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Grassland vegetation along roads differing in size and traffic density

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Plant species composition in the highway intersections and along the highways and urban and rural roads was compared with that of field habitats (abandoned fields and field verges) and semi-natural grasslands in order to ascertain the importance of road verges as alternative habitats for the grassland flora. Species composition varied more within than between the road types. The mean number and cover of the indicator species of the semi-natural grassland vegetation in roadside habitats fell somewhere between the values obtained for field habitats and semi-natural grasslands. Plant species composition of the road verge vegetation was rarely comparable to that of semi-natural grasslands due to the young age of the verges, disturbance from road maintenance, and too intensive management, especially along the urban roads. However, sites with a good grassland vegetation were found along all road types in old verges on nutrient poor and sandy soil. Those variables were independent of the size of the road, whereas the variables related to the road size (verge width, pH, Na, Ca) proved less important for the grassland species.

Key words: management, road verge, semi-natural grassland, vegetation

Introduction

A continuous decrease in the area of semi-natural grasslands throughout Europe (e.g. Vainio *et al*. 2001) has increased the importance of alternative habitats for grassland species. Most of the possible habitats, however, are poorly suitable for grassland species. For example, waste lands, power line areas and verges along fields are either unmanaged or the management amounts solely to bush removal (Bäckman & Tiainen 2002, Kuussaari *et al*. 2003), which usually leads to tall vegetation and low species diversity (Hansson & Persson 1994).

Roadsides are regularly mown in order to ensure visibility and thereby improve traffic safety. Continuous mowing or grazing is an essential factor in both the creation and the maintenance of a species rich semi-natural vegetation. In Finland, the recommendation is for semi-natural meadows to be mown in late July or early August (Heritage landscapes working group 2000), while the roadside vegetation is mainly mown once or twice a year between mid-

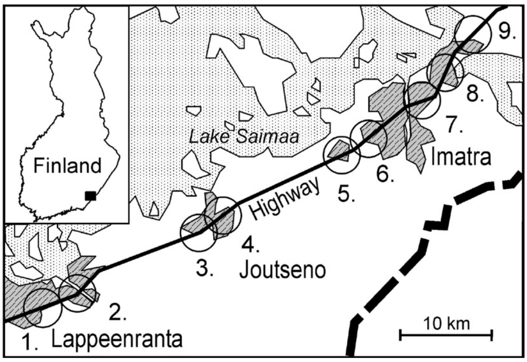

Fig. 1. The location of the nine study areas near the cities of Lappeenranta, Joutseno and Imatra (gray with oblique hatching) in SE Finland.

June and October (Finnra 2000). In addition, unlike the situation with meadows, the cut material is rarely removed from roadsides. Despite the deviation from the traditional management, many grassland plants, including threatened ones, have been recorded along the roads (Eisto *et al*. 2000, Rassi *et al*. 2001).

Road maintenance and traffic exert many adverse effects on the vegetation of verges and they tend to favour species able to adapt to disruptive factors of a different nature. As compared with the adjacent habitats, the physical environment is characterised by increased windiness and changes in temperature, soil density and water content (Farmer 1993, Forman & Alexander 1998, Trombulak & Frissel 2000). Exhaust emissions, particles and fluid leaks from vehicles, dust from the pavement materials, and deicing salts all alter the chemical environment (Liem *et al*. 1985, Angold 1997, Granby *et al*. 1997, Günthardt-Goerg *et al*. 2000, Viskari *et al*. 2000). In addition, the environmental conditions of road verges and their role as corridors promote the dispersal of exotic species (Schmidt 1989, Trombulak & Frissell 1999, Parendes & Jones 2000, Gelbard & Belnap 2003), makes the survival of the native flora even more difficult.

Most of the road-related effects on the environment depend on the width and the traffic density of the road. For example, deicing salt, $NaCl_2$, which is toxic to many plants and increases the pH along the road (Liem *et al*. 1985, Bogemans *et al*. 1989) in southeast Finland is used only on highways (Finnra 2002). Oxides of nitrogen from vehicle exhausts may increase the nitrogen content of soil near roads with heavy traffic (Angold 1997). The calcium content may be increased along both the paved and gravel roads by either the limestone dust commonly used as a filling material in asphalt or the spreading of $CaCl_2$ on gravel roads for dust binding during summer (Finnra 2002).

The width of the verge is usually related to the road size. In the field verges, the increase in the width of the verge is considered to increase plant species diversity (Shippers & Joenje 2002, Ma *et al*. 2003). A similar species–area relationship along roads should result in a higher number of species in highway verges and intersections as compared with that in the verges of smaller roads. But does the sum of the negative effects of road use and management on growth conditions along the most intensively used roads exceed the positive effect of wide verges? To ascertain whether the road type affects plant species composition we studied the vegetation and environmental conditions in highway intersections and along highways and smaller roads, comparing these with the other open environments, such as semi-natural grasslands, abandoned fields and field verges. The study was focused on grassland species in order to clarify the importance of road verges as alternative habitats for the flora of semi-natural grasslands.

Material and methods

The study was carried out at 85 sites located in nine areas along the highway Vt 6 in southeast Finland (Fig. 1). The study sites equally represented four roadside habitat types with different traffic densities and widths of road and verge (Table 1):

1. Intersections were completely surrounded by roads, ramps and a highway.
2. Highway verges were located near intersections: five sites were located along a four-lane motorway and 12 verges along a two-lane highway.
3. Urban road verges were located along paved roads in sparsely populated areas near towns.
4. Rural road verges were located along gravel

roads (13) and narrow paved roads (4) in rural areas.

