ELSEVIER

Agriculture, Ecosystems and Environment 89 (2002) 127–135

Agriculture Ecosystems & Environment

www.elsevier.com/locate/agee

Impact of agricultural fields on vegetation of stream border ecotones in Denmark

A.B. Hald*

National Environmental Research Institute, Frederiksborgvej 399, DK-4000 Denmark

Abstract

A 2 m wide uncultivated border along streams is a statutory requirement in Denmark, as this is meant to stabilise the stream bank physically, to protect streams from surface water runoff and soil loss from the fields. In order to evaluate these benefits and to assess nature quality of non-forested border ecotones, a multidisciplinary project was initiated. This paper assesses the impact of agricultural land use of the bordering neighbour field on the botanical quality of the vegetation of stream border ecotones. Botanical quality is also evaluated in relation to distance to fields in annual crop rotation. In comparison with reference ecotones bordering permanent natural grassland, the border ecotones of fields in annual crop rotation had poorer species richness, especially among the Phreatophyte species. The remaining species were more often associated with eutrophic and productive biotopes. The impacts may be a consequence of nutrient load, pesticide drift and physical disturbance from the fields in rotation. The differences in botanical quality were more pronounced for the vegetation of the stream border than of the stream bank. This is a consequence of the borders being closer to the fields in rotation than the banks.

Keywords: Annual crop rotation; Botanical quality; Buffer zone; Permanent grassland

1. Introduction

A 2 m wide uncultivated border is a statutory requirement along most streams in Denmark (Section 69 in Anonymous, 1992). This uncultivated border with a vegetation cover of perennial plant species is meant to stabilise the stream bank physically, to protect streams from surface water runoff, and soil loss from the fields. Furthermore, the border, which together with the stream bank makes up the border ecotone, is a potential habitat for plant species from both the wet and dry biotopes (Naiman et al., 1993). The stream border is also expected to be an important dispersal corridor for these plant species (Skoglund, 1990; Nilsson et al., 1993; Johansson et al., 1996). The literature concerning buffer zones along streams mostly deals with their capacity to retain and transform nutrients and pollutants and the interactions of these functions with the width of the buffer zone (see, e.g. Yates and Sherian, 1983; Muscutt et al., 1993; Haycock et al., 1993, 1997; Vought et al., 1995; Mander et al., 1997; De Snoo and De Wit, 1998). There are few papers dealing with nature quality values of border ecotones, their potential for dispersal of plants and factors influencing these properties. Skoglund (1990), Nilsson et al. (1993) and Johansson et al. (1996) have found evidence for dispersal of propagules along rivers. Naiman et al. (1993) and Décamps (1993) consider riparian ecotones to be of special importance as species dispersal corridors, including dispersal during changing environmental conditions.

* Tel.: +45-46-30-12-00; fax: +45-46-30-12-12.
E-mail address: abh@dmu.dk (A.B. Hald).

0167-8809/02/$ – see front matter
PII: S0167-8809(01)00324-3

Van Diggelen (1998) emphasises the importance of dispersal of propagules by water for restoration of riparian wetlands.

A multidisciplinary 5-year Danish project was initiated in 1997 in order to evaluate the benefits of a border in relation to stream bank stability and protection of the stream from surface runoff and soil loss and to assess nature quality of the borders. The project aims to evaluate the impact of climate, physical factors of the cultivated soil and agricultural management, and to assess the risk of soil erosion in the cultivated field. Another aim is to determine the characteristics of the border vegetation, which influence the ability of the border to protect the stream from the eroded materials. This paper will focus on the final project aim, namely to evaluate the impact of agricultural land use of the neighbouring field on the botanical quality of the border ecotone and the effects of distance to field in annual arable crop rotation. Botanical quality is measured as species richness, proxies for productivity and the potential of the border ecotones as dispersal corridors.

1.1. Hypotheses

In the 1950s, most areas along Danish streams were used as hay meadows or they were grazed. Fields in arable crop rotation were located away from the flooding risk of the stream valleys during winter. Intensification of agricultural practise has resulted in most of these areas along streams being drained and changed into fields sown to arable crops or to semi-permanent cultural grassland in rotation, i.e. in rotation at least once every 7th year. Some of the meadows still exist as permanent natural grassland, but they have been improved more or less for agricultural grass production. These meadows are now characterised as moist to dry natural grassland.

