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Grassland plant species on road verges in Mid Sweden

- Influence of semi-natural grasslands and impact of road maintenance

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Abstract

Semi-natural grasslands have decreased in Sweden and alternative habitats are vital for many grassland plant species. In Jämtland, Mid Sweden, species-rich road verges cover a surface half the size of the remaining semi-natural grasslands in the same area. These road verges may act as substitute for diminishing semi-natural grasslands. However, there is a lack of information about the species composition on these road verges. It is also little studied if semi-natural grasslands in the landscape influence the road verge flora and how road maintenance activities impact the verge habitat. In this study, the flora of species-rich road verges was compared with the flora of meadows. 216 sample plots were inventoried for plant species abundance on 16 roads and 8 meadows. Also, the impact of maintenance activities (ditch drainage, reconstruction) on the road verge flora was evaluated. The results from my study indicated that although many grassland species are found on road verges, the road verge flora differs from the flora of meadows (semi natural grasslands). Present maintenance activities lower the species-richness on road verges and the re-vegetation seems to be slow. Inner verges and outer verges should be treated separately in inventories and studies due to large differences in plant species abundances. Moreover, species-rich road verges in Jämtland have few semi-natural grasslands in their surroundings and may be seen as rather isolated from grasslands with high flora qualities in the landscape. To better understand what influence the flora on road verges, long term monitoring and further landscape analyses, combined with historic land use analyses, are recommended.

Key words: species-rich road verges, road management, plant dispersal, landscape ecology

Introduction

Road networks cover an increasing part of the earth's surface, and over 5000 km² of the total land area in Sweden (Swedish Road Administration 1996). Reviews of the impact of roads mainly discuss adverse ecological effects like fragmentation of habitats (Forman & Alexander 1998), dispersal of invasive and exotic plant species (Coffin 2007), pollution and disturbance effects (Spellerberg 1998). Nevertheless, a positive effect of roads is that the road verge can harbour plant species that are rare or declining in the surrounding landscape (Hovd & Skogen 2005, Huhta & Rautio 2007, Ranta 2008).

Semi-natural grasslands (meadows and pastures) have decreased drastically in Sweden due to modernization in the agriculture (Ihse 1995) and many specialized grassland plant species are now found in small populations. In fact, over 65 percent of the red listed vascular plants in Sweden have a linkage to the agricultural landscape (Gärdenfors 2005). To increase the visibility and thereby the traffic safety, road verges are regularly cut. This makes road verges a potential habitat for grassland species. These are often short growing, poorly competitive species that are well adapted to the disturbance of hay-making (Ekstam & Forshed 1992). Many of the plant species found on road verges in Sweden are species that earlier were common in semi-natural grasslands (Nilsson 2000). However, the importance of the road verge as an alternative habitat for meadows species is discussed. The species composition of Swedish road verges is little studied (Persson 1990) and why some grassland species are less abundant on road verges is not fully understood.

As an administrative authority, the Swedish Road Administration has an official governmental responsibility to work with sustainable development and biological diversity (Swedish Road Administration 1994). Due to the potential floristic values of the road verge habitat, the Swedish Road Administration has mapped road verges with high botanical values in Sweden (Swedish Road Administration 1994). The road verges compiled in the inventory are named "species-rich road verges" (Swedish= Artrika vägkanter). However, few studies are conducted on how different management regimes (cutting time etc.) and regular maintenance activities affect the flora on these species-rich road verges.

Two major maintenance activities affecting the road verge habitat are ditch drainage and reconstruction of roads. Ditch drainage improves the drainage of the road structure and is performed when the ditch ability to store and drain water from the roadway has decreased (Swedish Road Administration 2003). Reconstruction is often a larger scale operation that can be done for various reasons, e.g. increase the width of the roadway, change the filling of the road structure and replace broken culverts (Sundin pers. com.) There are recommendations for maintenance of roads with species-rich road verges in Mid-Sweden (Ljung 1997, Swedish Road Administration (Central region) 2000), but follow-up studies show that floristic values sometimes are lost even though mitigation measures (e.g. returning the topsoil or leaving the outer verge intact) are prescribed (Ljung 2001, Swedish Road Administration 2006). No larger studies known are made to differentiate whether certain grassland species growing on road verges are more affected by these physical disturbances than other.

Overall, road verge flora is often influenced by the adjacent land use (Bochet et al. 2007, Hoffmann & Kwak 2007). The influence of the not adjacent, but surrounding landscape and the regional species pool on the road verge flora is less known. The ability for species to colonize road verges will probably depend on several factors, like life history characters. Species with long distance dispersal of their seeds (dispersal by wind) have for example been seen to dominate road verges shortly after disturbance (Bochet et al. 2007). Seed dispersal along roads can be facilitated by cars and machines, but mainly benefit plant species with small and light seeds (Zwaenepoel et al. 2006).

In this study I compared the flora of species-rich road verges in Mid Sweden with the flora of semi-natural grasslands in the same region. I examined the similarity of species composition and also the differences in occurrence on a species level. More, I compared the flora of species-rich road verges (hereafter RV) with flora on “disturbed species-rich road verges” (hereafter DRV). The DRVs have all been affected by maintenance activities during the last eight years. I also evaluated the importance of semi-natural grasslands in the surrounding landscape for the road verge flora. Finally, as earlier studies of road verges mostly have used subjective sampling methods, I evaluated two different methods of sample data from road verges.

With the results from this study as a starting-point, recommendations for management and further studies of species-rich road verges in Mid Sweden are given.