Roadside habitats were compared with semi-natural grasslands (8 sites) and field habitats (5 abandoned fields, 4 field verges). Two sites in each road type were located in each area, but semi-natural grasslands were not always found near the highway intersections.

Most of the roadside habitats were mown once (in August) or twice (in the end of June and August) during the summer (59 sites, 87%). Five verges (7%) were regarded as unmown because the mown area was so narrow that the vegetation of the verge remained practically undisturbed. In addition, four wide and partly forested intersections (6%) were also regarded as unmown as they were mown only along the roads. Except for three grazed grasslands, the grasslands and the field habitats were unmanaged during the study years. During the last decade two dry grasslands were irregularly mown, while three grasslands and all nine field habitats were either unmanaged or the management constituted only the removal of bushes.

The vegetation data for each 250-m site was collected from ten sample plots (1 m × 1 m) systematically located at 25-m intervals in the middle of the area between the road edge and ditch. Along the smallest rural roads, the plots were partially located over the ditch. In intersections, semi-natural grasslands and field habitats, the study transect of sample plots was projected through the area. The plots were mostly studied before mowing (except for two sites sampled four weeks after mowing) between 13 June and 10 July in 2002 (5 areas, 50 sites) and 2003 (4 areas, 35 sites). The abundance of each taxon

Table 1. Properties of the site, soil and the surrounding environment in the four road types, field habitats (abandoned fields/field verges) and semi-natural grasslands. Values are given either as a range (traffic, speed), the number of sites (sandiness, humus, mowing), proportions (adjacent environment) or mean ± S.D. (all other variables).

	Intersections (n = 17)	Highway verges (n = 17)	Urban road verges (n = 17)	Rural road verges (n = 17)	Field habitats (n = 9)	Semi-natural grasslands (n = 8)
Site characteristics						
traffic (× 1000 cars/d)	9–15	9–15	1.5–6	< 0.3	0	0
speed (**median** & range)	several	80–**100**	40–**50**–80	**40**–60	0	0
width of road (m)	several	18.3 ± 8.1	9.6 ± 2.2	5.9 ± 1.8	0	0
Site and soil properties						
age of verge/site***[S]	10 ± 10[a]	19 ± 9[a]	17 ± 10[a]	20 ± 8[a]	19 ± 7[a]	55 ± 28[b]
width of verge/site (m)***[S]	56 ± 23[a]	10.3 ± 3.6[b]	8.4 ± 1.6[b]	2.6 ± 1.2[c]	47 ± 43[ab]	68 ± 28[a]
pH***[S]	6.40 ± 0.65[ab]	7.10 ± 0.85[b]	6.78 ± 0.74[ab]	6.13 ± 0.54[a]	6.18 ± 0.44[ab]	5.88 ± 0.51[a]
Na (g kg^{-1})*	0.16 ± 0.12	0.36 ± 0.26	0.20 ± 0.09	0.20 ± 0.10	0.14 ± 0.08	0.18 ± 0.18
Ca (g kg^{-1})*	2.35 ± 1.43	3.32 ± 2.36	2.43 ± 0.97	2.16 ± 1.77	1.41 ± 0.55	1.68 ± 0.96
K (g kg^{-1})	1.37 ± 0.65	1.36 ± 0.49	1.50 ± 0.71	1.94 ± 0 99	1.56 ± 0.70	2.16 ± 2.49
N_{tot} (g kg^{-1})	1.16 ± 0.82	1.73 ± 1.20	1.31 ± 0.81	1.60 ± 0.87	1.51 ± 0.50	1.85 ± 0.60
P_{tot} (g kg^{-1})	0.44 ± 0.17	0.50 ± 0.40	0.75 ± 0.92	0.45 ± 0.18	0.71 ± 0.45	0.70 ± 0.30
C_{org} (%)	2.63 ± 2.17	5.29 ± 5.95	2.51 ± 2.30	3.76 ± 3.57	3.68 ± 2.74	7.10 ± 7.15
sandiness (0/1/2/3)	2/5/3/7	3/4/5/5	1/1/10/5	1/4/8/4	3/2/4/0	2/0/3/3
humus cont. (0/1/2/3)	2/5/6/4	0/6/3/8	1/2/10/4	3/2/5/7	0/3/3/3	0/2/5/1
Adjacent environment						
fields (%)*** [S]	0 ± 0[a]	8 ± 22.2[a]	6 ± 24.3[a]	62 ± 40.3[b]	32 ± 33.7[ab]	0 ± 0[a]
forests (%)*** [S]	4 ± 12.2[a]	51 ± 49.1[ab]	66 ± 40.6[b]	19 ± 35.6[a]	20 ± 20.3[ab]	3 ± 5.3[ab]
Mowing						
no/once/twice	4/7/6	3/12/2	2/6/9[m]	0/15/2	9/0/0	8[g]/0/0
weeks 25–27/28–30/later	6/0/13	10/0/6	10/3/13	5/9/5	0	0

Kruskal-Wallis test: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
[S] = significant after sequential Bonferroni correction.
[m] two sites were mown 3–5 times.
[g] three sites were managed by grazing.

was estimated by the projection cover using a percentage scale (0%–100%). The taxonomy is as defined by Hämet-Ahti *et al*. (1998).

