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VASCULAR PLANT SPECIES DIVERSITY AND COMPOSITION OF ESTONIAN AGRICULTURAL LANDSCAPES

Master thesis

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1. INTRODUCTION

1. 1. The biodiversity of agricultural landscapes

Transition from traditional agricultural activities to intensive land-use practises during last century has resulted in enormous changes in the environmental conditions of agricultural landscapes and landscape patterns. The expansion of fields, mechanisation, intensive use of different chemicals and fertilisers – these are the keywords that characterise the 20th century agricultural revolution in whole Europe (Meeus et al. 1995, Stuart Chapin III et al. 2000, Tilman et al. 2001). The impact of mentioned processes can be recognised in steep decrease in the biodiversity of agricultural landscapes that in turn affects biodiversity values at larger scales. Transition from traditional agricultural methods to intensive techniques has been the main reason for the habitat loss of several species (Priorr 2003). The viability of still persistent populations of native species is threatened by continuing habitat isolation or fragmentation and disturbance from agricultural activities. Furthermore, according to Hobbie and colleagues (1994), the time when species can actually adapt to those abrupt changes, is 5-6 folds longer than extinction processes. But the ongoing growth of human population calls for higher agricultural production. Therefore, agricultural activities and nature protection should be unified to guarantee sustainable environment for the maintenance of biodiversity. Such an approach should take into account the temporal and spatial dynamics of species in agricultural landscapes and should decrease the pressure of intensively managed landscapes on adjacent natural ecosystems.

The biodiversity of agricultural landscapes is substantial for maintaining diversity at larger scales but it serves different ecological objectives at local scales as well. Higher functional diversity controls several essential processes in the landscape, e.g. flows of matter and agricultural chemicals, microclimate, hydrological conditions and pest dispersal (Altieri 1999, Banks 2000). Intensive agriculture has favoured the cultivation of monocultures and the decline in biodiversity to achieve maximum short-term production and profit and thus has seriously influenced the capacity of agricultural ecosystems to resist environmental changes (Thomas and Kevan 1993). Besides the importance of self-regulation abilities of agroecosystems, the significance of cultural and historical background of agricultural landscapes has been emphasised during last years as well (Ahern 1995, Le Coeur et al. 2002, Antrop 2005).

Biodiversity can be explored at different spatial and temporal scales: from genetic, species, habitat and ecosystem diversity perspectives as well as from the aspects of structural and functional heterogeneity and temporal changes. The most common approach for measuring biodiversity includes the evaluation of species richness and evenness. However, it must be kept in mind that it is essential to understand linkages between different organisation levels of nature when the aim is to protect the integrity of biodiversity and not only one of the before-mentioned aspects (Duelli 1997, Büchs 2003).

The main reasons for the decrease in the biodiversity of agricultural landscapes are related to habitat loss and isolation (Brokaw 1998, Alard and Poudevigne 1999). It is possible that semi-natural linear elements of agroecosystems (e.g. field margins, hedgerows, road verges, ditches) to some extent compensate the mentioned effects and that several species use these elements as alternative habitats and dispersal routes from one suitable environment to another (Le Coeur et al. 2002). Yet, the loss of large stable habitat patches, which are not subject to intensive agricultural disturbances, results in the changes in species composition and the dominance of generalist species in the landscape (Burel et al. 1998).

Scattered isolated habitat patches in agricultural landscapes can be compared to oceanic islands. Similarly, the equilibrium theory of island biogeography has been applied to describe the biodiversity patterns of isolated spatial elements of mainland ecosystems (MacArthur 1972, Holl and Crone 2004). According to the theory, the species richness of a habitat "island" is positively correlated with the area of an "island" and negatively affected by the distance from the "mainland" or another habitat patch which acts as a source of seeds. These are the main factors influencing the immigration of species, the rate of local extinction and recolonisation or species turnover. However, the island theory of biogeography cannot explicitly be used to explain the diversity patterns of landscapes because the heterogeneity of habitats within a patch and human influence are not considered in this concept (Duelli 1997, Brose 2001, Wagner and Edwards 2001). Besides, several species are still capable of using agricultural matrix and linear elements (e.g. hedgerows, road verges) to move from one suitable habitat "island" to another (Pimm 1998). Nevertheless, the island biogeographic theory was one of the conceptual frameworks for the development of metapopulation theory (Hanski 1998).