Material and methods

Study area

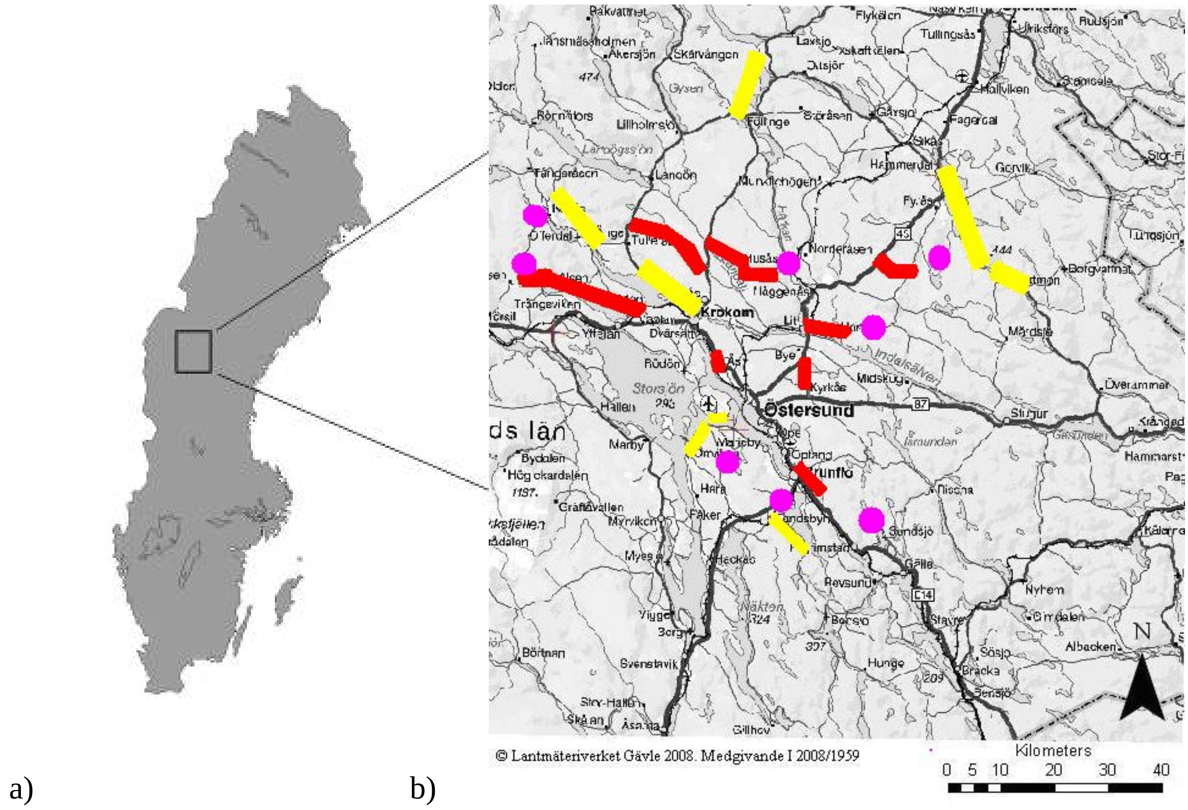
The study took place in the central parts of the county of Jämtland, Sweden (Fig. 1a). In Jämtland, over 2600 kilometres of road, or nearly 50 percent of the road network, has been identified as having species-rich road verges (Ljung 1997). This is a high percentage of species-rich road verges compared to other parts of Sweden. The rich road verge flora is partially due to the lime-rich bedrock in the central parts of Jämtland (Ljung 1997).

Design

To compare the flora on species-rich road verges (RV) and disturbed species-rich road verges (DRV), 16 roads were selected for the study (Fig. 1b). Eight roads had been either ditch cleared or rebuilt since the year 2000 (DRV) while the other eight roads had had no maintenance (RV). Moreover, eight meadows in the same region were randomly selected to function as a reference of the meadow flora (Fig. 1b).

Data from the first inventory of species-rich road verges (Ljung & Pettersson 1997), when species-rich road verges in Jämtland were compiled, were used for finding potential road objects. Road verges with mainly "meadow vegetation" were singled out from road verges with other types of vegetation since the focal point of the study was meadow plant species on road verges.

In order to compare the flora on RV and DRV, it was important to localize road verges that had had a similar flora before the maintenance action took place on the DRV. Therefore, two criteria had to be met: firstly, all roads should be situated in the same climatic region (boreal). This was made to avoid differences in species composition due to parameters like temperature and snow cover. Secondly, the flora of the road verge should be classified as "highest quality" in the original inventory, i.e. category "1". This was to make sure that the DRV were not less diverse before the maintenance action. The latter criterion could be met for all roads but one (see road 766 in Appendix 1b). Information on when roads had been ditch cleared or rebuilt was given from operation area managers and contractors (Bexar Pers. Communication; Arljung Pers. Communication). The roads were between 2.5 to 24 kilometres long (Appendix 1a. and 1b.).



a) b)

Fig. 1. a) Region of Sweden where the study took place. **b)** Map showing the 8 RV (yellow), 8 DRV (red) and 8 meadows (purple) included in the study.

Meadows were randomly selected from the Survey of semi-natural pastures and meadows in 2002-2004 (Swedish Board of Agriculture 2005). Pastures dominate the semi-natural grasslands in Sweden (Swedish Board of Agriculture 2005) but were excluded from this study since grazing is a different form of disturbance regime that partly favours other plant species than hay-making (Ekstam & Forshed 1996). The meadows were between 0.1 and 2 ha. The majority belonged to the Nature 2000 habitat 6510, "Lowland hay meadows" (Appendix 1c). Four out of the eight meadows were classified as "potential restoration meadows" in the Survey of semi-natural pastures and meadows. This meant that they had decimated species-richness due to lack of management.

Field study

The field study took place in July 2008. Data for each road were collected from four random road sites. To get samples that were not aggregated, but represented the entire road length, each road was divided in four equally long segments. One site was randomly selected in each segment. At each site, two sample plots consisting of a 1x1 m square, were placed. The first sample plot was placed at the inner verge, between the road and the ditch, and the other sample plot at the outer verge, between the ditch and the adjacent land. Within each sample plot, presences of all vascular plant species were recorded. The presence or absent method was used as it is less time-consuming than coverage estimations. The nomenclature followed Mossberg & Stenberg (2003). Grassland species were classified as in Ekstam & Forshed (1992) and included all categories of grassland species (A+B+C). This meant that also species that can survive a rather long time without management (i.e. hay-making or grazing) were included.

Data for each meadow were also collected through random sample plots. To imitate the sampling design of roads, four sites were randomly located on each meadow. From each site, the 1x1 square was thrown twice, in two different locations, and the presences of species was recorded within the sample plots.

Previous studies of road verge vegetation have to a large extent consisted of data from representative (Nilsson 2000) or selective (Tikka et al. 2000) areas, where one subjective sample has been collected for each object. In this study both selective (representing the principal flora of each object) and random samples were used. This way, differences between random and subjective sampling could be measured and discussed.

192 random samples and 24 subjective samples were collected. To clarify: eight random samples from the eight RV, eight random samples from the eight DRV, eight random samples from the eight meadows and one subjective sample from each of the eight RV, eight DRV and eight meadows were collected.

The adjacent land use for each road sample plot was classified into four categories: forest, arable field, semi-natural grassland or other land use. “Forest” included old forest, plantations as well as clear cuts. “Arable field” was used for fields with all types of crops while “semi-natural grassland” represented both meadows and pastures. Land uses that did not fit into the first three categories were placed in “the other land use” and included for example gardens, railway tracks and water.

Statistical analyses

Statistical analyses were performed with NCSS 2004 (Hintze 2004).

All ANOVA analyses were rerun in SAS 9.1 (SAS Institute Inc.) with the response variable modelled as a poisson or negative binomial distribution. These results did not differ qualitatively from the ones obtained in NCSS, where the response variable was seen as normally distributed, so only the NCSS results are reported.

To test for differences in mean species-richness and mean number of grassland species per sample plot between habitats (RV, DRV and meadows), nested ANOVAs were used. In the model, each road (RV) object was nested into the group “road verges”, each disturbed road (DRV) object nested into the group “disturbed road verges” and each meadow object nested into the group “meadows”. To test for statistical differences between inner and outer road verge, the verge was added to the above model while the meadow group was excluded. To identify differences within significant factors in all ANOVA analyses, the Tukey test was used as a post-hoc test.