There are no records of the botanical quality of the stream border ecotones in the 1950s. Therefore, border ecotones along moist to dry permanent natural grassland are used as references. One hypothesis tested is that the botanical quality of non-forested border ecotones next to fields in annual rotation or cultural grassland does not differ from the quality of the border ecotones next to permanent, but more or less improved natural grassland. The second hypothesis tested is that the botanical quality of the border ecotone is independent of the distance to the field in annual rotation.

2. Methods

2.1. Selection of Slope Units

In total, 135 fields in annual crop rotation or with intensive cultural grassland, situated next to a stream and expected to have a high risk of water-initiated soil erosion, were selected from 18 study areas throughout Denmark. A field in annual rotation—or with cultural grassland—and including the stream border and stream bank is called a rotational Slope Unit in this project. Further, each study area included one or two permanent natural grassland fields as reference Slope Units. These grassland Slope Units had soil type, topography, distance to the water table and stream order as similar as possible to the rotational Slope Units. Most of the natural grassland fields were grazed and a few had been abandoned as grazed fields a few years ago.

To identify different types of rotational Slope Units, all of the 135 Slope Units were characterised in 1997 in relation to openness, soil type, dominant vegetation type and width of the buffer zone between the field in annual rotation and the stream and grouped accordingly (Table 1). The buffer zone included the cultural grassland if present. For more intensive studies, three Slope Units were selected randomly from nine of the non-forested types, giving a total of 27 rotational Slope Units. Further, each of the study areas in which rotational Slope Units were selected for intensive study was matched by two grassland Slope Units. In total, we used 30 grassland Slope Units.

2.2. Analyses

Within each Slope Unit, three permanent plots were located on the stream border and three paired plots were located on the stream bank. These were located within a 50 m length of stream, bank and border. As streams are biotope features measured in units of length, the plots had a length of 1 m, but of varying width. On the bank, plots were placed from the border edge down to the level of the water in summer. In the border, the width of the plot was equal to the width

Table 1
Characteristics of buffer zone of the 135 rotational Slope Units, i.e. a stream border next to fields in annual rotation[a]

All over type	Soil type	Dominating vegetation type	Width of buffer zone (m)	# Slope Units
Non-forested and un-grazed	Clay	Herbs	<2	3[b]
		Herbs	>2	8[b]
		Grasses	<2	11[b]
		Grasses	>2	13[b]
	Sand	Herbs	<2	1
		Herbs	>2	7[b]
		Grasses	<2	19[b]
		Grasses	>2	23[b]
Non-forested and grazed	Clay	Grasses	>2	7[b]
	Sand	Grasses	>2	26[b]
Forested	Both types	Both types	Both types	17

[a] The buffer zone includes cultural grassland if present.
[b] Three rotational Slope Units of this type included in the intensive analyses.

of the border, up to a maximum of 2 m (equal to the statutory requirement). These plots were less than 2 m wide if not of the statutory width or if the border had been increased in width very recently. If a fence wire was present the border plot, was placed between the fence wire and the border/bank edge, again up to a maximum width of 2 m.

The vegetation in the plots was recorded during July using an abundance-cover method. For each plot, the proportion of the total cover in the plot was allocated to different species and bare ground giving a total cover of 100%. Species contributing to the cover in a plot by 5% or more were included in the group of dominating species. As the permanent plots

Table 2
Botanical quality (biodiversity, proxies for productivity and dispersal potential) of border and bank in relation to land use of the neighbouring field and *P*-value of *t*-test comparing variables within borders or within banks

Variable	Border			Bank		
	R[a]	*G*[b]	*t*-Test	*R*[a]	*G*[b]	*t*-Test
# Slope Units in *t*-test	27	30	*P*	27	30	*P*
Biodiversity						
# Species per 3 m	16	28	<0.001	17	24	<0.001
# Species per 0.3 m^2	8	17	<0.001	8	12	<0.01
# Dominating species[c] per 3 m	6	8	<0.001	6	6	NS
Productivity						
Canopy height (cm)	74	55	<0.001	83	82	NS
Biomass (gm^{-2})	427	305	<0.01	–	–	–
Ellenberg N index	7.2	5.9	<0.001	7.4	6.2	<0.001
% Cover *U. dioica, E. repens, G. aparine*	52	13	<0.001	34	13	<0.001
% Plots with *G. aparine*	72	38	–	67	54	–
Dispersal corridor						
% Phreatophytes per 0.3 m^2	13	33	<0.001	23	36	<0.01
% Aphreatophytes per 0.3 m^2	75	53	<0.001	62	49	<0.01
# Phreatophytes, total	35	81	–	49	74	–
# Aphreatophytes, total	67	72	–	53	83	–