Vegetation analyses were focused on two ecologically different groups of species, i.e. grassland species and weeds, based on positive or negative indicators of semi-natural grassland vegetation defined by Pykälä (2001). Positive indicators were divided into good (GI) and moderate indicators (MI). Species in the latter group are indicators only if they were abundant at the site (Pykälä 2001). In our study a species was regarded as abundant if it was found in at least five of the ten plots at the site or the sum of cover of the ten plots exceeded 100%. *Festuca rubra* (MI) was excluded from the group of grassland species because it is very often sown on verges.

Environmental variables at the site, soil conditions and surrounding habitat which might affect species composition were measured or estimated (Table 1). The age of the site indicated how many years had passed since the road was built or the soil of the site was tilled. The oldest age of the road habitats was set at 25 years based on the intervals between the road and ditch repairs. Soil pH and nutrients (Na, Ca, K, P, N, org. C%) were determined from samples collected in August 2003. The samples consisted of three or four subsamples taken at a depth of 10–15 cm and at 30-m intervals along the middle of the site. Sodium, calcium and potassium were determined from dried samples using atomic absorption spectrophotometry, total phosphorus was measured spectrophotometrically, and total nitrogen by the Kjehldahl method. The sand and humus content was visually estimated during soil sampling and classified as (0) absent, (1) small, (2) moderate or (3) high. The proportions of the adjacent fields and forests were estimated along each 250-m site. In intersections, grasslands and field habitats, the proportions were estimated at a distance of 10 m from the sample plot line.

Differences in environmental variables and the number and summed cover of grassland species and weeds between the habitat types were statistically tested using the Kruskal-Wallis test followed by the rank examination according to Siegel and Castellan (1988). A sequential Bonferroni correction was used to lower the risk of significant differences by chance. Since the method severely reduces the efficacy of tests, we used an error rate of 10% as suggested by Chandler (1995).

The importance of environmental variables on the species composition was evaluated using a canonical correspondence analysis (CCA; ter Braak 1986). In the CCA, the importance of a variable is presented in the length of its arrow plotted to the ordination diagram with a given r^2 value (McCune & Mefford 1999). In the analysis, the same maximum age limit as that set for road habitats (25 years) was used for the semi-natural grasslands for decreasing deviation in the ordination diagrams. The importance of variables in the roadside habitats on the number and cover of grassland species and weeds was studied using Pearsson correlations.

Results

Four of the five environmental variables (verge width, pH, Na, Ca) that may be dependent on the size of the road differed among the habitat types in the single Kruskal-Wallis test, but after the Bonferroni correction only the difference in the width of the verge and pH remained significant (Table 1). As expected, the pH, and sodium and calcium contents were highest along the highways. The amount of nitrogen was high in both highway verges and semi-natural grasslands. The other variables with significant differences among the habitat types were the age of the site and the proportion of the adjacent forests and fields.

Altogether 47 grassland species were found, 37 in road habitats, 28 in semi-natural grasslands and 12 in field habitats (Appendix). More than five grassland species were found at eight sites, four of which were semi-natural grasslands (7–10 species). There was also one site in each road type with six or seven grassland species. On the other hand, not a single grassland species was found in six urban road sites, 1–3 sites in other road types, three abandoned fields and one field verge. The lowest number of indicators in the semi-natural grasslands was 2–3 species found in the three poorly managed sites.

Due to the strong variation among the sites, no significant differences in the number of grassland species were found among the habitat types after the Bonferroni correction (Table 2). Only the mean cover of good indicators was higher in grasslands as compared with that in the intersections. The mean number and the total cover of grassland species in the roadside habitats (2.2–2.9 species/4.7%–9.2%) were slightly higher than those in field habitats (1.6/3.4) but lower as compared with those in the semi-natural grasslands (5.6/17.0).

The number and cover of weeds were 2–3 times higher than those of good indicators in the semi-natural grasslands, while the corresponding relationships in the roadside habitats were 11–20 and 19–207 in the number and cover of species, respectively. The most abundant weeds, *Taraxacum* ssp., *Cirsium arvense*, *Elymus repens*, *Anthriscus sylvestris* and *Artemisia vulgaris*, were found in more than 50 sites out of the 85.

Habitat types were rather widely dispersed in the CCA-ordination, indicating no major differences among the types (Fig. 2). The age of the site, sandiness of the soil and abundance of the adjacent forests and fields were the most important variables ($r^2 > 0.3$) affecting the distribution of sites and species in the ordination diagram. Although the width of the site and pH differed among the habitat types, these were weak variables in the ordination. The sites were more or less divided into young and old ones. Only five intersections were older than ten years, while in the other road types the number of such sites varied from 10 to 14. Most of the grassland species, especially good indicators, favoured old sites characterised by a nutrient poor and sandy soil (Fig. 3). Only three good indicators were located among the young sites.

The correlation matrix among the species groups and environmental variables in the road sites supported the ordination results (Table 3). The abundance of grassland species was positively correlated with the age of the site. Weeds preferred somewhat opposite environmental conditions as compared to those preferred by the grassland species. They were mainly found in the road habitats with high content of humus and nutrients, especially nitrogen.