Species composition of RV, DRV and meadows was compared using Jaccard similarity index. The index measures the number of species shared by two different samples (i.e. RV and meadows) and the number of species unique to each sample. It can be expressed as:
$C_j = a / (a + b + c)$ were “a” is total number of species present in both samples, “b” is number of unique species present in one sample and “c” is the number of unique species present in the other sample (Magurran 2004). The presences of annuals were compared between the habitats since many opportunistic species are annuals. A high percentage of annuals could thus indicate a disturbed ecosystem. The occurrences of annuals were tested through Kruskal-Wallis test due to non normal distributed data. To further compare the structure of the flora of the three habitats, the dominance of the ten most common species in each habitat (RV, DRV and meadows) was measured. Generally, dominance of a few species indicates a lower biological diversity than if species are more evenly distributed (Magurran 2004). The commonness of species was calculated as the total occurrences of a species, in relationship to all the occurrences in that habitat. (E.g. out of 1267 total occurrences in meadows, 41 were *Acrostis capillaries. A. capillaries* then counted for 3.2 % of the total occurrences). The proportion of the ten most common species was then compared between habitats in order to evaluate the dominance of the most common species.

Moreover, to test if the frequency of specific grassland species varied between habitats (RV, DRV and meadow), the presence of each grassland species in the sample plots was compared by a Kruskal-Wallis test. Species present in at least 10 of the 192 random sample plots were included. For species with a significantly higher frequency in one of the habitats, a comparison of life history characteristics was made. Seed dispersal strategies were taken from Müller-Schneider (1986) while seed weights were taken from Grime et al. (1981). Additionally, the species preferred nitrogen content in soil was compared (Ekstam & Forshed 1992).

The effect of adjacent land use on species-richness and number of species per plot (pooled value from the two sample plots) was tested with ANOVA. The land use (forest, arable field, semi-natural grassland and other land use) was set as a fixed parameter.

GIS (ArcMap 9.2) was used for performing a landscape analysis. A shape file presenting pastures and meadows in Jämtland was down-loaded from the homepage of the Swedish Board of Agriculture (www.sjv.se). The area of semi-natural grassland within a circle of 2 kilometres radius from each road sampling plot was calculated (Fig. 2). The 2 kilometres radius has earlier been used (Öster et al. 2007) for mapping land surrounding semi-natural grasslands. Linear regression was used to test for relationships between the mean area of semi-natural grasslands within the radius per road and the mean species-richness of each road. The same type of analysis was used when comparing the area of semi-natural grassland and the mean number of grassland species per road.

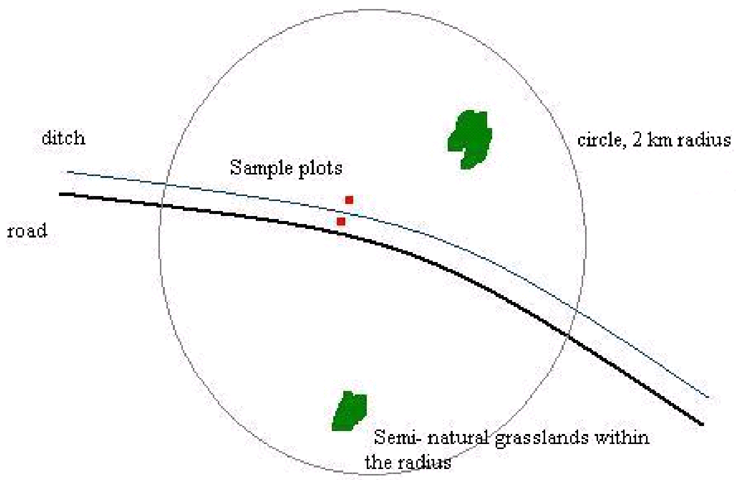


Fig. 2. Schematic drawing of the landscape analysis.

A comparison of the area of species-rich road verges in Jämtland and the area of semi-natural grassland in Jämtland was performed. For estimating the total area of species-rich road verges in Jämtland, a mean width of the road verge of 3 meter of each side of the road (Sundin, Pers. Communication) was used. Data presenting the area of semi-natural grasslands were down-loaded from the homepage of the Swedish Board of Agriculture (www.sjv.se).

Linear regression was used to test for relationships between the mean species-richness per road and the time passed since the maintenance activity of the road was finalized. Moreover, to exclude dissimilarities in the flora due to different traffic densities, linear regression was used for test for relationships between the mean species-richness per road and mean traffic density of each road. Relationships between the mean number of grassland species per road and mean traffic density were tested using the same analysis.

Finally, to evaluate the two different sampling designs (random samples vs. subjective samples), the mean species-richness per road and meadow was compared with the species-richness in the subjective sample from the same road or meadow.

Results

In total, 216 species were recorded in the 216 (random and subjective) sample plots (Appendix 2). Out of these, 105 were grassland species. Among the encountered species, there were no red listed (Gärdenfors 2005) but five protected species (Swedish = fridlysta; SFS 2007). Few non-native, potentially invasive species were recorded.

Both the total species-richness and the total number of grassland species were highest on road verges (RV) and lowest in meadows (Table 1). In contrast, both the mean species-richness per sample plot and the mean number of grassland species per sample plot were highest in meadows and lowest on disturbed road verges (DRV) (Table 2), although not statistically significant. However, meadows had a significantly higher number of grassland species per sample plot than DRV when restoration meadows were excluded from true meadows (Table 3). There were significant differences in number of grassland species per sample plot between different meadows (ANOVA $F_{7, 56} = 6.50$, $p < 0.001$).

Table 1. The number of species recorded in the different habitats.

	Meadows	**RV**	**DRV**
Total no. of species	125	168	156
Total no. of grassland species	75	83	80
Unique species [1]	11	28	29

[1] Species only recorded in this habitat

Table 2. The effect of habitat on the species-richness and the number of grassland species per sample plot (ANOVA).

	Meadows	**RV**	**DRV**	**d.f**	**MS**	**F**	**P**	**Tukey[1]**
Mean species-richness/sample plot	17.4	17.0	14.8	2	127.8	1.94	0.168	
Error				168	27.1			
Mean no. of grassland species/ sample plot	12.9	10.7	9.9	2	154.5	3.09	0.067	
Error				168	15.8			

[1] Significance value p < 0.05

Table 3. The effect of habitat on the number of grassland species per sample plot (ANOVA) when restoration meadows and meadows separated.

	Meadows	Rest. Meadows	RV	DRV	d.f	MS	F	P	Tukey [2]
Mean no. of grassland species/ sample plot [1]	14.5	11.3	10.7	9.9	3	158.3	3.57	0.032	Meadows> DRV
Error					168	15.8			

[2] Significance value $p < 0.05$

In an extended ANOVA model for road samples, the type of road verge (i.e. inner verge or outer verge) was added as a parameter. The verge had a significant effect (Table 4) as outer verges (furthest from the road) had higher species-richness per sample plot (mean 17.9) than inner verges (mean 14.5). The disturbance also had a significant effect. DRV had lower species-richness per sample plot than RV.

Table 4. Summary of the effects of disturbance and verge on the species-richness per sample plot (ANOVA)

Source of variation	d.f.	MS	F	P	Tukey [1]
Disturbance	1	203.7	4.63	0.049	RV> DRV
Object	14	44.0	1.59	0.093	
Verge	1	326.4	11.77	< 0.001	outer > inner
Error	108	27.7			

[1] Significance value $p < 0.05$

The type of verge also had a significant effect on the number of grassland species per sample plot (Table 5). Outer verges had a higher mean number (11.3) of grassland species than inner verges (mean 9.6).