According to metapopulation theory, a metapopulation consists of several spatially separated subpopulations that are related through the dispersal of individuals between subpopulations (Hanski 1996, Hanski 1998). In agricultural landscapes, many species exist as subpopulations in scattered habitat patches that are interrelated due to dispersal of individuals and seeds. Consequently, the survival of a whole population depends upon the relationship between extinction and recolonisation rates among habitats (Hanski 1998). It has been suggested that the protection of endangered species should consider the application of metapopulation model instead of maintaining one large population. The genetic properties of a metapopulation are likely to be more variable, thus, the habitat patchiness in landscape scale may support the viability of several species (Wolf et al. 2000).

Source-sink model is one of the special cases of metapopulation model. In this model, one viable subpopulation has positive regrowth rate and therefore it acts as a source of individuals to other (sink) subpopulations where population regrowth would be negative without supporting immigration from source habitat (Pulliam 1996, Cousins and Eriksson 2001).

The before-mentioned models are applicable if the distance and connectivity between subpopulations enable the dispersal from one suitable habitat to another. However, several studies have shown that too long distance between habitat patches and isolation are the main reasons for poor colonisation in fragmented landscapes (Alard and Poudevigne 1999, Butaye et al. 2001, Jacquemyn et al. 2001, Petit et al. 2004). As a result, species composition and diversity patterns will depend on the dispersal traits and seed bank longevity of different plant species (Ehrlén and Eriksson 2000, Geertsema et al. 2002, Piessens et al. 2005). Overall species richness will not probably change but the result can be recognised in the changes of plant species composition and evenness of species (Burel et al. 1998, Kleyer 1999).

Agroecosystems are temporally and spatially quite unstable as they are affected by year-to-year chemical and mechanical disturbances. The viability of metapopulations depends on the temporal dynamics of disturbance and suitable habitats, i.e. whether the ratio of colonisation and extinction would reach the balance with landscape changes. Laurance (2002) points out that the community dynamics of fragmented landscapes may be more abrupt and unpredictable than that of the landscape with large natural-vegetation patches. Keymer and colleagues (2000) concluded that each species has its own particular extinction threshold level, i.e. value that characterises species' ability to resist environmental changes. In the case of abrupt changes, the critical threshold is likely to be reached quicker and the outcome is the extinction of a local population.

1. 2. Patch-corridor-matrix model

The approaches of landscape ecology have been applied during last decades to analyse the impact of agricultural and other human activities on biodiversity (Forman 1995). Patch-corridor-matrix model is a helpful tool for landscape ecologists and landscape planners**.** The model enables to describe the spatial dynamics of different processes (e.g. matter flows, the movement of species) at landscape scale and to construct possible landscape scenarios for the future. According to patch-corridor-matrix model, a landscape mosaic is composed of three main types of spatial elements (Forman 1995):

- matrix – the background ecosystem or land use type in a mosaic that is characterised by extensive cover, high connectivity and major control over dynamics (e.g. cultivated fields in agricultural landscape);
- patch – considerably homogenous nonlinear area that is distinctive from its surroundings (e.g. forest patches in the field);
- corridor – linear strip that differs from the adjacent land on both sides (e.g. roads between fields, ditches etc.).

Additional spatial attributes may be e.g. nodes (patches attached to corridors), boundaries (separating spatial elements) and unusual features (rare landscape element types).

The plant species richness and composition of different landscape elements is affected by different spatio-temporal factors: the topography of an area, land use and its spatial dynamics (Cousins and Eriksson 2001), patch area and the internal ecological conditions of a landscape element (Honnay et al. 1999), distance and connectivity between elements (Butaye et al. 2001), the land use of adjacent areas (Wagner et al. 2000). The probability of a species being present in a certain point in the landscape depends on its ecological properties - dispersal abilities, germination, reproduction type and competition strategies. Those factors determine the size of an actual species pool of a landscape (Zobel et al. 1998). According to species pool hypothesis, the species richness of a community depends on the size of a local species pool that in turn is dependant upon the size of a regional species pool. The size of a particular species pool, either community, local or regional, is the result of different spatial and temporal processes. Regional species pool is influenced by evolutionary events and long-term historical dispersal events. Local species pool is characterised mainly by species dispersal patterns. The ecological conditions of a certain community determine the size of the actual/community species pool (Pärtel et al. 1996, Zobel et al. 1998). Consequently, it is possible to study the factors influencing species richness within one community or patch at local scale and to associate diversity values to the characteristics of one patch (e.g. perimeter, area and ecological conditions). At larger scales, the distance between patches, habitat connectivity and other landscape features are analysed. Different studies on the biodiversity of agricultural landscapes have been focused on different groups of factors and the results depend on a particular scale considered (community, landscape, region). However, all the before-mentioned scales and factors should be taken into account to organise effective strategies for biodiversity protection in agricultural landscapes.