[a] Field in annual rotation or with cultural grassland (rotational Slope Units).
[b] Permanent natural grassland (grassland Slope Unit).
[c] Species with 5% cover or more in the plot.

were of unequal size, the abundance-cover analysis was supplied with a frequency analysis using a Raunkiær circle of 0.1 m^2 located in the centre of the permanent plot. The height of the plant green canopy was measured in the centre and in each of the four quadrants of the plots. The above-ground biomass of the border canopy was harvested in late July in two 0.1 m^2 samples close to one of the three plots and dried at 80 °C. Species richness of the border and the bank was calculated as number of species, both per unit area and per unit length, and as the number of dominant species per unit length. Ellenberg nitrogen index (Ellenberg et al., 1992), weighted according to species abundance-cover value, was calculated and included as a productivity variable. In agreement with the ecotone character of stream borders (Holland et al., 1990), the species were divided into wetland species (Phreatophytes) and species from dry habitats (Aphreatophytes) according to Londo (1988). The means of variables included in the evaluation of botanical quality were compared with *t*-tests. In comparing means, one value (mean per plot or aggregated from three plots) was included for each Slope Unit. Samples with high species richness, low productivity and high potential source for dispersal of wild plants were ranked as highest botanical quality.

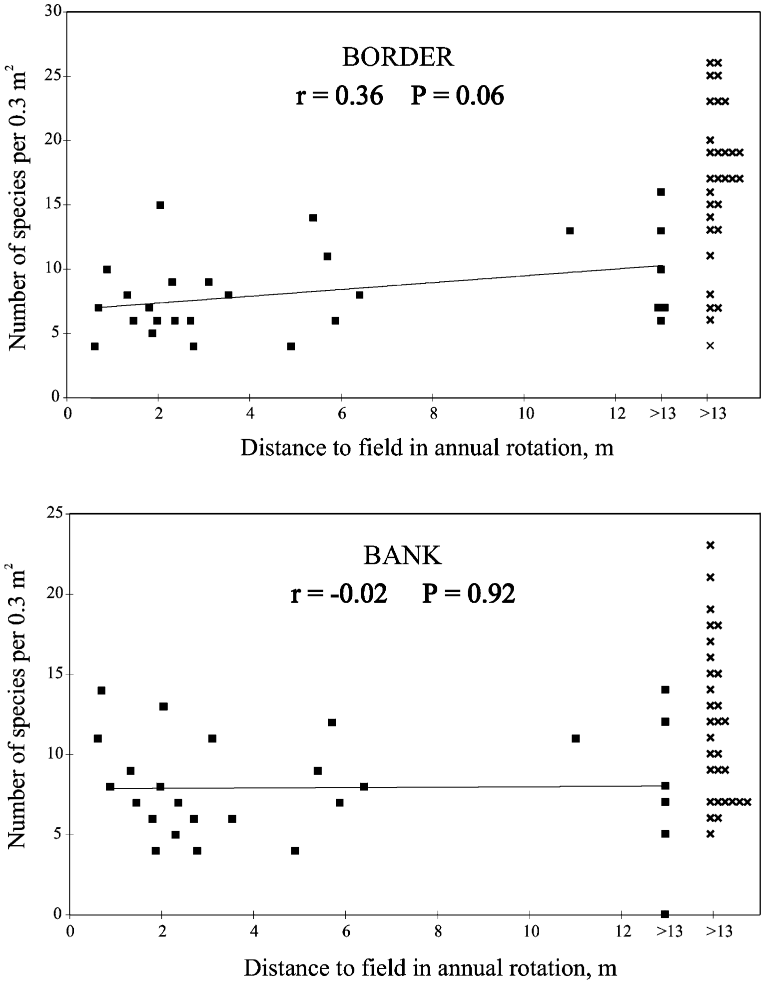

Fig. 1. Number of species in border and bank in relation to distance to field in annual rotation. Border ecotones next to fields in rotation or cultural grassland (■) or natural grassland (×). Distance to field in annual rotation is set to >13 m for cultural and natural grassland. Pearson correlation coefficient (*r*) and *P*-value for rotational Slope Units is shown.