Table 5. Summary of the effects of disturbance and verge on the number of grassland species per sample plot (ANOVA)

Source of variation	d.f.	MS	F	P	Tukey [1]
Disturbance	1	36.1	1.64	0.221	
Object	14	308.7	1.55	0.107	
Verge	1	95.5	6.69	0.011	outer > inner
Error	108	14.3			

[1] Significance value $p < 0.05$

The species composition differed between habitats. Jaccard Similarity index showed that road verges and disturbed road verges had the most similar species composition; C_j = 0.67. (1.0 represents total similarity, i.e. all species are found in both habitats.) Meadows and road verges had less similar species compositions, C_j = 0.58, while the species composition in meadows and on disturbed roads was the least similar; C_j = 0.51.

Although the species composition differed between habitats, no difference was found in the occurrence of annuals. (Kruskal-Wallis df= 2, H= 4.721, p= NS).

The ten most common species counted for roughly the same proportion of all the total occurrences in all three habitats (Appendix 3). The highest proportion of the most common species was seen on DRV, were ten species counted for 28.7 % of all occurrences. Different species were the most common in different habitats. The most common species on road verges was *Achillea millefolium* (Appendix 3). *Taraxacum sect Ruderalia* was most common on disturbed road verges while *Geranium sylvaticum* was the most common species in meadows (Appendix 3).

Some grassland species had significantly higher frequencies in one of the habitats than in at least one other habitat (Table 6). *Cirsium helenioides,* showed a tendency towards being more frequent in meadows than on DRV (p=0.060). *Trifolium repens* showed a tendency of having a higher frequency on RV than in meadows (p=0.062). For all species with significantly higher frequencies in one of the habitats, life history characteristics were compared. All species with higher frequencies in meadows prefer, or are adapted to, soils with low or medium nitrogen content (Table 6a). The majority of species more frequent on road verges (RV and DRV) had their main distribution on soils with high nitrogen content (Table 6b, 6c). All species were perennial species. Their seed weight varied from 0.05 to 5.18 mg. No trend showing lighter seeds in species more common on RV or on DRV was seen. The most common way of seed dispersal was by wind, even though both dispersal with animal vectors and other dispersal forms (water, unassisted, anthropogenic etc.) were common as well. No differences in seed dispersal strategies were seen between species more common in one of the habitats.

Table 6. Characteristics of the grassland species more common in one of the habitats than in at least one other habitat. Seed dispersal strategies: 1. Wind 2. Animals 3. Other.

ND indicates that no data was found in the literature studied.

a) Species with higher frequencies in meadows than on DRV (and /or RV).

Species	**Seed dispersal strategy**			**Seed weight (mg)**	**Life form**	**Optimal N-content in soil**
	1	**2**	**3**			
Veronica chamaedrys[1]	X			0.18	perennial	medium
Potentilla erecta [2]		X	X	0.58	perennial	low
Campanula rotundifolia [2]	X	X		0.07	perennial	low
Anthoxanthum odoratum [2]	X	X	X	0.45	perennial	low
Geranium sylvaticum		X	X	ND	perennial	medium
Agrostis capillaris	X	X	X	0.06	perennial	low
Cirsium helenioides	X			ND	perennial	medium

[1] More frequent in meadows than on RV.
[2] More frequent in meadows than on both DRV and RV.

b) Species with higher frequencies on RV than in meadows.

Species	**Seed dispersal strategy**			**Seed weight (mg)**	**Life Form**	**Optimal N-content in soil**
	1	**2**	**3**			
Trifolium repens		X	X	0.56	perennial	high
Trifolium pratense	X	X	X	1.35	perennial	low
Achillea millefolium	X	X	X	0.16	perennial	high
Festuca rubra [2]	X	X	X	0.79	perennial	-

[2]Also more frequent on RV than on DRV

c) Species with higher frequencies on DRV than in meadows.

Species	**Seed dispersal strategy**			**Seed weight (mg)**	**Life form**	**Optimal N-content in soil**
	1	**2**	**3**			
Anthriscus sylvestris	ND			5.18	perennial	high
Elytrigia repens	X		X	ND	perennial	high
Festuca pratensis	X		X	1.53	perennial	high
Achillea millefolium	X	X	X	0.16	perennial	high

The adjacent land had significant effect on the species-richness per plot (Table 7). Plots adjacent to forest had the highest species-richness (Fig. 3). No significant effects of adjacent land use was found for grassland species ($F_{3, 43}$ =2.19, p =NS).

Table 7. Summary of the effects of disturbance and adjacent land use on the species-richness per plot (ANOVA)

Source of variation	d.f.	MS	F	P	Tukey [1]
Disturbance	1	19.1	0.40	0.538	
Object	14	48.1	1.39	0.198	
Land use	3	180.8	5.24	0.004	forest > arable=other
Error	45	32.9			

[1] Significance value $p < 0.05$

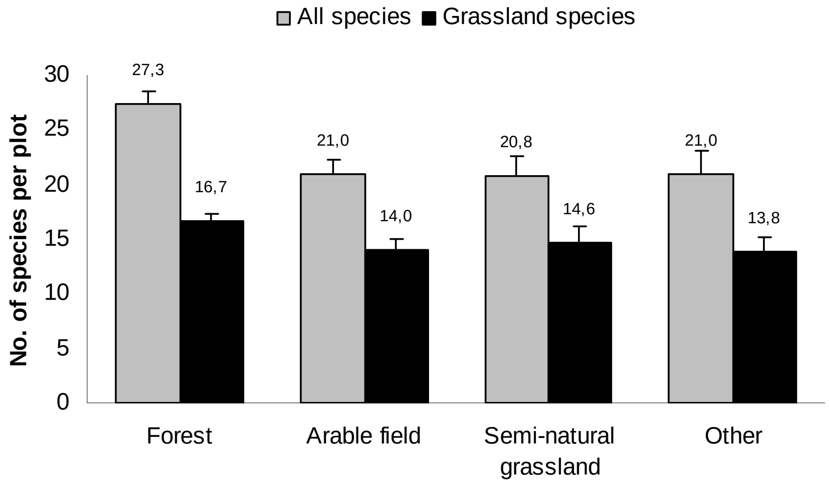


Fig. 3. Mean (with SE) number of species and grassland species for plots with different adjacent land use.

The species-rich road verge area in Jämtland is approximately 1560 ha, which equals 44 % of the area of semi-natural grasslands (3537 ha) in Jämtland. If restoration objects are excluded from the semi-natural grasslands, the area of species-rich road verges makes up 51 %. The area of semi-natural grasslands varied from 0 to 29 ha within the circle of 2 km radius around each road sample plot. The mean area of semi-natural grasslands within the circle was 3.2 ha which is equal to 0.25 percent of the land in the circle. No relationships were seen between the mean species-richness per road and the mean area of semi-natural grasslands in the surrounding landscape (RV: r_s= 0.209, n= 7, p= NS, DRV: r_s= 0.026, n= 8, p= NS), neither between the mean number of grassland specialist species per road and the mean area of semi-natural grasslands in the surrounding landscape (RV: r_s = 0.022, n= 7,p= NS, DRV: r_s= 0.019, n= 8, p=NS).