1. 2. 1. Patch characteristics

The use of intensive agricultural techniques has enabled to create new cultivated areas and forced to enlarge the existing fields. The expansion of fields and the preference of monocultures has homogenised landscape pattern: natural and semi-natural habitats are fragmented, have unstable ecological conditions and due to decreased area are more affected by agricultural disturbances (Hietala-Koivu 1999).

How large should a patch be to guarantee the viability of a local population? Plants and herbivores appear to be more tolerant to changes in habitat area than species higher in a food chain (Forman 1995). Dupré and Ehrlén (2002) found that habitat area was a determinate factor for habitat specialist plant species. Larger area provides suitable ecological conditions for interior species and habitat specialists (Forman 1995). The decline in species richness and the dominance of nitrophilous plant species may be accompanied by the decrease in patch area because small patch area causes lower capacity of buffering against the disturbance and fertilisers from adjacent fields (Forman 1995, Mikk and Mander 1995). The importance of edge effect increases with the decrease in patch size, thus generalists and edge species will dominate (Whittaker 1998, Kiviniemi and Eriksson 2002). Elongated or convoluted shape of a patch may cause similar effect

(Forman 1995). Consequently, species richness is not an ultimate indicator of habitat quality but the proportion of species with higher habitat requirements should be considered as well. Nevertheless, smaller patches in agricultural landscapes serve some important ecological functions (Table 1). Besides being important habitats for edge species, such patches may act as stepping stones enabling dispersal. Some patches may represent remnant habitats of a rare community type and are therefore essential refugia for species adapted to those specific conditions (Forman 1995, Hanski 1998, Whittaker 1998, Piessens et al. 2005). Honnay and colleagues (1999) concluded that even quite small patches are sufficient habitats for maintaining vegetation diversity if appropriate management and suitable habitat conditions are guaranteed.

Table 1. The ecological significance of patch size (Forman 1995)

Large patch	**Small patch**
Water quality protection for aquifer and lake	Habitat and stepping stone for species dispersal
Habitat to sustain the populations of patch interior species	High species densities and high population sizes of edge species
Core habitat and escape cover for large-home-range vertebrates	Matrix heterogeneity that decreases nutrient runoff and erosion
Source of species dispersing through the matrix	Habitat for small-patch-restricted species
Buffer against extinction during environmental change	The protection of small scattered habitats and rare species – remnants and refugia

But why is patch size so important for the maintenance of a population? Small isolated populations may undergo “bottleneck” effect that decreases its genetic variability (White et al. 1999, Culley et al. 2003). Lower genetic variability in turn may affect species’ fitness and its ability to resist environmental changes (Hobbie et al. 1994, Jacquemyn et al. 2002). Due to lowered adaptability, the population becomes more susceptible to agricultural disturbances. Without any change of genetic material, an isolated population may experience inbreeding that also contributes to local extinction (Washitani 2000, Wolf et al. 2000). Finally, more competitive and disturbance-tolerant generalist and ruderal species become advantageous.

According to the theory of island biogeography, a larger patch has expectedly higher species richness. However, among the main patch characteristics, the quality of habitat patches appears to be as important determinant of species presence in the landscape as area or isolation (Dupré and Ehrlén 2002, Fleishman et al. 2002). The next phases of life cycle after the dispersal of a plant seed depend on the ecological conditions of a particular habitat. In agricultural landscape, most of the potential habitats are in one way or another influenced by agricultural disturbance, either by pesticides, fertilisers or mechanical pressure caused by heavy machinery. According to CSR-model (Grime 1979), R-strategists dominate in the habitats that experience frequent and high disturbance, i.e. plants being adapted to short life cycle and large seed crop during one growing season. C-strategists prefer more stabile environment and moderate disturbance, although some species with competitive strategy, for example *Elymus repens*, may be very common in disturbed habitats as well (Kleijn et al. 1997). Consequently, with the increase in agricultural disturbance it may be expected that the proportion of R-strategists would increase (Geertsema et al. 2002).