3. Results

3.1. Species richness

The total number of species in the plots was lower in the border ecotones next to rotational fields than next to grassland (Table 2). Also the number of dominant species, that is species with 5% cover or more in the plot, was less in the border ecotones next to rotational fields than along grassland. These findings were more pronounced for the vegetation of the border than for the bank.

Table 3
Rank of occurrence of the 30 most frequent Aphreatophytes and Phreatophytes species in the borders and banks of stream border ecotones next to permanent natural grassland (*G*)[a]

Border						Bank					
Aphreatophytes			Phreatophytes			Aphreatophytes			Phreatophytes		
Species[b]	Rank		Species[b]	Rank		Species[b]	Rank		Species[b]	Rank	
	G	*R*		*G*	*R*		*G*	*R*		*G*	*R*
fest_rub	1	13	holc_lan	1	5	urti_dio	1	1	fili_ulm	1	1
urti_dio	2	1	fili_ulm	2	11	arrh_ela	2	3	epil_hir	2	2
poa_tri	3	7	ranu_rns	3	4	poa_tri	3	6	phal_aru	3	3
arrh_ela	4	5	phal_aru	4	9	holc_mol	4	9	glyc_max	4	
aego_pod	5	4	desc_cae	5	8	fest_rub	5		peta_hyb	5	
elyt_rep	6	2	taraxacz	6	3	aego_pod	6	2	scir_syl	6	
holc_mol	7		agro_sto	7	6	elyt_rep	7	5	holc_lan	7	
poa_pra	8	15	glyc_max	8		gali_apa	8	7	junc_eff	8	10
loli_per	9	14	scir_syl	9		anth_syl	9	4	lo_ul.ul	9	
agro_ten	10		alop_pra	10	1	rubu_ida	10	8	desc_cae	10	
anth_syl	11	3	ranu_acr	11		cirs_arv	11	12	ranu_rns	11	12
gali_apa	12	6	epil_hir	12	10	dact_glo	12		ange_syl	12	
dact_glo	13	10	junc_eff	13		loli_per	13		alop_pra	13	9
rume_asa	14		impa_nol	14		rume_asa	14		myos_pal	14	
cirs_arv	15	8	agro_gig	15	15	agro_ten	15		chry_alt	15	
anth_odo	16		cirs_pal	16		trif_med	16		agro_sto	16	
ce_fo.tr	17		alop_gen	17		cham_ang	17		cirs_pal	17	
glec_hed	18		succ_pra	18		stel_gra	18		sola_dul	18	
trif_rep	19		lo_ul.ul	19		sile_dio	19	14	epil_c/r	19	7
lath_pra	20		equi_pal	20		lath_pra	20		ga_pa.pa	20	
achi_mil	21		bell_per	21		vici_cra	21		alop_gen	21	
stel_gra	22		achi_pta	22		gali_mol	22		cirs_ole	22	8
cyno_cri	23		myos_pal	23		ce_fo.tr	23		ranu_acr	23	
hier_pil	24		epil_c/r	24		gale_tet	24		equi_pal	24	
plan_lan	25		ca_pr.pr	25		geum_urb	25	15	taraxacz	25	
c_hirta	26		c_distic	26		cent_sca	26		card_ama	26	
gali_sax	27		geum_riv	27		cyno_cri	27		caly_sep	27	15
lotu_cor	28		lych_flo	28		poa_pra	28		lysi_vul	28	5
vici_cra	29		gale_spe	29		vero_cha	29		glyc_flu	29	
rume_cri	30		equi_arv	30	2	trif_rep	30		ment_aqu	30	
myrr_odo	>35	9	caly_sep	>35	7	myrr_odo	>35	10	geum_riv	>35	4
arte_vul	>35	11	glyc_dec	>35	12	alli_pet	>35	11	merc_per	>35	6
rubu_ida	>35	12	stac_syl	>35	13	rubu_ida	>35	13	calt_pal	>35	11
			lysi_vul	>35	14				stac_syl	>35	13
									eupa_can	>35	15

[a] For comparison, the rank of the 15 most frequent species from ecotones next to fields in annual rotation (*R*) are indicated.
[b] Species list and abbreviations used are found in Appendix A.