Discussion

Species composition varied more within the roadside habitat types than among the types. This was not surprising because there were no differences among the habitat types in the most important variables affecting the plant species composition, namely the age of the site and sandiness. The occurrence and abundance of grassland species, especially good indicators,

Table 2. The mean number and cover (± S.D.) of all species, grassland species and weeds in the highway intersections (Is) and in the verges along highways (Hw), urban roads (Ur) and rural roads (Rr), and in field habitats (abandoned fields/field verges) and semi-natural grasslands. Grassland species were divided into good (GI) and moderate indicators (MI) of a semi-natural grassland vegetation (*see* Appendix).

	Is	Hw	Ur	Rr	Field habitats	Grasslands	Kruskal-Wallis *p*
Number of species							
all sp.	39.1 ± 11.7	37.6 ± 8.9	41.5 ± 7.8	46.9 ± 10.5	42.7 ± 12.2	43.0 ± 7.5	0.158
grassl. sp.	2.2 ± 1.6	2.8 ± 1.8	2.1 ± 1.9	2.9 ± 2.0	1.6 ± 1.7	5.6 ± 3.3	0.038
GI	0.5 ± 0.7	0.9 ± 1.2	0.6 ± 1.3	1.1 ± 0.9	0.9 ± 1.2	2.8 ± 2.5	0.038
MI	1.7 ± 1.1	1.9 ± 1.6	1.5 ± 1.3	1.8 ± 1.4	0.7 ± 1.0	2.9 ± 1.6	0.082
weeds	10.1 ± 3.8^{ab}	9.5 ± 3.4^{ab}	11.9 ± 4.4^{a}	12.1 ± 3.5^{a}	11.7 ± 3.1^{ab}	6.3 ± 2.4^{b}	0.005^{S}
weeds/GI	20	11	20	11	13	2	
Cover of species							
grassl. sp.	8.4 ± 6.1	9.2 ± 7.5	4.7 ± 4.9	8.3 ± 11.3	3.4 ± 4.7	17.0 ± 15.6	0.042
GI	0.1 ± 0.1^{a}	1.4 ± 2.4^{ab}	0.6 ± 1.1^{ab}	0.6 ± 1.3^{ab}	0.9 ± 1.6^{ab}	5.6 ± 8.1^{b}	0.016
MI	8.3 ± 6.0	7.8 ± 7.2	4.1 ± 4.8	7.7 ± 11.3	2.5 ± 4.5	11.4 ± 9.6	0.025
weeds	20.7 ± 13.7	26.0 ± 20.2	21.1 ± 13.3	33.5 ± 18.2	33.4 ± 6.7	16.8 ± 14.0	0.032
weeds/GI	207	19	35	56	37	3	

^{S} = significant after sequential Bonferroni correction.

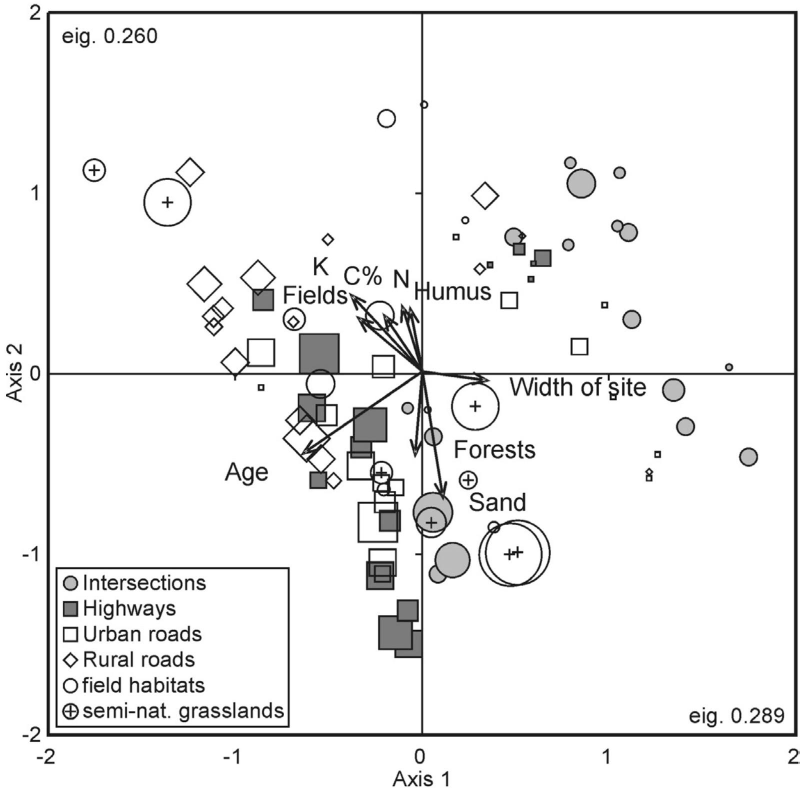

Fig. 2. CCA-ordination of the road verges, field habitats and semi-natural grasslands. Environmental variables with r^2 > 0.1 (with scores on either axis) are plotted. The size of the symbol is indicative of the number of grassland plants.