1. 2. 2. Linear elements in agricultural landscapes

Field margins cover a considerable proportion of agricultural landscapes besides cultivated fields and natural-vegetation patches. Due to direct and indirect human influence, these habitats can be treated as a separate type of semi-natural habitats (Figure 1). These linear elements may connect fragmented (semi-)natural patches into an integrated network that provides habitat conditions and enables dispersal opportunities for several species. The functional importance and organisation of such networks has been one of the main study objects of landscape ecologists and has been used as a conceptual framework for planning biodiversity protection strategies of agricultural landscapes (Ahern 1995, De Snoo 1999, Tikka et al. 2001, Le Coeur et al. 2002).

Different researchers have given a number of definitions for field margins. In general, all the following semi-natural elements adjacent to cultivated area can be treated as field margins (Bunce et al. 1994):

- hedgerows, forest edges;
- road verges and grassy margins adjacent to fields;
- river and ditch boundaries;

- different kinds of margins and borders separating the fields – grassy strips, stonewalls etc.

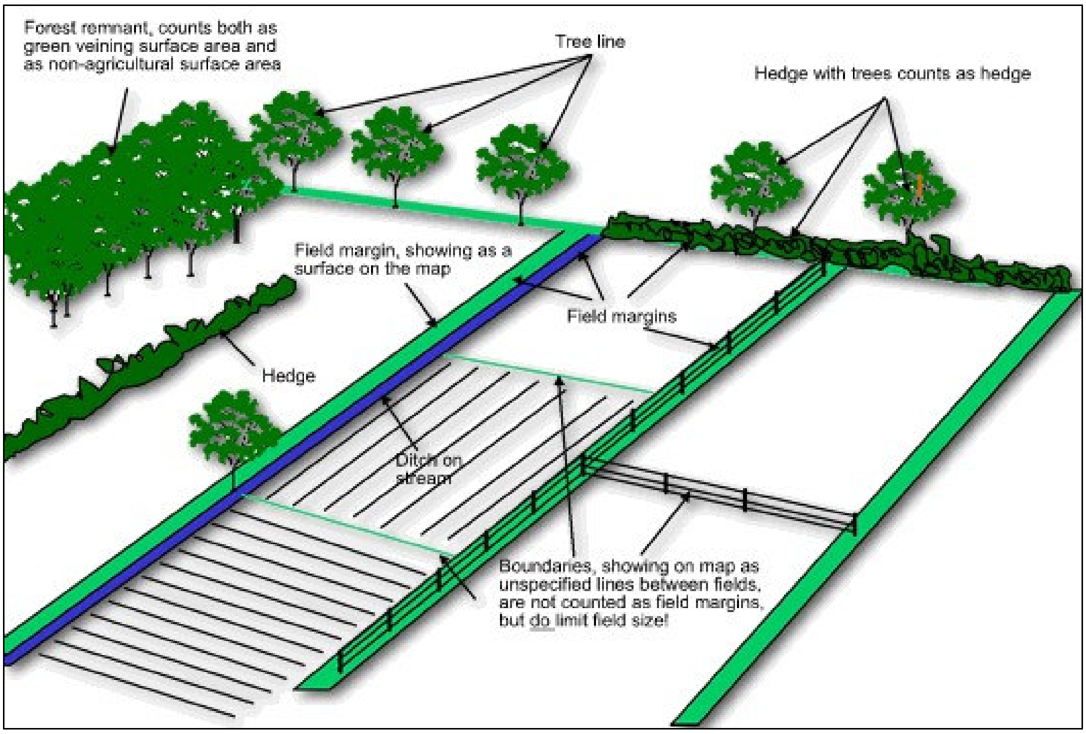


Figure 1. Linear elements in agricultural landscape mosaic – field margins, ditches, hedgerows (introduction to the project "Greenveins" [www.greenveins.nl])

According to Greaves and Marshall (cf. Marshall and Moonen 2002), a field margin can be divided into different zones depending on the proximity and impact of the adjacent field: 1) pre-existing boundary attached to margin that may encompass hedge, ditch or fence; 2) non-cultivated margin strip between the crop and the boundary; 3) the crop edge – the outer meters of the crop (Figure 2). Structurally, field margins can be divided as the following:

- corridors – adjacent agricultural land use on both sides of the element (e.g. hedgerow in the field, roads between fields);
- edges – transition zones between cultivated area and natural vegetation patch (e.g. edge between forest and field or between meadow and field).

