Sustainable Agriculture Research; Vol. 1, No. 2; 2012
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Plant Species Diversity and Composition of Plant Communities in Buffer Zones with Variable Management Regimes

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Received: April 5, 2012 Accepted: May 10, 2012 Online Published: July 15, 2012

doi:10.5539/sar.v1n2p152 URL: http://dx.doi.org/10.5539/sar.v1n2p152

Abstract

Field boundaries with permanent vegetation cover are a key habitat for farmland biodiversity. Buffer zones are wide field boundaries established to prevent nutrient leaching and erosion into waterways and serve as habitats for farmland wildlife. Our main hypothesis was that several years of grazing or cutting management results in greater plant species richness and heterogeneity in buffer zones in comparison with sites managed for only a few years. We also hypothesized that litter cover and soil phosphorus (P) level would decrease after several years of management, in comparison sites with relatively few years of management. Through this study we aimed to gain a better understanding of how to increase biodiversity in buffer zones. The study included 15 buffer zones within a single landscape. Mean species richness was significantly higher in the group of sites grazed over several years (21 species) in contrast to extensively cut sites (14.8 species) and/or grazed sites (18 species). Species heterogeneity did not respond to different management regimes. Management, slope aspect and litter were significant explanatory factors for species composition. The amount of soil phosphorus measured at three different depths was significantly lower in the buffer zones managed by cutting or grazing for a few years in contrast to those that were grazed for several years. Management that positively affected species diversity did not result in the expected decrease in soil phosphorus. Therefore, we propose that the greater species richness at grazed sites results mainly from disturbances caused by grazing.

Keywords: agriculture, buffer zone, cutting, grazing, management, plant community, species diversity

1. Introduction

The decline in farmland biodiversity has been reported in several recent studies (see Stoate et al., 2009). Field boundaries with permanent vegetation cover are one of the key habitats for farmland biodiversity and their establishment is supported by agri-environmental schemes (AES) in many European countries. Their main purpose is to prevent nutrient leaching and soil erosion from fields to waterways. Despite the activity of AES, biodiversity has not increased (Blomqvist, Tamis & De Snoo, 2008) and only particular groups of organisms have responded positively to AES (Kleijn, Berendse, Smit, & Gilissen, 2001; Kleijn et al., 2004; Roth, Amrhein, Peter, & Weber, 2008). One type of field boundary is represented by buffer zones, which comprise, on average, 15 m wide boundaries with permanent vegetation. Buffer zones are able to support greater plant species diversity than narrower boundaries by supporting increased heterogeneity of vegetation (Ma, Tarmi, & Helenius, 2002; Marshall, West, & Kleijn, 2006). Therefore, buffer zones could function as sites of greater species diversity in comparison with commonly used narrow boundaries (1 m to 3 m wide). Species may be dispersal-limited in field environments (Leng, Musters, & De Snoo, 2009) and there is therefore a need for species-rich habitats that could act as sources of species for species-poor habitats.

When buffer zones are managed, it is usually through grazing or cutting. Management that decreases the amount of phytomass, i.e. grazing or cutting with removal of the cuttings, increases species diversity in grasslands (Foster & Gross, 1998; Jacquemyn, Brys, & Hermy, 2003; Wahlman & Milberg, 2002) and field margins (De Cauwer, Reheul, D'Hooghe, Nijs & Milbau, 2005). In cutting, all species are treated homogeneously, compared with the heterogeneous effects of grazing, mainly resulting from selective grazing of plant species and cap formation in the vegetation (Jacquemyn et al., 2003). Management affects plant species richness indirectly by the amount of litter produced and its nutrient content, thick litter layers possibly reducing establishment and survival of seedlings (Bobbink & Willems, 1993; Foster & Gross, 1998).

High nutrient content in the soil may negatively affect plant species richness in field boundaries (Kleijn & Snoeijing, 1997), for example by influencing species colonization, hampering establishment and allowing species with high nutrient optima to survive early establishment (Blomqvist, Vos, Klinkhamer, & Ter Keurs, 2003). Site effects, such as slope and aspect, may also affect the microclimate and consequently species composition.

The use of diverse seed mixtures of meadow plant species can increase species diversity in field boundary vegetation (Bokenstrand, Lagerlöf, & Redbo, 2004) and the use of simple grass seed mixtures may result in reduced species diversity (Kleijn, Joenje, Le Coeur, & Marshall, 1998). However, simple grass seed mixtures are economical and easily available to the farmer, compared with diverse mixtures of herbs and grasses, which can contain exotic plant species not adapted to local conditions. In this study, all sites were established by sowing simple grassland seed mixtures of two to four species, which is the most common practice.