The mean species-richness per road showed no relationships with the mean traffic density of the same road (RV: r_s= 0.427, N= 6, p= NS, DRV: r_s= 0.171, n= 8, p= NS). Neither were there any relationships between the mean number of grassland species per road (RV: r_s= 0.027, n= 6, p= NS, DRV: r_s= 0.153, n= 8, p= NS) and the traffic density.

No relationships were found between the mean species-richness per road and the time elapsed since the latest maintenance action (r_s = < 0.001, n= 8, p =NS).

As for the comparison between the two sample methods (random vs. representative), the representative sample contained a higher number of species than the mean of the random samples in 17 out of the 24 studied objects (Fig. 4). The largest difference between the representative and the mean of the random samples was 18 species.

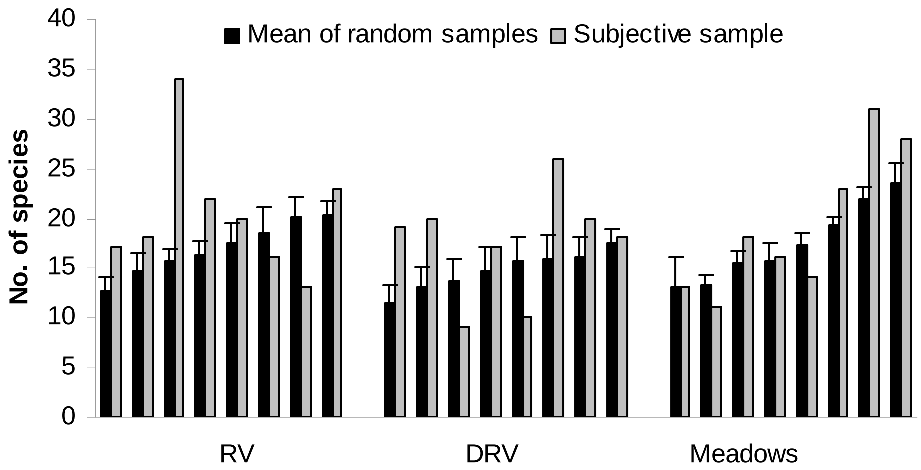


Fig. 4. Mean (with SE) number of species in the random samples (black bars) and number of species in the subjective sample (grey bars) for each object.

Discussion

Semi-natural grasslands have decreased drastically in the Swedish landscape. In Jämtland, species-rich road verges cover approximately 50% of the area of semi-natural grasslands. Species-rich road verges in Jämtland may add valuable habitat for grassland species and might be of importance for conservation of the biological diversity. However, few studies are conducted on the species composition on Swedish species-rich road verges. Similarly, few studies are conducted on how the road verge flora is affected by local as well as landscape parameters. Thus, due to the lack of information it is important to study species-rich road verges in order to establish their importance as possible conservation areas when semi-natural grasslands are diminishing. It is also essential to provide the Swedish Road Administration with feedback on their management of species-rich road verges and how it affects the flora. The results in this study showed that; 1) Although many grassland species are found on road verges, the road verge flora differs from the flora of meadows (semi-natural grasslands). 2) Present maintenance activities lower the species-richness on road verges. Additionally, the re-vegetation seems to be slow. 3) Inner verges and outer verges should be treated separately in inventories and studies due to large differences in plant species abundances. 4) Species-rich road verges in Jämtland have few semi-natural grasslands in their surroundings and can be seen as rather isolated from grasslands with high flora qualities in the landscape.

Flora of meadows vs. road verges

The species composition of the roads (RV, DRV) and meadows differed. This was mainly because the road verge habitats had considerably higher total species-richness than meadows. The high total number of species on the road verge can partially be explained by the heterogeneity of the road verge habitat, and by the influence of the adjacent land. As roads often pass through a varied landscape, abiotic parameters vary along the road length as well as on different sites on the road verge (Swedish Road Administration 1994). Also the disturbance regimes differ between road verges and meadows and will favour different plant species. The results in this study showed a higher total number of grassland species on road verges than in meadows, but this could partially be due to the broad definition of a grassland species used in this study, which included not only grassland specialist species but also ubiquitous grassland species. Among species that only were present on the road verge, some rather exclusive grassland species like *Gentiana amarella* were found, but the majority of the unique road verge species were species common in forests, gardens and fields. A few exclusive grassland species were only present in meadows. In conclusion, road verges were found to be species-rich, but only in part with flora resembling meadow flora. Road verges can therefore not be considered as direct substitutes for meadow habitat in the surrounding landscape. This corresponds to previous studies from Norway and Finland (Norderhaug et al. 2000 and Tikka et al. 2000). However, due to the high total number of species on road verges they could be described as truly unique habitats.

This study revealed some differences in the occurrences of individual grassland species between meadows and road verges. Species more frequent in meadows than on road verges are all considered as characteristic species of traditional meadows. For example, *C. rotundifolia*, that was found more often in grasslands than on road verges (RV and DRV) has been proven a good indicator species of grassland quality since it responds quickly to both degradation and improvement of habitats (Lindborg et al. 2005). In terms of the species more common on road verges; *F. rubra* is included in the seed mixture recommended to be sown on road cuts to prevent erosion (Swedish Road Administration 2005) which probably explains the high frequencies of that specific species on road verges. *T. pratense,* that here was reported common along road verges, is common on road verges also in Norway (Norderhaug et al. 2000).

Species with higher frequencies in meadows than on road verges (RV, DRV), all shared the character of preferring low or medium nitrogen levels in the soil. On the other hand, most of the species with high frequencies on road verges (RV, DRV) had a higher nitrogen preference or tolerance (according to literature; see methods). This is interesting since the amount of nitrogen in the road verge soil has been discussed as a factor influencing the species composition on the road verge (Persson 1995, Forman & Alexander 1998).

There was no trend in the mean seed weight for the grassland species more frequent in one of the habitats. This contrasts Winqvist (2003) who noted that grassland species growing on forest road often have small and light seeds. It also contrasts the theory that many species with light seeds should be seen on road verges due to dispersal by cars (Zwaenepoel et al. 2006). The differences in dispersal strategies between species did not show any obvious trend between habitat types. The majority of the grassland species could disperse their seed by wind which to some extent opposite the observation that many grassland species often have unassisted, or short distance, dispersal of their seeds (Hodgson & Grime 1990).

The dominance of the ten most common species did hardly differ between the habitats, but the species mutual order differed between the habitats. Possibly, coverage data would have given a better indication of dominance than the presence or absent data collected. The most common species in each habitat coincide with other inventories and studies of roads and grasslands. *A. millefolium* is well adapted to light, dry, nitrogen rich sites (Ekstam & Forshed 1992) and has a wide distribution in Sweden (Glimskär Pers. comment). *Alchemilla sp* is common in grasslands all over Sweden while *Bistorta vivipara* is one of the few meadow species with a centre of population in the northern parts of the country (Glimskär et al. In press 2008).

Flora of road verges vs. disturbed road verges

The lower Jaccard index between DRV and meadows compared to RV and meadows indicates that grassland species were lost due to maintenance activities and, or, that new species appear on the disturbed road verge. The lower number of species per sample plot in DRV compared to RV (when allowance was made for type of verge) strengthens this theory. However, no increases were seen in the occurrence of annuals. It is likely though, that the actual coverage of one or a few opportunistic species could be high at disturbed sites. This it not seen if only present or absent data are collected, but it could be indicated by the low mean species-richness per plot of the disturbed road verges.