The historical functions of field margins and hedgerows have changed: they designated the borders of private property, protected cropfields from cattle, acted as wind barriers, provided fruits and wood. Interesting mosaic agricultural landscapes evolved as a result of intervening activities of humans and local topography. In France, where hedgerows were especially characteristic features, such a landscape mosaic was named with a special term – "bocage" (Fry 1994). However, the original meaning of hedges was lost with agricultural revolution and many hedgerows have been removed. The use of below-ground drainage has decreased the area of opened ditch verges in Estonia. Nevertheless, parallel to the fallback of the conventional purposes of those spatial elements, historical, cultural and ecological importance of field margins is nowadays being emphasised. Furthermore, field margins offer several ecological and agricultural benefits at present as well – they prevent from erosion and nutrient runoff, act as windbreaks and provide habitats for beneficial species for agriculture (Fry 1994, Marshall and Moonen 2002).

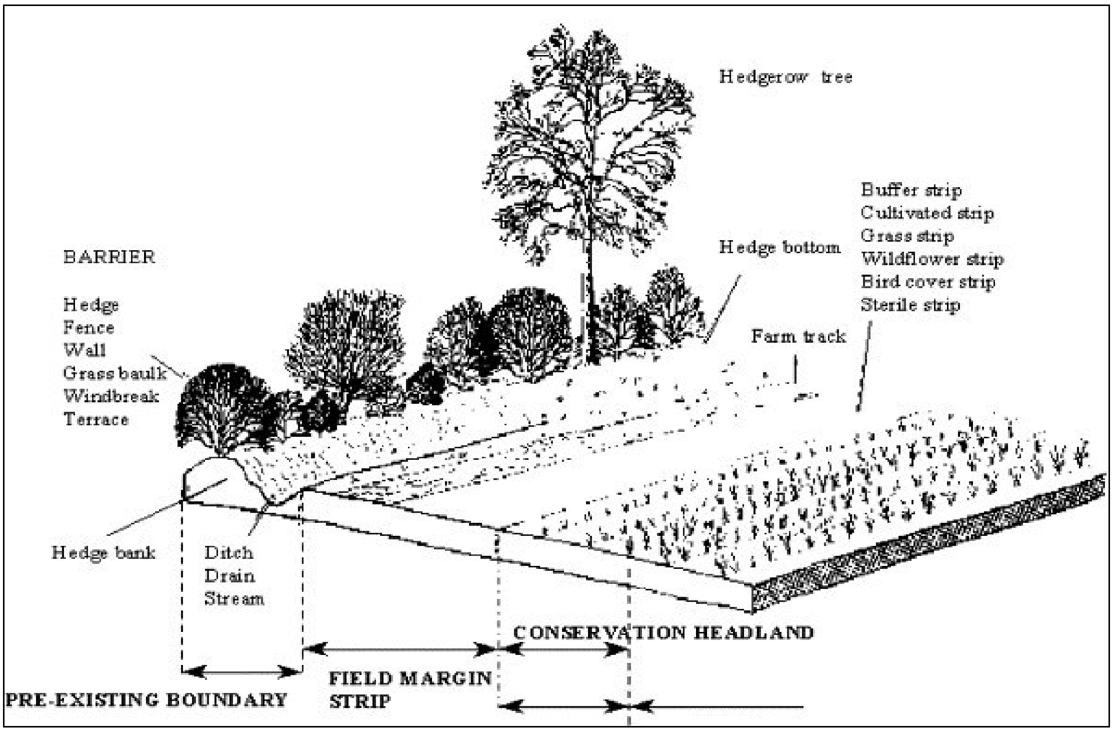


Figure 2. The structure of an arable field margin (cf. Marshall and Moonen 2002)