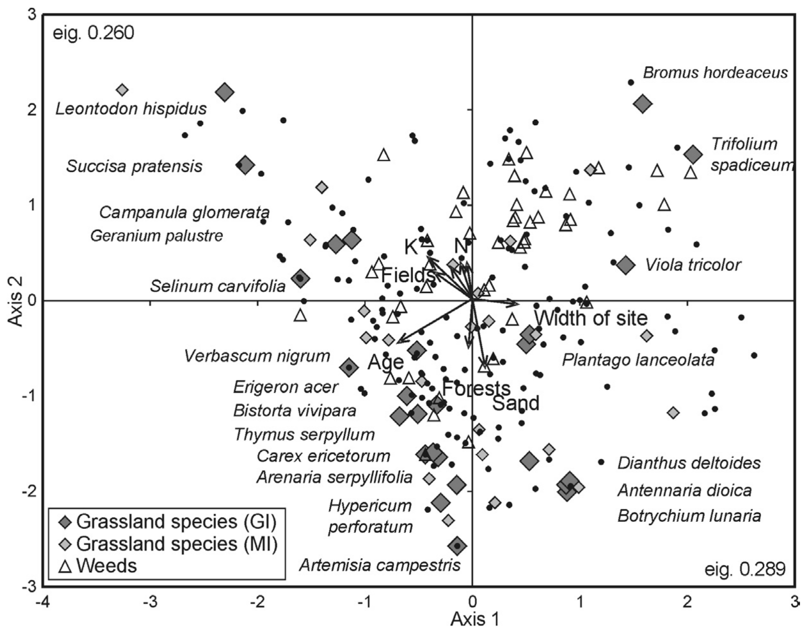

Fig. 3. CCA-ordination of plant species in the road verges, field habitats and semi-natural grasslands. All species mentioned are good indicators (GI) of semi-natural grasslands (*see* Appendix).

was smallest in the youngest type, intersections, with a mean age of only ten years. The oldest sites, semi-natural grasslands, had the highest number of grassland indicators and on the other hand, the lowest number of weeds. Age constitutes an important factor for the development of the grassland vegetation in other open habitats as well (Marshall & Arnold 1995, Poschlod *et al.* 1998, Csecserits & Rédei 2001). The development of valuable semi-natural grassland requires, however, continuous management by mowing or grazing for at least 50, but mostly over 100, years (Vainio *et al.* 2001).

Sandiness indicated the other important feature of valuable grasslands, nutrient poor soil. In particular, low levels of nitrogen, phosphorus and potassium are associated with grasslands of high botanical value (Janssens *et al.* 1998, Critchley *et al.* 2002). Although the occurrence of grassland species was on average higher in the semi-natural grasslands than in any other habitat types, the sites were rather rich in nutrients. The mean values of nitrogen and phosphorus were increased by two unmanaged and overgrowing grasslands and a recently restored pasture (N: 2.1–2.7 g kg^{-1}, P: 0.8–1.1 g kg^{-1}), which had the lowest number of grassland species (2–3 species). On the other hand, sites along roads with nutrient-poor sandy soil and a relatively long history of mowing supported almost as high a number of grassland species as the best dry semi-natural grasslands.

In our study, the difference in plant species composition between the roadside habitats and semi-natural grasslands was not so clear as in studies made by Tikka *et al.* (2000) and Norderhaug *et al.* (2000). The verges of rural roads have earlier been shown to be important for the maintenance of plant species diversity in the agricultural landscapes (Eriksson *et al.* 1995, Cousins & Eriksson 2001), but according to our study, important habitats for grassland species can settle both in the intersections and in the verges along different types of roads.

Although there were no statistical differences in the mean number and cover of species among the verges of different sizes of roads, some features were characteristic for the vegetation of certain road types. The cover of grassland species was lowest along the urban road verges, probably due to the over-intensive management with two or more mowings during the summer and soil disturbance due to roadworks and the maintenance of municipal services (sewerage, cables, etc.). In Finland, mowing twice a year is recommended only on sites that suffer from a predominance of grasses or other competitive species (Hansson & Persson 1994, Herit-

Table 3. Pearsson correlations between the species groups (*n* = number of species, % = cover of species) and the environmental variables in the roadside habitats. Values between –0.15 to +0.15 are excluded.

	Grassland species good indicators		Grassland species moderate indicators		Weeds	
	n	%	*n*	%	*n*	%
Weeds *n*	–	–0.18	–	–		0.52***S
Weeds %	–	–	–	–	0.52***S	
All sp.	0.35**S	–	0.37**S	0.18	0.37**S	–
Width	0.21	–	–	–	–	–0.21
Age	0.50***S	0.35**S	0.45***S	–	–	–
Sandiness	0.16	–	0.23	–	–0.33**	–0.38**S
Humus cont.	–	–	–	–	0.22	0.37**S
pH	–	0.20	–0.20	–	–	–
Na	–	–	–0.18	–0.15	–	0.16
Ca	–	–	–	–0.15	–	0.19
K	–	–	–	–	0.26*	0.16
N_{tot}	–0.20	–	–0.19	–	0.22	0.44***S
P_{tot}	–	–	–0.23	–	0.25*	–
C_{org} (%)	–	–	–	–	0.19	0.36**S
Forests	–	0.16	–	–	–0.29*	–0.29*
Fields	–0.23	–	–	–	0.19	0.25*

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.
S = significant after sequential Bonferroni correction.

age landscapes working group 2000, Hellström 2004). In central Europe and the UK, the most species rich vegetation was recorded on verges mown twice a year (Oomes & Mooi 1981, Parr & Way 1988), but there the growing season is longer than it is in Finland.