3.2. Productivity

The border ecotones next to rotational fields had higher productivity than the vegetation of the borders next to permanent grassland. This was indicated by the different proxy variables: the canopy of the field layer was higher, the biomass was higher, the vegetation had a higher Ellenberg nitrogen index, and the three eutrophic species *Urtica dioica*, *Elytrigia repens* and *Galium aparine* had higher cover (Table 2). Further, the annual species *G. aparine* was found in the highest percentage of plots in border ecotones along fields in annual rotation. These findings were more pronounced for the vegetation of the border than of the bank.

3.3. Dispersal corridors and occurrence of species

The proportion of wetland species (Phreatophytes) among the species in the plots was lower in the border ecotone next to rotational fields compared with ecotones next to permanent grassland. The opposite was the case for species from dry habitats (Aphreatophytes). These differences were more pronounced for the vegetation of the border than of the bank (Table 2). The species density of the border of the rotational ecotone tended to be correlated with the distance to the rotational fields (Fig. 1). No such tendency was found for the bank. Comparing the rank of occurrence of the 30 most common species from natural grassland border ecotones with rotational border ecotones, it can be seen that the rank of species was more alike for the border than for the banks and more alike for the Aphreatophytes than for the Phreatophytes (Table 3). It should be noted that species like *E. repens* and *G. aparine* had higher ranks in the border of rotational Slope Units than of permanent grassland Slope Units (Table 3). In the bank, the rank order of these two species was about the same.

4. Discussion

4.1. Influence from agricultural activity

The differences found almost certainly resulted from agricultural activities in the adjacent field. The condition of the stream border ecotones differed systematically only in type of land use of the adjacent area, as other locality characteristics, such as soil type, topography, distance to water table and stream order were held as similar as possible.

The border ecotones adjacent to fields in annual rotation had lower species richness, higher productivity, and lower potential value as dispersal corridors for species from both the dry and wet habitats than border ecotones adjacent to natural grassland. These impacts of agricultural activities could have been mediated through nutrient load, pesticides drift or physical disturbance. The proxy variables for productivity thus all indicate a more eutrophic ecotone along rotational fields than along permanent grassland. Further, the differences were more pronounced for the part of the ecotone nearest to the rotational field, i.e. the stream border, than for the most distant part of the ecotone, i.e. the stream bank. The negative effects on the stream border were also found to increase as the distance to field in annual rotation decreased. The annual species, *G. aparine*, occurs on disturbed sites. In agreement with this—and independently of bordering field type—it had high occurrence on the stream banks that are frequently disturbed by the changing water level in the stream during the year. The highest rank of this species on the borders of rotational Slope Units thus indicates disturbance, e.g. from pesticides opening the permanent vegetation carpet in the border for germination sites or physical disturbance from other activities in the field.

The conclusion that the direct neighbourhood to fields in rotation has a significant negative influence on the botanical quality of the stream border vegetation mediated through nutrient load is also in agreement with the findings of the rank order of *E. repens* and *G. aparine* being about the same in the bank of the two ecotone types. The conclusion that the borders of the rotational Slope Units are disturbed from agricultural activities, e.g. pesticides and field work, is supported by the fact that *G. aparine* occurred at about the same frequency in the banks of the two ecotone types.

4.2. Dispersal potential

Concerning the number of species potentially dispersed from border ecotones, fewer species—both Phreatophyte and Aphreatophyte species—may potentially be dispersed from border ecotones of rotational fields than from border ecotones of grassland. In addition to that, the species dispersed from the border ecotone of rotational fields are among the more eutrophic ones, as indicated by the higher Ellenberg nitrogen index. Thus, especially among the Phreatophytes, the role of the stream banks as source and potential corridor for the most common species was dependent on the type of the neighbouring field. This aspect has to be taken into consideration, as riparian restoration projects often have to rely on stream banks as a source of plant propagules and dispersal corridors, as mentioned by Van Diggelen (1998).

