down from the field headland of the crops as well as the top of the ditch bank were excluded from the inventory, as these may be disturbed by tillage.

Given that most semi-natural habitats in agricultural landscapes are linear, adopting a fixed sampling area created problems in terms of both practical application and analysis. For these linear habitats, plots of fixed length were taken so that the full ecological gradient of the habitat was included. To this end, plant species numbers were recorded over the total width of the ditch bank in ten consecutive plots each 25 m long (total length 250 m).

In each crop, plant species numbers were recorded 1, 15 and 25 m from the field edge and at the centre of the field for each crop. At each distance from the field edge five recordings of species numbers were taken on plots with a fixed size of 25 x 1 m (total length 4 x 125 m).

Establishing a suitable minimum sampling area involves several problems. If plant species richness is determined for the farm as a whole, differences in farm size will preclude comparison. This approach implies substantial effort, moreover. Therefore the scope for using a sampling area of fixed size was examined, although possibly varying across habitats or crops to allow for heterogeneity of vegetation.

The species-area relationship (Arrhenius, 1921; Preston, 1960, 1962; MacArthur and Wilson, 1967) was used to determine the minimum sampling area of ditch banks, crops and field margins. The variable ditch bank width due to the inventory of the complete ecological gradient could be properly included in the species-area curves before determining the sampling area. This species-area relationship has the form $S = c.A^z$ (Arrhenius, 1921; Preston, 1960, 1962; MacArthur and Wilson, 1967), with which the species numbers (S) were calculated in relation to the area (A : in square metres) and the c - and z -value. The value of c depends on the taxonomic group chosen, the biogeographic region and the population density (Connor and McCoy, 1979; Rosenzweig, 1996). Species-area curves were calculated using the program Estimates (Colwell and Coddington, 1994; Colwell, 1997). The values of c and z were calibrated from the curve after logarithmic transformation by determining the intercept (c) and the slope (z).

For the *ditch banks*, the differences in c - and z -values under different management regimes were tested with General Linear Model univariate analysis of variance (GLM followed by Least Significant Difference test (LSD), SPSS 11.0) taking c - and z -values as dependent variables and management regimes and regions as fixed factors in the analysis. Interactions between regions and management regimes were also tested for.

To establish differences in c and z for the various *crops*, GLM-univariate analysis (SPSS 11.0) was again used (Sokal and Rohlf, 1981; Oude Voshaar, 1995). The model was defined by the different distances into the crop, the crops themselves and the three study regions as fixed factors, adding the farm as a nested random factor. All possible interactions were tested for.

Standardising the plant species numbers to a fixed area for each habitat with the species-area relationship permitted inter-farm comparison independent of ditch bank width. Differences in the c - and z -values were used to determine the appropriate sampling areas per habitat.

Plant species numbers were calculated for different sampling areas (ditch bank: 250 - 500 m²; crops and field margins: 25 - 125 m²) per farm and tested using GLM-

univariate analysis (LSD) after logarithmic transformation to check for continued consistency of all differences found between the c- and z-values of the species-area curves. With the sampling area selected, the same differences as determined for the c- and z-values of the species-area curves, should be detected. To avoid problems of overestimating plant species numbers due to extrapolation (Palmer, 1990) or different scales (Crawley and Harral, 2001), for each habitat the sampling area was selected within the range of the actually inventoried area.

To identify the amount of rare plant species in the vegetations, the presence of Red List species was inventoried (van der Meijden, 1996). In addition, a national rarity index (Tamis and van 't Zelfde, 2003) was used to analyse the composition of the vegetation, based on species presence in the Netherlands on a 1×1 km grid (Tamis and van 't Zelfde, 2003). In this index plant species have been divided in the following groups: no longer present or rare, fairly rare, fairly common, common and very common based on the number of kilometre grid cells where the plant species was found in 1995. This classification was used to determine which types of plant species were found on ditch banks and in crops on Dutch arable farms.

To establish the threshold values frequency distributions of plant species numbers for the sampling area per habitat and crop were calculated. Based on this frequency distribution, threshold values could be calculated. As an example, 90 percentiles of the distributions were given for conventional managed ditch banks, crops and field margin to determine the number of plant species on the best 10% of the conventional farms and the 50 percentile for the ecologically managed ditch banks to set achievable thresholds.