Species more frequent on DRV than on meadows can all be classified as trivial grassland species or even “meadow weeds”. *A. sylvestris* can be considered a threat to species-rich road verges since it out compete other grassland species and is hard to control with cutting only once a year (Persson 1995). This study indicates that the species might be favoured by maintenance activities on the road verge. *E. repens* is a well known agricultural weed, often present in field boundary vegetation (Macdonald & Smith 1990). However, few non-native species were recorded on disturbed road verges. This is positive as maintenance activities otherwise can favour exotic, and potentially invasive, species (Tyser & Worley 1992, Rentch et al. 2005). Especially *Lupinus polyphyllus* is a concern on Swedish road verges (Sundin Pers. com.) and the presence of the species lower both the species-richness and the cover of low growing plants on road verges (Valtonen et al. 2006).

Flora on inner verges vs. outer verges

Outer verges (furthest from the road) had a higher species-richness and higher number of grassland species than inner verges. The inner verge is possible more exposed to traffic and regular maintenance (snow clearance etc.) than the outer verges. The inner verge might also be a drier habitat due to the drainage of the road structure. It is positive that species still are present on the outer verges after maintenance activities. On the other hand, the re-vegetation on inner verges seems to be a slow process. No relationship was found between the time since maintenance and the species-richness per road. The results indicating that species number do not increase with time is somehow contradicting to other studies (Nilsson 2000, Jantunen et al. 2006). However, these studies looked at time spans longer than eight years and many grassland species actually disperse step-wise into "new" habitats (Cousins & Lindborg 2008).

Adjacent land

The adjacent land use proved to influence the species-richness also in this study. The highest species-richness was recorded in sample plots adjacent to forest. Correspondingly, Öster et al. (2007) found that the total species-richness were high in grasslands in forested landscapes. Jakobsson (2005) explained the high species-richness on road verges adjacent to forest with the half shaded light conditions that allow species with different light preferences to grow on a small area. That no effects of the adjacent land use were seen on the mean number of grassland species per plot somehow contrast the conventional idea that species spread easily into the road verge from the grassland. As previously mentioned, this could be due to the broad definition of the grassland species in this study.

Landscape analysis

Road verges and their populations of grassland species are little studied in a landscape perspective. Previous studies mainly focused on the adjacent landscape (Tikka et al. 2000, Jakobsson 2005, Hoffman & Kwak 2007). No known studies have been looking at Swedish species-rich road verges and the influence of the surrounding, but not adjacent landscape. This is surprising as populations of grassland species on species-rich road verges may be involved in metapopulation dynamics. Road verge populations might for example be dependent on semi-natural grassland (source populations) in the landscape. Evaluating species on a metapopulation level will often help to understand the species in a better way than only looking at a single or few populations (Primack 1993).

This study revealed that only a very small part of the landscape surrounding the species-rich road verges in Jämtland consists of semi-natural grasslands. No relationships between the area of semi-natural grasslands and the number of grassland species on the road verge could be detected. This indicates that species-rich road verges are relatively isolated from semi-natural grasslands of good quality. On the other hand, the data used were rather rough (only grasslands qualified in the “Survey of semi-natural pastures and meadows” were included). Moreover, the landscape analyses did not include e.g. trivial grasslands within the 2 km radius where many of the species defined as grassland species in this study most likely were present. Further, the amount of semi-natural grassland in the surroundings of road verges that are not included in the species-rich road verges has so far not been measured. A comparison between species-rich and non species-rich road verges is a logical continuation of this study.

However, the results may indicate that road verges could be more isolated than previously thought. Thus, rather local factors, adjacent landscape and history traits may be more important for the road verge flora than the regional species pool. It is however not stated at what distance grasslands can influence the road verge flora. Different plant species can probably be regarded as isolated at different distances to other populations due to dissimilarities in pollen and seed dispersal (Hodgson & Grime 1990). Looking from a landscape ecology perspective, also the matrix between the habitats is most likely of importance for species dispersal. Moreover, road verges are often highly heterogeneous habitats and can be hard to define and limit when conducting metapopulation studies. To distinguish between influence of the surroundings and influence of the road it self is intricate. The branched road network is extensive and at some point, roads will run adjacent to grasslands. Therefore, the dispersal of different plants species along roads ought to be more studied. Further, road verges have also been discussed as important dispersal corridors for both plants (Tikka et al. 2001) and animals (Bennet 1991, Söderström & Hedblom 2007).

Lately, also the importance of the historic landscape has attracted attention to semi-natural grasslands and the flora (Gustavsson 2007). Several studies indicate that historic landscape rather than the present land use control the distribution of grassland species (Gustavsson et al. 2007, Mildén et al. 2007). Sessile organisms sometime respond slowly to changes in the environment, and plant species that are long lived can persist in degraded habitats (Ekstam & Forshed 1992). For instance, the rather exclusive grassland species *Primula veris* was found in a restoration meadow object in this study although the object had not been mowed or managed in a long time. If the road verge grassland flora mainly is the result of the historical land use instead of the present day landscape, this has implications for the management of road verges. Grassland species populations on the road verge can then in many cases be seen as “relict populations” with little prospects of returning to the same place if once gone. This adds additionally importance to accurate management and maintenance of road verge.

Road inventory design

The evaluation of different sample designs showed a risk of overestimating the species-richness on road verges when only taking subjective samples. As road verges are narrow but often long habitats that can reach lengths of several kilometres, it is hard to get an overview of what is representative of the entire road. Earlier studies and inventories might have overestimated the floral quality over large distances of roads. A more accurate way of describing the road verge might be that there are zones with very high species-richness and-along the same road-zones with more moderate, or low species-richness. This is of importance when estimating the number of individuals of a species along a road or when evaluating the values of road verges as a habitat.

No relationships between the mean species-richness or the mean number of grassland species per road and the traffic density of roads were seen. Jantunen et al. (2007) got similar results and noted a high variation within roads with similar traffic density. Moreover, Jämtland has a low population density and few large roads. Thus, although the traffic density was considered high in this study it is rather moderate seen in a national perspective. Differences in the flora of road verges due to heavy traffic may be better studied somewhere else in the country.

Management implications

The results of this study may indicate that the mitigation measure of leaving outer verges intact seem to be implemented by contractors, which is positive. However, the higher species richness on the outer verges can also be due to other factors as mentioned above. The slow re-vegetation of road verges is a problem. Although eight years had gone since the maintenance, large differences in the flora could still be seen. Keeping “islands” of undisturbed land on the inner verge have previously shown to favour re-vegetation (Persson 2003). This method should perhaps be implemented even more to faster revegetate species-rich road verges in Jämtland due to the results of this study. Nevertheless, the inner verge will probably still be rather affected by maintenance actions as it is important that the drainage of the roadway works properly. Rare species like *G. amarella* that only was found on inner verges should be given high protection status. The same is true for other rare species that almost solely grow on inner verges: *Myricaria germanica*, *Astragalus penduliflorus* and *Botrychium* sp (Pettersson. Pers. comment).

If the road verge flora should contain meadow plant species, soil nitrogen levels have to be kept low according to this study. Imitating the management of meadows, i.e. remove the hay after cutting, will limit the amount of nutrients on the road verge and probably increase the number of grassland species on the road verge. Removal of the hay has previously been shown to increase the total species-richness on the road verge in only a few years (Persson 1995).