4.3. Buffer zone needed

If stream border ecotones are to be maintained as important potential propagule sources and dispersal corridors for a high number of plant species from both the wet and dry habitats, the botanical quality has to be maintained at a high level. Therefore, a buffer zone—or grassland—may need to be established to reduce the agricultural influence on the 2 m wide uncultivated border along streams. Data from UK indicates that sown grass margins in arable fields may enhance botanical diversity in the border (Moonen and Marshall, 2001). However, the number of observations of stream borders here was too few to be able to define a threshold width.

5. Conclusions

The botanical quality of the border ecotones next to fields in annual crop rotation was lower than the quality of the border ecotones next to fields with permanent natural grassland. They were poorer in species richness, especially among the Phreatophyte species. The remaining species were the more eutrophic and productive ones. These findings may be a consequence of nutrient load, pesticide drift and physically disturbances from fields in rotation. The differences in botanical quality were more pronounced for the vegetation of the stream border than of the stream bank—a consequence of the stream borders being closer to the fields in rotation than are the banks.

Acknowledgements

Special thanks to my students and Orla Bjørneskov for help with the field analyses. This work was partly financed by the Danish Research Programme ‘Farmers as Area Managers’.

Appendix A

List of species in Table 3. Nomenclature follows Hansen (1981).

Abbreviation	Species
achi_mil	*Achillea millifolium*
achi_pta	*Achillea ptarmica*
aego_pod	*Aegopodium podograria*
agro_gig	*Agrostis gigantea*
agro_sto	*Agrostis stolonifera*
agro_ten	*Agrostis tenuis*
alli_pet	*Alliaria petiolata*
alop_gen	*Alopecurus geniculatus*
alop_pra	*Alopecurus pratensis*
ange_syl	*Angelica sylvestris*
anth_odo	*Anthoxanthum odoratum*
anth_syl	*Anthriscus sylvestris*
arrh_ela	*Arrhenatherum elatius*
arte_vul	*Artemisia vulgaris*
bell_per	*Bellis perennis*
c_distic	*Carex disticha*
c_hirta	*Carex hirta*
calt_pal	*Caltha palustris*
caly_sep	*Calystegia sepium*
card_ama	*Cardamine amara*
ca_pr.pr	*Cardamine pratensis* ssp. *pratensis*
ce_fo.tr	*Cerastium fontanum* ssp. *Triv. var. triv.*
cent_sca	*Centaurea scabiosa*
cham_ang	*Chamaenerion angustifolium*
chry_alt	*Chrysosplenium alternifolium*
cirs_arv	*Cirsium arvense*
cirs_ole	*Cirsium oleraceum*
cirs_pal	*Cirsium palustre*
cyno_cri	*Cynosurus cristatus*
dact_glo	*Dactylis glomerata*
desc_cae	*Deschampsia caespitosa*
elyt_rep	*E. repens*

Appendix A (*Continued*)

Abbreviation	Species
epil_c/r	*Epilobioum ciliatum/E. roseum*
epil_hir	*Epilobium hirsutum*
equi_arv	*Equisetum arvense*
equi_pal	*Equisetum palustre*
eupa_can	*Eupatorium cannabinum*
fest_rub	*Festuca rubra*
fili_ulm	*Filipendula ulmaria*
gale_spe	*Galeopsis speciosa*
gale_tet	*Galeopsis tetrahit*
gali_apa	*G. aparine*
gali_mol	*Galium mollugo*
ga_pa.pa	*Galium palustre* ssp. *palustre*
gali_sax	*Galium saxatile*
geum_riv	*Geum rivale*
geum_urb	*Geum urbanum*
glec_hed	*Glechoma hederacea*
glyc_dec	*Glyceria declinata*
glyc_flu	*Glyceria fluitans*
glyc_max	*Glyceria maxima*
hier_pil	*Hieracium pilosella*
holc_lan	*Holcus lanatus*
holc_mol	*Holcus mollis*
impa_nol	*Impatiens noli-tangere*
junc_eff	*Juncus effusus*
lath_pra	*Lathyrus pratensis*
loli_per	*Lolium perenne*
lotu_cor	*Lotus corniculatus*
lo_ul.ul	*Lotus uliginosus* ssp. *uliginosus*
lych_flo	*Lychnis flos-cuculi*
lysi_vul	*Lysimachia vulgaris*
ment_aqu	*Mentha aquatica*
merc_per	*Mercurialis perennis*
myos_pal	*Myosotis palustris*
myrr_odo	*Myrrhis odorata*
peta_hyb	*Petasites hybridus*
phal_aru	*Phalaris arundinacea*
plan_lan	*Plantago lanceolata*
poa_pra	*Poa pratensis*
poa_tri	*Poa trivialis*
ranu_acr	*Ranunculus acris*
ranu_rns	*Ranunculus repens*
rubu_ida	*Rubus idaeus*
rume_asa	*Rumex acetosa*
rume_cri	*Rumex crispus*