Previous studies of buffer zones have mainly focused on the short-term effects of establishment and management on species diversity (Kleijn et al., 1998; De Cauwer et al., 2005), or rarely the long-term effects of using different plant mixtures and annual cutting (Bokenstrand et al., 2004). We explored the effects of various management practices, by grazing or cutting, on the species composition and diversity of plant communities. We focused on buffer zones established with simple seed mixtures and located within a single landscape.

Our main hypotheses were that several years of management by grazing or cutting results in greater species richness and heterogeneity and decreased litter cover and soil phosphorus (P) level, in comparison with sites receiving only a few years of management. Through this study we aimed to gain a better understanding of how to improve biodiversity in buffer zones.

2. Material and Methods

2.1 Study Area

The study was conducted in the Jokioinen and Ypäjä communities in southern Finland during 2002. This region is a typically flat agricultural landscape. The average length of the thermal growing season is 165 days and the fields are mainly used for cereal and forage production. In total, 15 buffer zones were chosen from the area of 92 km^2 (67.45°N - 67.54°N, 29.79°E - 31.09°E). They were located on the banks of the Loimijoki River or its branches. All buffer zones from the area were included in the study and all sites represented clay soils. Although the landscape is mainly flat, the gradient of the slopes varied from flat to relatively steep, depending on the depth of the channel at a site.

The environmental variables used in the redundancy analysis are listed in Table 1. The age of the study sites ranged from 7 to 22 years. The width also varied within each site and for this study it was measured from the same location as that for the vegetation sampling. Neither the age nor width was significantly different between the treatment groups.

2.2 Botanical Studies and Litter

Botanical studies were undertaken in July 2002. A transect of 50 m² (length 25 m, width 2 m) was established for each buffer zone. The transects started from the buffer zone edge (from the waterway side) and continued towards the field. If the old ditch bank of natural vegetation occurred between the waterway and the established buffer zone, it was excluded from the sample area. The transect was positioned diagonally in buffer zones less than 25 m wide The distance of the transect from the field was always kept to at least 1 m, to exclude the area most likely disturbed by cultivation (Kleijn & Verbeek, 2000). Species richness was assessed from the 50 m² transect. Three 1m^2 quadrats were examined along the transect to estimate species composition. Two of these were located 2 m from the ends of the transect and one in the middle (distances from one end 2-3 m, 12-13 m, 22-23 m). Plant species coverage percentages were estimated, with absolute coverage values ranging from 0.25% to 100% per species. The mean coverage value for each species was assessed as an average value from the three 1 m^2 quadrats. Species nomenclature was based on Hämet-Ahti, Suominen, Ulvinen and Uotila (1998). Litter was measured as the coverage-percentage of the ground layer of the vegetation.

Table 1. Descriptive statistics of the environmental variables used as explanatory factors in the redundancy analysis and the results of paired comparisons between the variables. The amounts of Ca and P are expressed as mg l^{-1} soil. Significance: ns = non-significant, * $P < 0.05$, ** $P < 0.01$. Aspect describes direction of slope. Slope describes the steepness.

	Management 1	Management 2	Management 3		Paired comparisons[2)]		
	Mean(S.E.)	Mean(S.E.)	Mean(S.E.)	F[1)]	M1 vs M2	M1 vs M3	M2vsM3
N = 15	4	6	5				
SOIL							
Ca (mgl^{-1})	2359(212)	2684(96)	1515(171)	12.4**	ns	**	**
P (mg l^{-1} per litre of soil)							
0–2 cm	5.8(0.7)	12.8(4.3)	14.6 (1.5)	9.8**	**	**	ns
2–5 cm	3.9(0.4)	8.8(3.0)	9.1(1.4)	10.5**	**	**	ns
5–10 cm	4.1(0.7)	8.0(2.6)	6.7(0.9)	7.79*	**	ns	ns
0–20 cm	7.8(0.9)	7.8(1.4)	7.9(1.0)	ns			
SITE							
Age (years)	11(1.1)	11.8(0.6)	13.8(2.5)	ns			
Width (m)	21.4(5.1)	16.2(2.9)	31.2(4.7)	ns			
Litter (% coverage)	33.9(12.3)	49.2(9.6)	73.3(10.1)	ns			
Aspect (number)							
North	1	0	1				
South	2	4	1				
West	1	1	0				
East	0	1	0				
Flat	1	0	2				
Slope (number)							
Steep	1	2	2				
Moderately steep	3	4	0				
Flat	2	0	2				
DIVERSITY							
Species richness	14.8(1.2)	18(1.1)	21(2.7)	4.6*	ns	*	ns
Species dominance (Simpson's index)	0.69(0.05)	0.80(0.02)	0.65(0.06)	ns			