The number of species and weeds in particular was highest in the narrow verges along the rural roads. Apparently this was at least partly caused by the monitoring method. In the narrow verges, species with different habitat requirements can grow in a square metre plot covering an area from the dry ditch bank to the moister ditch bottom. The same trend in the species richness between the verges of small gravel roads and the paved main roads were found by Norderhaug *et al.* (2000) and Tikka *et al.* (2000). They explained the trend by the differences in the surrounding environment, lack of sown grass and lower levels of soil disturbance during the construction of gravel roads. Species richness and the abundance of weeds may also be a result of the present unstable conditions of the narrow verge between a gravel road and the adjacent habitats. In our study, the verges of rural roads were, on the one side, under the influence of the road use and maintenance (e.g. dragging and dust) and on the other side, under the influence of the cultivation methods of fields (e.g. the spread of agrochemicals) which all exert some influence on the vegetation (Farmer 1993, Marshall & Moonen 2002, Shippers & Joenje 2002, Smart *et al.* 2002). By contrast, the plots along the highway verges lay several metres away from both the road and the adjacent biotope and thus physical disturbance was rarer than along the urban or rural roads. The higher traffic density results in a higher level of exhaust emission as compared with that along the rural roads but the traffic on the highways studied (9000–15 000 cars/day) is still rather low as compared with that on many roads in central Europe.

We can conclude that some characteristics in the roadside vegetation were related to the size of the road, but the differences were almost obscured by the variation in the species composition within the road types. Ullman and Heindl (1989) described the high diversity of habitats and plants on road verges as a consequence of a large-scale gradual change from anthropogenic to natural site conditions and also a small-scale one within the profile of roadsides. Many grassland species were present along the road verges, but the species composition in general was not comparable to the semi-natural grasslands due to the too intensive management, the disturbance from road maintenance and the adjacent environment and, in the majority of sites, to the young age of the verge. Thus, most of verges studied so far formed poor habitats for the grassland species. Nevertheless, in practice the roadsides are probably important for the grassland flora owing to the large amounts of open areas with varying environmental conditions. The total length of the Finnish road network is approximately 384 000 km and the estimated total area of road habitats is 140 000 hectares (Jantunen *et al.* 2004), which is 50-fold as compared with the area of the remaining semi-natural grasslands on mineral soils (Vainio *et al.* 2001). The decreasing use of nutrient rich soil during the construction of verges, improvements in the mowing management, and the restricting of the tillage area along road verges, if possible, would lead to a general improvement in the diversity and would provide better opportunities for many grassland species to survive along the roads in the future.

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References

Angold, P. G. 1997: The impact of road upon adjacent heathland vegetation: effects on plant species composition. — *J. Appl. Ecol.* 34: 409–417.

Bäckman, J.-P. C. & Tiainen, J. 2002: Habitat quality of field margins in a Finnish farmland area for bumblebees (Hymenoptera: *Bombus* and *Psithyrus*). — *Agric. Ecosyst. Environ.* 89: 53–68.

Bogemans, J., Neirinckx, L. & Stassart, J. M. 1989: Effect of chloride salts on ion accumulation in spruce (*Picea abies* (L.) sp.). — *Plant Soil* 113: 3–11.

Chandler, C. R. 1995: Practical considerations in the use of simultaneous inference for multiple tests. — *Anim. Behav.* 49: 524–527.

Cousins, S. A. O. & Eriksson, O. 2001: Plant species occurrences in a rural hemiboreal landscapes: Effects of remnant habitats, site history, topography and soil. — *Ecography* 24: 461–469.

Critchley, C. N. R. & Fowbert, J. A. 2000: Development of vegetation on set-aside land for up to nine years from a national perspective. — *Agr. Ecosyst. Environ.* 79: 159–174.

Csecserits, A. & Rédei, T. 2001: Secondary succession on sandy old fields in Hungary. — *Appl. Veg. Sci.* 4: 63–74.

Eisto, A.-K., Kuitunen, M., Lammi, A., Saari, V., Syrjäsuo, S. & Tikka, P. M. 2000: Population persistence and offspring fitness in the rare bellflower *Campanula cervicaria* in relation to population size and habitat quality. — *Conserv. Biol.* 14: 1413–1421.

Eriksson, Å., Eriksson, O. & Berglund, H. 1995: Species abundance patterns of plants in Swedish semi-natural pastures. — *Ecography* 18: 310–317.

Farmer, A. M. 1993: The effects of dust on vegetation — a review. — *Environ. Pollut.* 79: 63–75.

Finnra 2000: *Viherhoito tieympäristössä*. — Finnish Road Administration, Helsinki.

Finnra 2002: *Kaakkois-Suomen tiepiirin ympäristöraportti 2002*. — Finnish Road Administration, Kaakkois-Suomi Road Region, Kouvola.

Forman, R. T. T. & Alexander, L. E. 1998: Roads and their major ecological effect. — *Ann. Rev. Ecol. Syst.* 29: 207–231.

Gelbard, J. L. & Belnap, J. 2003: Roads as conduits for exotic plant invasion in a semiarid landscape. — *Conserv. Biol.* 17: 420–432.

Granby, K. & Christensen, C. S. 1997: Urban and semi-rural observations of carbonylic acids and carbonyls. — *Atmos. Environ.* 31: 1403–1415.