Further studies

To get a better understanding of how the vegetation of species-rich road verges evolves, and what effects different management regimes have, permanent road stretches with permanent plots should be monitored (Swedish Road Administration 2001). If possible, different management regimes should be tested in the same area, to exclude differences due to local differences in e.g. soil chemistry. The present or absent data used in this study shows a change only as the last individual of a species is lost (Ekstam & Forshed 1996) while coverage data, or counting of individuals, show trends on an earlier stage and can be recommended for monitoring projects. Likewise, the Jaccard index can be regarded as a rather insensitive way of comparing two habitats (Greig-Smith 1957). No consideration is for example taken to the frequencies of the occurring species. Other ways to measure the species composition might be more relevant.

To better study how ditch drainage or reconstruction affect species-rich road verges, larger studies based on thorough inventories before and after the maintenance action are recommended. Also, the effects should be studied for maintenance activities of a similar nature. For evaluating the impacts of road maintenance, and the value of mitigation measures, it is essential with thorough documentation of the mitigation measures performed. Likewise, it is important to yearly document how and when management (e.g. cutting) is performed. To better understand the magnitude of seed dispersal along the road, studies of seed transport via the machines cutting the road side vegetation are recommended.

For further landscape analyses, more detailed data (e.g. aerial photographs) and historical maps would be worthwhile to include for more complete studies. The list of grassland species could be more precise and should mainly focus on species that can be used as indicator species of semi-natural grassland qualities. Rare species require specific mapping and follow up studies.

In summary, in order to preserve and develop the floristic values of the road verge, a deeper understanding of factors influencing the road verge flora is required and further studies are essential.

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Appendix 1

a) Characteristics of road verges (RV)

Road	**Object number**	**Distance**	**Length (km)**	**Operation area**	**Classification of road verge**[1]	**Mean traffic density (cars/ 24 h)**
340	Z340:1	Krokom- Kvarnbäcken	13	Krokom	1	1212
344	Z344:1	Hammerdal - Skyttmon	22	Lit	1	400,5
344	Z344:2	Grundflyberget- Skyttmon	4	Lit	1	253
592	Z592:3	Vallsundet- Orrviken	9	Krokom	1	N.D
592	Z592:4	Vallsundet- Ändsjön	2,5	Krokom	1	N.D
559	Z559:1	Road 45- Tandsbyn-Loke-Berge	11	Bräcke	1	130
678	Z678:1	Änge-Bångåsen-Söderåsen- Hållan	13	Krokom	1	155
781	Z781:1	Föllinge-Mörtsjön	12.7	Lit	1 + 2	69

[1] From the original inventory of species-rich road verges: 1) indicates high quality of the flora 2) indicates that the road verge flora has potential to develop into a high quality flora.

b) Characteristics of disturbed road verges (DRV)

Road	**Object number**	**Distance**	**Length (km)**	**Operation area**	**Classification of road verge**[1]	**Mean traffic density (cars/ 24 h)**	**Main-tenance year**	**Maintenance action**
763	Z763:1	Lit- Handog	8	Lit	1	263	2004	Reconstruction
748	Z748:1	Offerdalsberg- Kälom-Road 339	18	Krokom	1	78	2005	Ditch clearing
666	Z666:2	Bleckåsen- Nälden	24	Krokom	1	357	2004	Reconstruction
746	Z746:1	Ringsta- Landvågen-Road 339	16	Lit	1	45	2006	Ditch clearing
766	Z766:1	Ollsta- Högarna	7	Lit	2	114	2004	Reconstruction
740	Z740:1	Lunne- Slåtte	4.5	Krokom	1	380	2007	Ditch clearing
742	Z742:1	Bringåsen -Kyrkås-Sjör- Nyvik	7	Lit	1+2	92	2001	Ditch clearing
610	Z610:1	Tängtorpet- Prästvägen	2.5	Krokom	1	1936	2005	Ditch clearing

[1] From the original inventory of species-rich road verges. 1) indicates high quality of the flora 2) indicates that the road verge flora has potential to develop into a high quality flora.

c) Characteristics of meadows

Name	**TUVA Object name**	**Size (ha)**	**Municipality**	**Natura 2000 habitat**[1]
Handog	AA7-QVS	0.7	Östersund	6510
Lassbyn	E5F-YEV	0.8	Östersund	6510
Målsta	335-HIT	1.2	Östersund	6510
Norderåsen	420-WDC	0.3	Östersund	6510
Samsta 3	057- QO10	0.6	Bräcke	Other
Solberg	3E6-KPH	0.1	Strömsund	6510
Truvbacken	E41-MAL	0.4	Krokom	6210 and 6410
Åflo	841-380	2	Krokom	6210 and 6410

[1]6510-Lowland hay meadows, 6210- Semi-natural dry grasslands and scrubland facies on calcareous substrates, 6410- M*olinia* meadows on calcareous. peaty or clayey-siltladen soils

Appendix 2

Recorded species.Grassland species in bold letters.

Latin name	Meadow	Road verge	Disturbed road verge
Achillea millefolium	X	X	X
Aconitum septentrionale	X	X	X
Agrostis capillaris	X	X	X
Agrostis gigantea	X	X	
Agrostis stolonifera		X	X
Alchemilla sp	X	X	X
Alnus incana		X	X
Alopecurus pratensis		X	X
Amelanchier spicata		X	
Angelica sylvestris	X	X	X
Antennaria dioica		X	
Anthoxanthum odoratum	X	X	X
Anthriscus sylvestris	X	X	X
Arabidopsis thaliana			X
Arctostaphylos uva-ursi		X	
Arenaria serpyllifolia			X
Artemisia vulgaris		X	
Astragalus alpinus		X	
Barbarea stricta		X	
Betula pendula			X
Betula pubescens	X	X	X
Bistorta vivipara	X	X	X
Botrychium lunaria	X	X	
Brassica rapa ssp.campestris		X	X
Calamagrostis epigejos		X	X
Calamagrostis purpurea	X	X	
Calamagrostis stricta	X		X
Calluna vulgaris		X	
Caltha palustris			X
Campanula rapunculoides		X	X
Campanula rotundifolia	X	X	X
Capsella bursa-pastoris			X
Cardaminopsis arenosa		X	X
Carduus crispus			X
Carex atrata	X		
Carex canescens		X	
Carex capillaris	X	X	
Carex digitata	X		
Carex flava	X	X	X
Carex lasiocarpa		X	
Carex nigra	X	X	X
Carex norvegica	X		X
Carex ornithopoda	X		X
Carex pallescens	X	X	
Carex panicea	X		X
Carex vaginata	X	X	X
Carum carvi	X	X	X
Centaurea jacea		X	
Cerastium fontanum	X	X	X
Chenopodium album		X	
Cirsium arvense		X	X
Cirsium helenioides	X	X	X
Cirsium vulgare			X
Crepis paludosa			X
Dactylis glomerata	X	X	X