4.3 Results

For the species-area curves of the *ditch banks*, average c- and z-values were calculated per region, since only regional differences were determined (Figure 1). No difference between mowing regimes was found and no interaction was determined (Table 1).

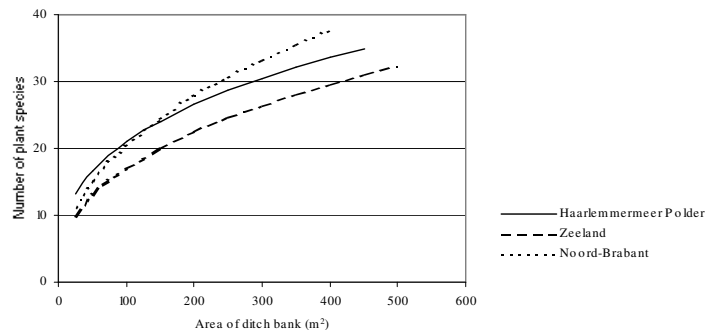


Figure 1: Number of plant species per area of ditch bank (m^2) for the Haarlemmermeer Polder, Zeeland and Noord-Brabant.

With respect to the c-value of the *crops* (Table 1), differences were found between crops, within crops and between farms. Between crops: ware potatoes and winter wheat were significantly different from one another ($P < 0.05$) and the average value for the sugar beet was in between the two others and not significant different from both other crops. Within the crops, the c-value of the first metre of the field was significantly higher than further into the crop (Table 1: second column). Also, an effect of differences between farms was found, as well as an interaction between crops and farm. No regional difference was found. Between the calculated z-values no difference was found. Only farms, however, did differ in z-values. Therefore, species-area curves were calculated for each crop for the first metre of the field and for the rest of the field.

As to the two types of *field margin strips*, no regional difference was found for either c- or z-values.

For the specific plant species found in ditch banks, crops and field margins, see the appendix of this thesis.

Table 1: Average c- and z-values of the species-area curves and calculated threshold values for ditch banks per region (Haarlemmermeer Polder, Zeeland and Noord-Brabant), crops for the first meter of the field and the rest of the field and field margins (GLM-LSD test: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$).

		c-value	z-value	Sampling area	Threshold value (90-percentile)
Conv. managed ditch bank:					
	Haarlemmermeer Polder	4.49*	0.34*	400 m ²	38
	Zeeland	2.77*	0.40*	400 m ²	34
	Noord-Brabant	2.70*	0.44*	400 m ²	49
Ecol. managed ditch bank:					
	Zeeland	5.65	0.37	400 m ²	51 ^a
Crops:					
ware-potatoes:	1 m	1.42***	0.44	100 m ²	15
	rest of the field	1.10***	0.40	100 m ²	10
sugar beet:	1 m	1.61***	0.42	100 m ²	11
	rest of the field	0.65***	0.49	100 m ²	8
winter wheat:	1 m	1.30***	0.44	100 m ²	12
	rest of the field	0.76***	0.44	100 m ²	7
Field margins:					
	1 m	5.65	0.37	25 m ²	10

^a 50-percentile

Regardless of the size of the sampling area, no difference in calculated plant species numbers in *ditch banks* was found between the two conventional management regimes similar to the differences found for the c- and z-values of the species-area curves. Again, there were only regional differences between plant species numbers, although these differences were not consistent for the various sizes of sampling area. With a sampling area between 250 and 300 m² species numbers in the Haarlemmermeer Polder and Noord-Brabant were similar, but significantly lower in Zeeland ($P_{\text{species number}} = 0.002$); with 350 m²

there were significant differences among all three regions ($P_{\text{species number}} = 0.002$) with numbers highest in Noord-Brabant; and from 400 till 500 m² numbers in the two clay regions Haarlemmermeer Polder and Zeeland were similar, but significantly lower than in the sandy region Noord-Brabant ($0.001 \leq P_{\text{species number}} \leq 0.002$). Within this last range of 400 till 500 m² the regional differences between sand and clay were consistent. We therefore opted to take 400 m² as the minimum sampling area.