[1)] Degrees of freedom for numerator = 2 and for denumerator = 7 for all analyses

[2)] Degrees of freedom for numerator = 1 and for denumerator = 7 for all analyses

2.3 Site Establishment

All buffer zones except one control site were established by sowing a simple grass seed mixture, the composition of which comprised two to four species. The mixtures included timothy *Phleum pratense* L., meadow fescue *Festuca pratensis* Huds. and red clover *Trifolium pratense* L., *P. pratense* and *F. pratensis*, *P. pratense* and *T. pratense*, or cocksfoot *Dactylis glomerata* L., *P. pratense*, *F. pratensis* and perennial ryegrass *Lolium perenne* L. The species sown were not estimated as a specific variable, but were analysed among other species for two reasons. Firstly, the sites were a minimum of 7 years old and the species used in the seed mixtures may also have already existed as volunteer species in the buffer zone. Therefore, it would be impossible to distinguish the proportion of the species sown. Secondly, most of the sites were established several years before management was initiated.

2.4 Management

Depending on site and year, the cutting was performed once in June, July or August. The grazing animals were heifers, except for horses in the oldest pasture. Grazing usually started in late May. The managed buffer zones were put into three groups according to their management regime. The first group (Man_1) included sites that were managed for not more than 4 y, the second (Man_2) sites managed during 5 y and the third (Man_3) sites grazed for at least 6 y. Man_1 included only 1-2 y of cutting + removal or grazing and a maximum of 2 y cutting without removal. Sites in Man_2 were mainly cut, but could also be grazed for a maximum of 2 y. If no grazing occurred at a site, the management included at least 2 y of cutting + removal. Man_3 included only grazing management, but a 2-3 y break could occur in grazing.

2.5 Site Characteristics

Each buffer zone was classified into one of five aspect groups, according to the direction to which the site faced. The groups were based on the four cardinal points (N = North, S = South, W = West and E = East). If the site was not directed precisely to one of the cardinal points, the nearest point was chosen. Flat sites were put into a separate group (F). The sites were put into three groups according to slope: steep, moderate and flat. This classification was based on visual estimation. Soil samples were collected in 2003 by taking 20 subsamples per zone (1 m intervals), using a soil bore. These subsamples were mixed to produce a single sample for soil analyses. Soil P was also analysed from three different depths (0-2, 2-5, 5-10 cm). The layer samples were collected with a spade from the middle of the 25 x 2–m transects. The amounts of calcium (Ca), P, potassium (K), and magnesium (Mg) were measured (mg 1^{-1} of soil) using acid ammonium acetate, pH 4.65 (Vuorinen & Mäkitie, 1955). Only Ca and P were included in further analyses, due to strong correlations between other soil factors.

2.6 Data Analyses

The relationships between the buffer zone vegetation and the management and edaphic factors measured were examined using the CANOCO for Windows 4.02 statistical package (Plant Research International, Wageningen, The Netherlands) (Ter Braak & Šmilauer, 1998). Site coordinates were included as covariables to determine the possible spatial structure of the data. Detrended correspondence analysis (DCA) was applied to measure the length of the gradients for the first two axes. The gradient was 3.4 for axis 1 and 2.5 for axis 2. Thus, the use of linear redundancy analysis (RDA) instead of unimodal canonical correspondence analysis (CCA) was appropriate (Jongman et al., 1995).

The default options of RDA (i.e. scaling based on interspecies correlations, species scores divided by standard deviation, no transformation, centring by species) were used. The mean coverage value from the quadrat data for each species was used in the analyses. Aspect, management and slope were used as dummy variables. The significance of the first RDA axis and the overall significance of the RDA models were evaluated with Monte Carlo permutation tests (799 permutations) in all analyses. The permutation test was also used to test the significance of the explanatory variables in the forward selection procedure. As listed in Table 1, explanatory variables, of which the *P*-value of conditional variance was greater than 0.05, were excluded from the final analyses.