Latin name	Meadow	Road verge	Disturbed road verge
Dactylorhiza maculata [1]	X		
Deschampsia caespitosa	X	X	X
Deschampsia flexuosa	X	X	X
Elymus caninus		X	X
Elytrigia repens		X	X
Empetrum nigrum	X	X	X
Epilobium adenocaulon		X	
Epilobium angustifolium	X	X	X
Epilobium collinum		X	X
Epilobium palustre			X
Equisetum palustre		X	X
Equisetum arvense		X	X
Equisetum fluviatile		X	X
Equisetum hyemale		X	
Equisetum pratense	X	X	X
Equisetum scirpoides		X	
Equisetum sylvaticum			X
Equisetum variegatum		X	
Erysimum cheiranthoides			X
Euphrasia sp.	X	X	X
Fallopia convolvulus		X	X
Festuca ovina	X	X	X
Festuca pratensis	X	X	X
Festuca rubra	X	X	X
Festuca vivipara			X
Filipendula ulmaria	X	X	X
Fragaria vesca	X	X	X
Fumaria officinalis		X	X
Galium album	X	X	X
Galium boreale	X	X	X
Galium uliginosum	X	X	X
Galium verum			X
Gentiana amarella		X	X
Geranium sylvaticum	X	X	X
Geum rivale	X	X	X
Gymnadenia conopsea[1]	X	X	X
Gymnocarpium dryopteris		X	
Helictotrichon pubescens	X	X	X
Hepatica nobilis[2]	X	X	X
Heracleum sphondylium	X	X	X
Hieracium Sect.Vulgata	X	X	X
Hieracium Sect. Hieracium		X	X
Hieracium umbellatum	X	X	
Hypericum maculatum		X	
Hypochoeris maculata	X	X	
Juncus alpinoarticulatus			X
Juncus compressus			X
Juniperus communis	X		
Knautia arvensis		X	
Lamium album			X
Lamium purpureum		X	
Lapsana communis			X
Lathyrus pratensis	X	X	X
Leontodon autumnalis	X	X	X
Leucanthemum vulgare	X	X	X
Linaria vulgaris		X	X
Linum catharticum	X	X	X
Listera ovata[1]	X	X	
Lotus corniculatus	X	X	X

Latin name	Meadow	Road verge	Disturbed road verge
Lupinus polyphyllus			X
Luzula multiflora	X	X	X
Luzula pallescens	X	X	
Luzula pilosa	X	X	X
Luzula sudetica	X	X	X
Maianthemum bifolia	X	X	X
Matricaria inodora		X	X
Melampyrum pratense	X	X	X
Melampyrum sylvatica	X	X	X
Melica nutans	X	X	X
Moneses uniflora		X	
Myosotis arvensis			X
Myosotis stricta	X		X
Orthilia secunda	X	X	X
Oxalis acetosella	X	X	
Paris quadrifolia	X	X	X
Parnassia palustris	X	X	X
Phleum alpinum	X		
Phleum pratense	X	X	X
Picea abies	X	X	X
Pilosella aurantiaca		X	
Pilosella cymosa	X	X	X
Pilosella floribunda	X	X	X
Pilosella lactucella		X	
Pimpinella saxifraga	X	X	X
Pinguicula vulgaris		X	X
Pinus sylvestris	X	X	X
Plantago major		X	X
Plantago media	X	X	X
Poa alpina	X	X	X
Poa annua			X
Poa nemoralis		X	
Poa pratensis	X	X	X
Poa trivialis		X	X
Polygala amarella	X	X	X
Populus tremula	X	X	
Potentilla crantzii	X		
Potentilla erecta	X	X	X
Primula farinosa	X		
***Primula veris*[3]**	X		
Prunella vulgaris	X	X	X
Pyrola media	X		
Pyrola minor	X		
Pyrola rotundifolia	X	X	
Ranunculus acris	X	X	X
Ranunculus auricomus			X
Ranunculus repens		X	X
Rhinanthus sp.	X	X	X
Ribes nigrum			X
Rosa majalis	X	X	
Rosa villosa			X
Rubus idaeus	X	X	X
Rubus saxatilis	X	X	X
Rumex acetosa	X	X	X
Rumex acetosella			X
Rumex longifolius	X	X	X
Sagina procumbens		X	X
Salix caprea	X	X	X
Salix myrsinifolia	X	X	X

Latin name	Meadow	Road Verge	Disturbed road verge
Salix phylicifolia	X	X	X
Saussurea alpina	X	X	
Selaginella selaginoides	X	X	
Senecio vulgaris			X
Silene dioica		X	
Solidago virgaurea	X	X	X
Sorbus aucuparia		X	X
Stellaria graminea	X	X	X
Stellaria nemorum		X	
Symphytum x uplandicum			X
Tanacetum vulgare		X	X
Taraxacum sect Ruderalia	X	X	X
Thalictrum alpinum	X	X	X
Thalictrum flavum		X	
Thalictrum simplex	X		
Thlapsi caerulescens	X	X	X
Thlaspi arvense		X	X
Tragopogon pratensis		X	
Trientalis europaea	X	X	
Trifolium medium	X	X	X
Trifolium pratense	X	X	X
Trifolium repens	X	X	X
Trifolium spadiceum		X	X
Triglochin palustris			X
Tussilago farfara		X	X
Urtica dioca		X	X
Vaccinium myrtillus	X	X	X
Vaccinium uliginosum	X	X	
Vaccinium vitis-idaea	X	X	X
Veronica chamaedrys	X	X	X
Veronica officinalis	X	X	X
Veronica serpyllifolia			X
Vicia craca	X	X	X
Vicia sepium	X	X	X
Vicia sylvatica	X	X	
Viola canina	X		X
Viola canina ssp. Montana	X		
Viola riviniana	X	X	X
Viola rupestris		X	
Viola tricolor		X	X
Veronica sp.		X	
Hieracium sp.		X	

[1] Protected species
[2] Protected species, i.e. illegal to remove (dig up) plants or to sell
[3] Protected species, i.e. illegal to sell

Appendix 3

The ten most common species in each habitat and the proportion of the species out of all occurrences in that habitat. Grassland species in bold letters.

RV	%	DRV	%	Meadows	%
Achillea millefolium	4,2	*Taraxacum sect Ruderalia*	4,4	***Geranium sylvaticum***	3,8
Trifolium pratense	3,6	***Achillea millefolium***	4,2	***Agrostis capillaris***	3,2
Taraxacum sect Ruderalia	3,2	***Ranunculus acris***	3,6	*Alchemilla sp*	2,9
Ranunculus acris	3,2	*Alchemilla sp*	2,8	***Bistorta vivipara***	2,5
Leucanthemum vulgare	2,6	***Trifolium pratense***	2,8	***Leucanthemum vulgare***	2,4
Geranium sylvaticum	2,5	***Leucanthemum vulgare***	2,4	***Anthoxanthum odoratum***	2,4
Festuca rubra	2,4	***Anthriscus sylvestris***	2,3	***Potentilla erecta***	2,4
Trifolium repens	2,4	***Phleum pratense***	2,1	***Achillea millefolium***	2,3
Alchemilla sp	1,9	***Carum carvi***	2,0	***Trifolium medium***	2,2
Acrostis capillaris	1,9	*Geranium sylvaticum*	2,0	*Taraxacum sect Ruderalia*	2,0
Percentage of the total occurrences	27,8%		28,7%		26,2%