For all sizes of sampling area (25 - 125 m²) in the *crops*, there was a difference in calculated species numbers between the first metre of the field and the rest of the field ($P_{\text{species numbers}} = 0.000$) similar to the c-values of the curves. No regional difference in plant species numbers was found for differently sized sampling areas. There were differences across crops ($0.004 \leq P_{\text{species numbers}} \leq 0.037$), although they varied with sampling area. Only with a sampling area of over 100 m² were differences between plant species numbers comparable to the differences found for the c-values. Therefore 100 m² was taken as the minimum sampling area (Table 1).

In the *field margins*, plant species numbers per sampling area (25 - 125 m²) followed the same pattern as for the c- and z-values with no regional difference found. For field margins the smallest sampling area of 25 m² was therefore taken.

No Red List species were found in any crop, field margin strip or on any ditch bank. Only one species with a protected status was found (*Lathyrus tuberosus*) on an ecologically managed ditch bank in Zeeland.

Most of the species found were classed as common or very common on the Dutch ladder of rarity (Table 2), with only a small number rare or fairly rare. Even on the floristically richer ecologically managed ditch banks, the majority of the plant species was common or very common.

Table 2: Percentage of plant species per rarity class for the ditch banks, crops and field margin strips.

	Ditch banks	Crops	Field margin strip
no longer present – extremely rare	0%	0%	0%
rare – fairly rare	1.4%	2.2%	1.6%
fairly common – common	20.7%	20.4%	18.7%
very common	77.8%	75.3%	79.7%

Based on the best 10% of the farms, in *ditch banks* the highest threshold value of 49 plant species was found in Noord-Brabant with respectively 34 and 38 in Zeeland and Haarlemmermeer Polder (Table 1). The conventionally managed ditch banks in Zeeland had significantly fewer plant species than those ecologically managed. Based on the 50-percentile of all plant species present, a threshold value of respectively 51 plant species per 400 m² was calculated for the ecologically managed ditch banks.

In the *crops*, calculated threshold values (90-percentile) ranged from 7 species per 100 m² (winter wheat) to 15 plant species per 100 m² (ware potatoes).

For *field margin strips*, finally, the calculated threshold value was 10 plant species per 25 m² (90-percentile).

4.4 Discussion and conclusions

Most of the landscape elements in agricultural landscapes are linear (Manhoudt and de Snoo, 2003) and the wider these are the more plant species they are likely to harbour (Marshall, 1992; Bickmore, 1999; Boutin *et al.*, 2002; Ma *et al.*, 2002). To avoid underestimating total species richness, therefore, the entire habitat gradient was included in the assessment. Because of the variation in ditch bank width in our study, this resulted in plots of varying sizes. By using the species-area relationship, however, it was possible to properly assess and compare the total plant species richness of linear habitats, independent of their width. Sampling effects due to variations in ditch banks width were also avoided (Melman *et al.*, 1991). In selecting the minimum sampling area for each type of habitat, it was important that all differences anticipated on the basis of the c- and z-values of the respective curves come to light and the curves should not cross outside the range of the selected sampling area: in Figure 1 the area should thus be larger than 200 m². For ditch banks on Dutch arable farms, a minimum standardised sampling area of 400 m² was required for inter-regional comparison to be valid. In the Haarlemmermeer Polder and Zeeland this meant sampling about 200 m of ditch bank and in Noord-Brabant 250 m. For crops a minimum sampling area of 100 m² could be used, as the differences in c-values were already significant with this plot size. For field margin strips, finally, the smallest sampling area of 25 m² could be taken, since no difference was found.

The sampling areas differed between habitat types. Other studies have proposed sampling areas that were based on the concept of minimum area in combination with the species-area relationship (Schaminee *et al.*, 1995). As a result, a wide range of sampling areas are in use and standardisation is therefore desirable (Albrecht, 2003). Friebe (Albrecht, 2003) has proposed adopting a sampling area of 100 m² for plant species inventories in arable fields in Germany, which is similar to the optimum figure for crops suggested here. The method developed in this study is generally applicable for semi-natural habitats or crops in different farming systems or countries, however, it might be necessary to validate.

To receive an environmental certificate, farmers must satisfy certain predefined criteria. If on-farm biodiversity is to be included as a new aspect of environmental certification schemes (Manhoudt *et al.*, 2002), suitable threshold values must be established for our indicator. Given the differences in plant species numbers on ditch banks between the clay and sandy region, threshold values should be defined per region (Waldhardt *et al.*, 2003).