Species richness (number of species S) and an evenness index (Simpson's D) were used as measures of species diversity. The reciprocal form of Simpson's index (1/D), in which the index value increases when evenness rises, was used (Magurran, 2004). The index values were calculated using BIODIV® software version 4.1 (Exeter Software, Setauket, NY, USA) (Baev & Penev, 1993).

Differences in species richness and evenness, the amount of soil P and Ca, litter coverage, and the width and age of the buffer zone were tested among the management intensity levels. Linear mixed models were applied for the analyses. The data on soil P and species evenness were log+1 transformed prior to the analyses. Statistical tests were conducted using the statistical packages SAS 9.1 for Windows (SAS Institute Inc., Cary, NC, USA) (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006).

3. Results

3.1 Species Number and Abundance

In total, 68 plant species were recorded from the 50 m^2 transects. The mean species number for all sites was 18, ranging between 10 and 30. The most frequent and often also the most abundant species in the 3 m^2 areas were common couch *Elymus repens* (L.) Gould (frequency 13 sites, mean cover 20%), *Phleum pratense* (15, 15%) and meadow foxtail *Alopecurus pratensis* (12, 9%). Species that were frequent with low coverage were cow parsley, *Anthriscus sylvestris* (L.) Hoffm. (11, 3.3%), creeping thistle, *Cirsium arvense* (L.) Scop. (10, 1.3%), *Festuca pratensis* (12, 5.7%), dandelion, *Taraxacum* sp. Weber (14, 6.3%) and white clover, *Trifolium repens* L. (11, 5.7%). All of the above are perennials. Annual species, such as scentless mayweed, *Tripleurospermum inodorum* (L.) Sch. Bip., (5, 0.7%) and hemp-nettle, *Galeopsis* sp. L. (2, 0.2%), occurred only sparsely, typically at low abundance.

3.2 Species Composition and Environmental Factors

Table 2. Variables included in the forward selection procedure in RDA (Monte Carlo permutation test, n= 799; only those statistically significant ($P < 0.05$) are included in the final RDA).

	Marginal variance[1)]	Conditional variance[2)]	F	*P*
SOIL				
Phosphorus (P)	0.02	0.05	1.45	0.270
Calcium (Ca)	0.11	0.01	0.82	0.526
SITE				
Age	0.05	0.07	2.07	0.087
Width	0.06	0.04	1.69	0.256
Litter	0.15	0.12	2.75	0.035
Aspect				
South (S)	0.18	0.18	3.44	0.011
North (N)	0.09	0.03	1.36	0.315
East (E)	0.05	0.02	3.47	0.226
West (W)	0.05	0.05	0.00	1.000
Flat (O)	0.07			
Slope				
Flat (F)	0.07	.	.	.
Moderate (M)	0.09	0.05	1.26	0.275
Steep (S)	0.04	.	.	.
MANAGEMENT				
Man_1	0.06	0.02	1.71	0.179
Man_2	0.13	0.12	3.07	0.019
Man_3	0.10	.	.	.

[1)] Marginal variance is that which explains individually if it is the only explanatory variable in the model

[2)] Conditional variance is the additional variance each variable explains at the time it was included in the model (Ter Braak & Šmilauer, 1998)

Three environmental variables appeared as significant explanatory variables for species composition in forward selection: Management (Man_2), Litter and Aspect (South), as indicated in Table 2 and Figure 1. When all three significant variables were included in the RDA analysis, the eigenvalue of the first axis was 0.193 and for the second axis 0.151. The first axis explained 26% of the species variation and 46% of the variation in species-environment relationships. For the second axis, the respective percentages were 20% and 36%. Cumulatively, the first two axes explained 46% of the species and 82% of the species-environment relationship. In the Monte Carlo test, the significance for the first axis was $P = 0.05$ (F = 3.073) and for all axes $P = 0.001$ (F = 3.734).