Appendix A (*Continued*)

Abbreviation	Species
scir_syl	*Scirpus sylvaticus*
sile_dio	*Silene dioica*
sola_dul	*Solanum dulcamara*
stac_syl	*Stachys sylvatica*
stel_gra	*Stellaria graminea*
succ_pra	*Succisa pratensis*
taraxacz	*Taraxacum* sp.
trif_med	*Trifolium medium*
trif_rep	*Trifolium repens*
urti_dio	*U. dioica*
vero_cha	*Veronica chamaedrys*
vici_cra	*Vicia cracca*

References

Anonymous, 1992. Vandløbsloven. Miljø-og Energiministeriet, Copenhagen.

De Snoo, G.R., De Wit, P.J., 1998. Buffer zones for reducing pesticide drift to ditches and risks to aquatic organisms. Ecotoxicol. Environ. Safety 41, 112–118.

Décamps, H., 1993. River margins and environmental change. Ecol. Appl. 3, 441–445.

Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W., Paulissen, D., 1992. Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18 (2. verbesserte und erweiterte Auflage), 258 pp.

Hansen, K. (Ed.), 1981. Dansk feltflora. Gyldendal. Copenhagen.

Haycock, N.E., Pinay, G., Walker, C., 1993. Nitrogen retention in river corridors: European perspective. Ambio 22, 340–346.

Haycock, N., Burt, T., Goulding, K., Pinay, G. (Eds.), 1997. Buffer zones. Their processes and potentials in water protection. In: Proceedings of the International Conference on Buffer Zones, September 1996. Quest Environmental, Harpenden, UK, 322 pp.

Holland, M., Whigham, D.F., Gopal, B., 1990. The characteristics of wetland ecotones. In: Naiman, R.J., Décamps, H. (Eds.), The Ecology and Management of Aquatic–Terrestrial Ecotones, pp. 171–198.

Johansson, M.E., Nilsson, C., Nilsson, E., 1996. Do rivers function as corridors for plant dispersal? J. Veg. Sci. 7, 593–598.

Londo, G., 1988. Nederlandse Freatofyten. Pudoc, Wageningen, 108 pp.

Mander, U., Kuusemets, V., Lohmus, K., Mauring, T., 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecol. Eng. 8, 299–324.

Moonen, A.C., Marshall, E.J.P., 2001. The influence of sown margin strips management and boundary structure on herbaceous field margin vegetation in two neighbouring farms in southern England. Agric. Ecosyst. Environ. 86, 187–202.

Muscutt, A.D., Harris, G.L., Bailey, S.W., Davies, D.B., 1993. Buffer zones to improve water quality: a review of their potential use in UK agriculture. Agric. Ecosyst. Environ. 45, 59–77.

Naiman, R.J., Décamps, H., Pollock, M., 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3, 209–212.

Nilsson, C., Nilsson, E., Johansson, M.E., Dynesius, M., Grelsson, G., Xiong, S., Jansson, R., Danvind, M., 1993. Processes structuring riparian vegetation. In: Menon, J. (Ed.), Current Topics in Botanical Research. Council of Scientific Research Integration, Trivandrum, pp. 419–431.

Skoglund, S.J., 1990. Seed dispersal agent in two flooded river sites. Can. J. Bot. 68, 754–760.

Van Diggelen, R., 1998. Moving gradients. Assessing restoration prospects of degraded brook valleys. Rijksuniversitet Groningen, 183 pp.

Vought, L.B.-M., Pinay, G., Fuglsang, A., Ruffinoni, C., 1995. Structure and function of buffer strips from a water quality perspective in agricultural landscapes. Landscape Urban Plan. 31, 323–331.

Yates, P., Sherian, J.M., 1983. Estimating the effectiveness of vegetated floodplains/wetlands as nitrate–nitrite and orthophosphate filters. Agric. Ecosyst. Environ. 9, 303–314.