Günthardt-Goerg, M. S., McQuattie, C. J., Maurer, S. & Frey, B. 2000: Visible and microscopic injury in leaves of five deciduous tree species related to current critical ozone levels. — *Environ. Pollut.* 109: 489–500.

Hämet-Ahti, L., Suominen, J., Ulvinen, T. & Uotila, P. 1998: *Retkeilykasvio*. — Finnish Museum of Natural History, Botanical Museum, Helsinki.

Hansson, M. L. & Persson, T. S. 1994: *Anthriscus sylvestris* — a growing conservation problem. — *Ann. Bot. Fennici* 31: 205–213.

Hellström, K. 2004: Variation in grazing tolerance and restoration of meadow plant communities. — *Acta Univ. Oul.* A 423: 1–51.

Heritage landscapes working group 2000: The management of agricultural heritage habitats in Finland. — *The Finnish Environment* 443: 1–162. [In Finnish with English summary].

Janssens, F., Peeters, A., Bakker, J. P., Bekker, R. M., Fillat, F. & Oomes, M. J. M. 1998: Relationship between soil chemical factors and grassland diversity. — *Plant Soil* 202: 69–78.

Jantunen, J., Saarinen, K., Valtonen, A., Hugg, T. & Saarnio, S. 2004: Vegetation and butterfly fauna in roadside habitats. — *Finnra Reports* 9/2004: 1–57. [In Finnish with English summary].

Kuussaari, M., Ryttäri, T., Heikkinen, R., Manninen, P., Aitolehti, M., Pöyry, J., Pykälä, J. & Ikävalko, J. 2003: Significance of power line areas for grassland plants and butterflies. — *The Finnish Environment* 638: 1–65. [In Finnish with English summary].

Liem, A. S. N., Hendriks, A., Kraal, H. & Loenen, M. 1985: Effects of de-icing salts on roadside grasses and herbs. — *Plant Soil* 84: 299–310.

Ma, M., Tarmi, S. & Helenius, J. 2002: Revisiting the species-area relationship in a semi-natural habitat: floral richness in agricultural buffer zones in Finland. — *Agr. Ecosyst. Environ.* 89: 137–148.

Marshall, E. J. P. & Arnold, G. M. 1995: Factors affecting field weed and field margin flora on a farm in Essex, UK. — *Landscape Urban Plan.* 31: 205–216.

McCune, B. & Mefford, M. J. 1999. *Multivariate analysis of ecological data*, ver. 4.0. — MjM Software, Gleneden Beach, Oregon, U.S.A.

Norderhaug, A., Ihse, M. & Pedersen, O. 2000: Biotope patterns and abundance of meadow plant species in a Norwegian rural landscape. — *Landscape Ecol.* 15: 201–218.

Oomes, M. J. M. & Mooi, H. 1981: The effect of cutting and fertilizing on the floristic composition and production of an *Arrhenatherion elatioris* grassland. — *Vegetation* 47: 233–239.

Parendes, L. A. & Jones, J. A. 2000: Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. — *Conserv. Biol.* 14: 64–75.

Parr, T. W. & Way, J. M. 1988: Management of roadside vegetation: the long term effects of cutting. — *J. Appl. Ecol.* 25: 1073–1087.

Poschlod, P., Kiefer, S., Tränkle, U., Fischer, S. F. & Bonn, S. 1998: Plant species richness in calcareous grasslands as affected by dispersality in space and time. — *Appl. Veg. Sci.* 1: 75–90.

Pykälä, J. 2001: *Maintaining biodiversity through traditional animal husbandry* — Finnish Environment Institute, Helsinki. [In Finnish with English summary].

Rassi, P., Alanen, A., Kanerva, T. & Mannerkoski, I. (eds.) 2001: *The red list of Finnish species*. — Ministry of the Environment, Helsinki. [In Finnish with English summary].

Schmidt, W. 1989: Plant dispersal by motor cars. — *Vegetatio* 80: 147–152.

Shippers, P. & Joenje, W. 2002: Modelling the effect of fertiliser, mowing, disturbance and width on the biodiversity of plant communities of field boundaries. — *Agric. Ecosyst. Environ.* 93: 351–365.

Siegel, S. & Castellan, N. J. 1988: *Nonparametric statistics for the behavioural sciences*. — McGraw-Hill, Singapore.

Smart, S. M., Bunce, R. G. H., Firbank, L. G. & Coward, P. 2002: Do field boundaries act as refugia for grassland plant species diversity in intensively managed agricultural landscapes in Britain? — *Agr. Ecosyst. Environ.* 91: 73–87.

ter Braak, C. J. F. 1986: Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. — *Ecology* 67: 1167–1179.

Tikka, P. M., Koski, P. S., Kivelä, R. A. & Kuitunen, M. T. 2000: Can grassland plant communities be preserved on road and railway verges? — *Appl. Veg. Sci.* 3: 25–32.

Trombulak, S. C. & Frissell, C. A. 2000: Review of ecological effects of roads on terrestrial and aquatic communities. — *Conserv. Biol.* 14: 18–33.

Ullmann, I. & Heindl, B. 1989: Geographical and ecological differentation of roadside vegetation in temperate Europe. — *Bot. Acta* 102: 261–269.

Vainio, K., Kekäläinen, H., Alanen, A. & Pykälä, J. 2001: Traditional rural biotopes in Finland. Final report of the nationwide inventory. — *The Finnish Environment* 527: 1–163. [In Finnish with English summary].