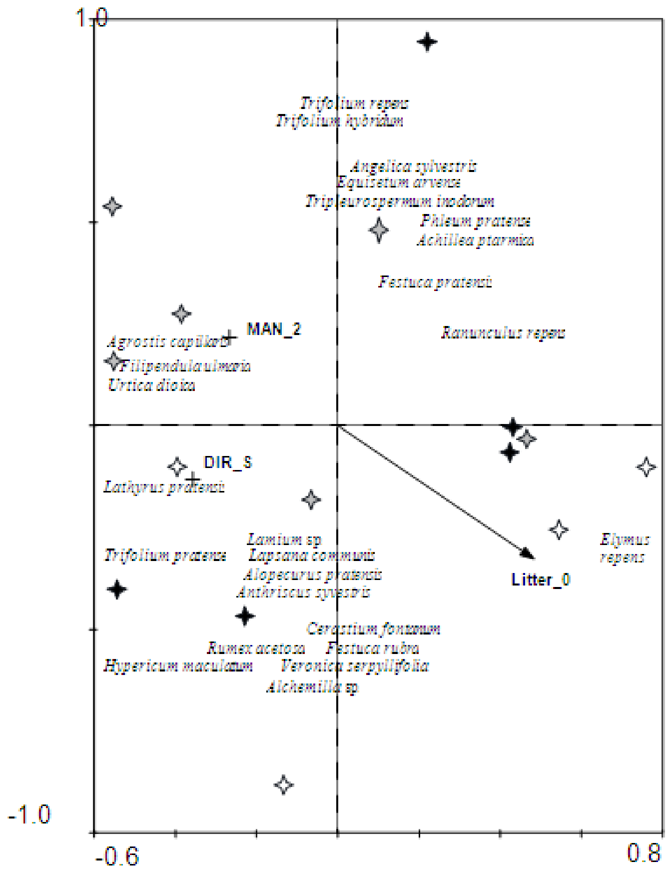

Figure 1. Ordination diagram of redundancy analysis. Plant species and statistically significant explanatory variables presented. Nominal variables Man_2 (5 years of management by cutting and/or grazing) and Dir_S (south aspect) have no arrows; the crosses indicate the location of the centroid of the variable. The number of plant species in the figure (of a total of 48) is 25. These were included with the fit range of 10–100% in the CanoDraw program. Site symbols are coloured according to the management group: Man_1 = black, Man_2 = grey and Man_3 = white.

As shown in Figure 1, the sites were not grouped in ordination, according to the management, because two other factors also significantly affected species composition. The abundance of litter and *Elymus repens* were positively associated. The amount of litter was highest in grazed sites (Man_3). The southern aspect seemed important and the most representative meadow species (lady's-mantle, *Alchemilla* sp., imperforate St John's wort, *Hypericum maculatum* Crantz, goldilocks buttercup, *Ranunculus auricomus* L. and thyme-leaved speedwell, *Veronica serpyllifolia* L.) were located in the vicinity of this aspect in the ordination graph. The management regime that included mainly cutting (Man_2) was an important explanatory factor for the species composition of four sites. There were no dominant species clearly associated with these sites, but *Taraxacum* sp. was rather abundant. Other species occurred only occasionally with variable abundances. *Trifolium repens* was highly abundant at one site, distant from the others in the ordination Figure 1.

3.3 Species Richness and Environmental Factors

As shown in Table 1, differences were detected between the management regimes regarding species richness, Ca, and P, which were measured from three soil layers. In pairwise comparisons, species richness was significantly higher in Man_3 than in Man_1. Species heterogeneity did not differ significantly between the management groups. The level of P was significantly lower in Man_1 in the upper layers, compared with Man_2 or Man_3, as indicated in Table 1. The Ca level was significantly lower in Man_3 in contrast to Man_1 and to Man_2. Total P (depth 0-20 cm) did not differ between the management groups.

4. Discussion

As expected, the management regime with long-term grazing resulted in significantly greater species richness in comparison with the management regimes with 5 or fewer years of cutting and/or grazing. The amount of P in the soil was not diminished by more active management. Species heterogeneity and the amount of litter did not differ markedly between the management regimes. However, species composition responded significantly to management, litter and site.

The species composition did not differ enough between the management regimes to form separate groups, based on management in the ordination analysis, although three factors were significant for the species composition. Changes in plant communities in response to management are usually slow (Pykälä, 2003). Our study sites comprised formerly arable land, and time was likely too short for considerable changes to take place in species composition or colonization of valuable meadow species. The development of representative meadows may never be possible. Species dispersal limitation may be crucial in restricting the increase in species diversity in agricultural landscapes (Leng et al., 2009), where the distance between suitable habitats may be considerable.