We have opted to base our indicator thresholds on the variation in plant species numbers among conventional farms and specifically on the best 10% of these farms. By adopting more prudent pesticide and nutrient regimes, the farmer should be able to satisfy this criterion. Even though no fertilisers or pesticides may be applied directly on ditch banks, the prescribed uncropped zone (V & W *et al.*, 2000) is too narrow to prevent pesticide drift or nutrient leaching, which impact accordingly on ditch bank vegetation. Several studies have shown that the introduction of a 3 - 6 m wide buffer zone where no pesticides or nutrients are used significantly increased the species richness of adjacent ditch

banks (Fischer and Milberg, 1997; Kleijn and Snoeijs 1997; de Snoo, 1997; de Snoo and van der Poll, 1999).

The threshold values relative to the ecological management could only be determined for ditch banks in Zeeland. Although only four ecologically managed ditch banks were inventoried, plant species numbers there were significantly higher than on conventionally managed ditch banks. It can therefore reasonably be concluded that ecological management aimed at reducing nutrient inputs and vegetation biomass clearly led to an increase in plant species numbers, a conclusion also found in other studies (Marrs, 1993; Schippers and Joenje, 2002; van Beek, 2004). However, in our study there was no increase in botanically more interesting plant species, all species found being classed as very common in the Netherlands.

The threshold values calculated for crops and field margin strips were low compared with those for ditch banks. Within crops, species numbers did not differ across regions. The significantly higher number of plant species found in the first metre of the field in comparison with the rest is confirmed by other studies (Marshall, 1989; Wilson and Aebischer, 1995).

Comparing plant species numbers in the various kinds of habitats (cf. 100 m² in Figure 2), conventionally managed ditch banks had the greatest number of plant species (17), more than sown field margins (13) or crops (9 - 11).

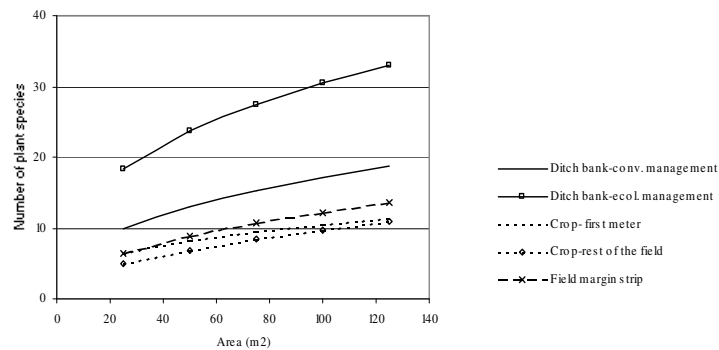


Figure 2: Number of plant species per area for ditch banks (under conventional and ecological management), crops (first metre of the field, rest of the field) and sown field margin strips in Zeeland.

Adopting a standardised sampling area makes this biodiversity indicator suitable for environmental certification and benchmarking. All types of farms can be evaluated and compared independent of their size. Every part of the farm should be representative for total plant species richness independent of its location on the farm. Other methods of determining plant species richness, e.g. extrapolation of species-area curves to the entire area of the farm, may lead to an overestimation (Palmer, 1990).

It is recommended to use the aggregate plant species diversity of ditch banks and crops to assess and evaluate on-farm biodiversity, even though these are all common species. Red List species cannot be used as an indicator for this purpose, because of their rarity in agricultural landscapes and on conventionally managed farms (Wilson, 1994; Albrecht, 1995; van der Meijden *et al.*, 2000; Sutcliffe and Kay, 2000). Plant species richness is in itself a meaningful indicator of biodiversity, but also relevant in the context of food webs (Duelli and Obrist, 1998; Robinson and Sutherland, 2002; Jeanneret *et al.*, 2003; Smeding and de Snoo, 2003). Used alongside criteria for the total area of semi-natural habitat on a farm, this indicator provides a useful tool for assessing on-farm biodiversity and, if appropriate management practices are introduced, for enhancing it too. To create an incentive to farmers, it is recommended that this indicator for on-farm biodiversity be used in benchmarks and environmental certification systems.

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