Viskari, E.-L., Vartiainen, M. & Pasanen, P. 2000: Seasonal and diurnal variation in formaldehyde and acetaldehyde concentrations along a highway in Eastern Finland. — *Atmos. Environ.* 34: 917–923.

Appendix. Good and moderate indicator species of semi-natural grassland vegetation in the highway intersections (Is) and along the highway (Hw), urban road (Ur) and rural road verges (Rr), and in the field habitats (F) and semi-natural grasslands (G).

	Number of sites						Mean cover of species					
	Is	Hw	Ur	Rr	F	G	Is	Hw	Ur	Rr	F	G
Good indicators												
Antennaria dioica	0	0	0	0	0	2	0	0	0	0	0	3.89
Arenaria serpyllifolia	0	0	1	0	0	0	0	0	0.03	0	0	0
Artemisia campestris	0	1	2	2	0	2	0	0.04	0.25	0.03	0	0.25
Bistorta vivipara	0	0	1	0	0	0	0	0	0.04	0	0	0
Botrychium lunaria	0	0	0	0	0	2	0	0	0	0	0	0.03
Bromus hordeacus	1	0	0	0	0	0	0.00	0	0	0	0	0
Campanula glomerata	2	2	2	8	1	3	0.01	0.01	0.01	0.24	0.03	0.19
Carex ericetorum	0	1	0	0	0	0	0	0.04	0	0	0	0
Dianthus deltoides	0	0	0	0	0	3	0	0	0	0	0	0.22
Erigeron acer	1	2	1	2	1	2	0.00	0.01	0.00	0.02	0.06	0.04
Euphrasia ssp.	0	0	0	1	0	1	0	0	0	0.00	0	0.02
Geranium palustre	0	0	0	0	1	0	0	0	0	0	0.33	0
Hypericum perforatum	0	1	0	1	1	1	0	0.03	0	0.01	0.03	0.00
Lathyrus sylvestris	0	3	0	0	0	0	0	0.79	0	0	0	0
Leontodon hispidus	0	0	0	1	0	0	0	0	0	0.01	0	0
Lychnis viscaria	1	0	1	0	1	2	0.01	0	0.00	0	0.01	0.34
Plantago lanceolata	0	0	0	0	0	1	0	0	0	0	0	0.01
Ranunculus polyanthemos	1	2	1	2	1	1	0.01	0.14	0.06	0.04	0.01	0.21
Selinum carvifolia	0	0	1	0	0	0	0	0	0.18	0	0	0
Succisa pratensis	0	1	0	0	1	2	0	0.01	0	0	0.17	0.41
Thymus serpyllum	0	2	0	0	1	0	0	0.31	0	0	0.22	0
Trifolium spadiceum	1	0	0	0	0	0	0.00	0	0	0	0	0
Verbascum nigrum	0	0	0	1	0	0	0	0	0	0.29	0	0
Viola tricolor	1	0	0	1	0	0	0.01	0	0	0.00	0	0
Moderate indicators												
Anthoxanthum odoratum	1	0	1	0	0	0	0.36	0	0.04	0	0	0
Festuca ovina	1	0	0	0	1	2	0.08	0	0	0	0.33	2.00
Fragaria vesca	0	4	0	1	0	0	0	2.76	0	0.13	0	0
Galium boreale	0	2	0	4	0	2	0	1.09	0	3.58	0	2.03
Hieracium ssp.	0	0	0	0	0	1	0	0	0	0	0	0.17
Hieracium umbellatum	0	2	1	0	0	0	0	0.16	0.06	0	0	0
Knautia arvensis	0	0	0	0	0	1	0	0	0	0	0	0.17
Lathyrus pratensis	8	4	6	6	2	1	4.21	0.96	1.68	1.70	1.29	0.74
Leucanthemum vulgare	1	1	2	2	0	0	0.29	0.10	0.78	0.17	0	0
Luzula multiflora	1	0	0	0	0	1	0.03	0	0	0	0	0.05
Pilosella officinarum	0	0	0	0	0	2	0	0	0	0	0	1.73
Pimpinella saxifraga	1	3	3	1	0	2	0.03	0.09	0.21	0.04	0	0.53
Potentilla argentea	0	0	0	0	1	0	0	0	0	0	0.36	0
Potentilla erecta	0	1	0	0	0	1	0	0.05	0	0	0	0.11
Rosa majalis	0	0	0	0	0	1	0	0	0	0	0	0.08
Rumex acetosa	1	1	1	1	0	2	0.03	0.01	0.08	0.02	0	0.08
Rumex acetosella	2	0	0	1	0	0	0.10	0	0	0.03	0	0
Solidago virgaurea	0	2	2	0	0	1	0	0.16	0.17	0	0	0.51
Stellaria graminea	0	1	0	4	0	3	0	0.05	0	0.10	0	0.11
Trifolium medium	0	1	0	0	0	1	0	0.45	0	0	0	2.96
Vicia cracca	10	8	9	8	2	0	2.83	1.87	1.10	1.84	0.53	0
Vicia sepium	2	1	0	2	0	1	0.36	0.03	0	0.03	0	0.08
Viola canina	1	1	0	0	0	1	0.02	0.02	0	0	0	0.04
Good + moderate ind.	18	23	16	19	12	28						
Weeds (44 species)	32	24	39	32	29	17						