It is important that tall, highly competitive species are limited through appropriate establishment and management for new species recruitment. In the present study, all management regimes resulted in similar abundances of these species, a result also reported in previous studies of mainly unmanaged boundaries (Tarmi, Tuuri, & Helenius, 2002). In the present study, and that of Tarmi et al. (2002), only *E. repens* was frequent and abundant in the boundaries, whereas several other generalist, fertile-soil-favouring species were frequent at usually low abundance, on average. *Elymus repens*, which may also produce thick litter layers if its biomass is not removed, was linked to litter abundance in the ordination analysis. The greatest amount of litter in grazed sites may be explained by the selective grazing. Only young shoots of *E. repens* are eligible for cattle. The abundance of litter is an important factor for species composition that affects seedling establishment and survival (Tilman, 1993; Ruprecht, Enyedi, Eckstein, & Donath, 2010; Tarmi, Helenius, & Hyvönen, 2011) and the results of this study also indicated the importance of litter as an explanatory factor for species composition.

When the boundary is invaded and dominated by one or several of such types of species, establishment by sowing and management limits their abundance. For example, *E. repens* and *C. arvense* can be reduced by cutting (Hansson & Fogelfors, 1998) and sowing grasses (Marshall, 1990). The weed-diminishing effects of sowing were also reported in several other studies (West, Marshall, & Arnold, 1997; Kleijn et al., 1998; Lawson, Ford, & Jonathan, 2004; De Cauwer, Reheul, Nijs, & Milbau, 2008).

The levels of P were lowest in the most extensively managed sites and the difference was most clear in the uppermost soil layers (0-2 cm and 2-5 cm). The result is congruent with Marrs (1993) that net uptake of P is not accomplished very effectively by grazing and the amounts decrease very slowly. Moreover, grazing increases nutrient cycling and may even increase production. Cutting and occasional grazing did not result in marked decrease in soil P.

The highest amount of P in the top soil (0-2 cm) and the decrease towards deeper layers indicate the accumulation of P in the soil from decayed plant material (Uusi-Kämppä & Jauhiainen, 2010) and from cattle dung. Additional cattle feeding may also have been practised at some sites. Thus, the cattle might not consume as much buffer zone vegetation as is available. Moreover, the amount of nutrients in the buffer zone increases with the dung produced from the additional feed.

The highest species richness occurred together with the high P content, which contrasts with the theory that low soil fertility supports higher species richness than does high soil fertility (Tilman, 1986). In our study, the most likely explanation for the highest species diversity at the grazed sites could be the disturbance effects of grazing on the soil (Marrs, 1993; Jacquemyn et al., 2003). Small patches caused by trampling or variation in soil fertility resulting from dung spots could create heterogeneity and increase species diversity. The effect of grazing or cutting on species depends on many factors, including intensity and timing (Smith & Rushton, 1994; Smith, Shiel, Millward, & Corkhill, 2000). Pykälä (2003) reported considerable variation in the quality of grazing (intensity, timing and possible use of supplementary forage).

5. Conclusions

Based on our results, none of the management practices was sufficient to result in marked changes in vegetation. The management regime incorporating long-term grazing resulted in significantly higher species richness in contrast to the other management regimes. Species heterogeneity did not differ markedly according to management regime Moderate disturbance had a positive effect on diversity despite high soil phosphorus. Litter accumulation in *Elymus repens* dominated, grazed sites may be avoided by careful timing of grazing.

Results indicate that further long-term experimentation is needed to determine the management practices that enhance the conservation value of buffer zones. Buffer zones that were formerly arable land represent challenging targets for improving botanical diversity of field environments.

Acknowledgments

We are grateful to Jaana Uusi-Kämppä for fruitful cooperation. We want to thank Ari Turtola for guidance in finding all the buffer zones appropriate for this study and for information on the known history of the study sites. We also thank Ari Seppänen for help in collecting the soil samples and Ester Leburgue for assisting in collecting the vegetation data. Juha Helenius gave valuable comments on the manuscript. This study was carried out in the project Laitumen ja suojavyöhykkeiden ympäristökuormitus (The environmental loading of pasture and buffer zones) financed by the Ministry of Agriculture and Forestry and MTT Agrifood Research Finland. Sanna Tarmi received financial support from the Ella and Georg Ehrnrooth Foundation and the Research Foundation of August Johannes and Aino Tiura. Terho Hyvönen received financial support from the Academy of Finland (project number 122477).

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