The potential of field margins as non-cultivated semi-natural habitats for plants (Kiss et al. 1997, Le Coeur et al. 1997, Kleijn et al. 1998, Moonen and Marshall 2001), insects (Fry and Robson 1994, Canters and Tamis 1999, Mänd et al. 2002), birds (Jobin et al. 2001) and for small mammals (Tew 1994) has been quite thoroughly investigated during last years. The plant species composition of a field margin depends on different factors that are more or less similar to those affecting species composition of patches, i.e. margin structure and length, adjacent land use, origin and age, distance to the nearest patch and management methods. Field margins differ from each other in regard to the presence and cover of tree or shrub layer. The height and closure of trees and shrubs determine the proportion of shade-tolerant and light-demanding species (Baudry et al. 2000, Le Coeur et al. 2002). Woody linear strips may offer suitable habitats for shade-tolerant forest species (Fry 1994, Petit et al. 2004). Opened and half-opened regularly mown road verges and field edges may compensate the habitat loss of species adapted to semi-natural grasslands (Wilson 1994, Cousins and Eriksson 2001). The diversity of insects (Dover et al. 2000), birds (Jobin et al. 2001) and small mammals (Tew 1994) is also dependent on the structure of tree and bush layer. However, disturbance-tolerant generalists are most typical in field margin vegetation because the misplacement and runoff of fertilisers and other chemicals from adjacent fields affect the ecological conditions of margins (Kleijn et al. 1997). Besides, due to linear and narrow structure, those spatial elements are often not wide enough to buffer the effect of chemical substances and fertilisers (Boatman et al. 1994, Ma et al. 2002). Field margins that are surrounded with cultivated area on both sides – corridors – are therefore more influenced by agricultural pollutants than the transition zones between fields and natural habitats. Similarly to patches, it has been demonstrated that the diversity of margins is positively correlated to area. Wider strips increase the range of habitat variability and the interior part of a margin is less disturbed (Forman 1995, Ma et al. 2002). Forest edges are also subject to the accumulation of air pollutants that lowers the probability of rare species being present there (Weathers et al. 2001). The diversity and species composition of margin vegetation depends on the adjacent land use type and cultivars, whether the field is used as cropland, pasture or grassland and whether the margin borders with forest, ditch or road (Freemark et al. 2002, Aude et al. 2003).

Field margins may offer suitable habitats for the subpopulations of a metapopulation. Linear elements may similarly to habitat patches support populations that are organised according to source-sink model acting as recipients of seeds from donor habitats or even functioning themselves as seed sources to other subpopulations (Fry 1994, Cousins and Eriksson 2001).

The dispersal function of field margins between natural habitat patches and within the corridors has been pointed out as one of the ecological benefits of linear elements. Sarlöv-Herlin and Fry (2000) investigated the relationships between the species composition of woody plants of hedgerows, their dispersal mechanisms and distance to the nearest forest patch. They found that the proportion of zoohorous species was negatively correlated to the distance to nearest forest patch. The results of several other studies support this phenomenon (e.g. Le Coeur et al. 2002, Petit et al. 2004) implying that field margins at least partly serve a conduit function for plants. Roads and road verges between fields, the banks of ditches, streams and rivers and water itself – all may act as corridors (Forman 1995, Tikka et al. 2001).

Of course, the corridor function of field margins is not so comprehensive – those elements may appear as real barriers preventing the movement of some species. Forman (1995) has compared field margins to semi-permeable membranes that have "canals" enabling the movement of certain species and matter. Fry and Robson (1994) demonstrated that hedgerows in the fields caused an isolation effect between two butterfly subpopulations. Similarly, such spatial elements may prevent the movement of plant seeds and pollen.

Much attention must be paid to the management methods of field margins to restore and maintain the diverse fauna and flora of those landscape elements. Species diversity and composition is influenced by adjacent land use caused by the application of fertilisers, pesticides and heavy agricultural machinery. Additional nitrogen and phosphor concentrations facilitate the growth of competitive perennials and fast-growing ruderals and thus may cause the decrease in species richness (Boatman et al. 1994, Cummins and French 1994, Kleijn and Snoeijing 1997, Marshall and Moonen 2002). Schippers and Joenje (2002) noticed considerable increase in plant species richness soon after the end of additional nitrogen application. However, the number of species may not reflect the actual quality of a field margin as a habitat; instead, the analysis of plant species composition may be more informative (Le Coeur et al. 1997).

Field margins are sprayed with herbicides, insecticides and fungicides to avoid the damage to crops caused by pests, weeds and pathogens. Pesticides do not affect only the undesirable pests but also their natural enemies and important pollinators (Washitani 2000, Marshall et al. 2003). It has been shown that in the case of correct and moderate management (e.g. mowing, pruning hedges etc.) it is possible to decrease the impact of pests and weeds without using any chemicals and at the same time equalise the competition conditions in favour of non-weed perennial plant species (Le Coeur et al. 1997, Kleijn et al. 1998, De Snoo 1999, Moonen and Marshall 2001). It has also been suggested not to cultivate the outer meters of a cropland – this area may buffer the margin zone from direct agricultural disturbances. Depending on the purpose, whether the objective is to create suitable conditions for natural regulators of pests or to control weed dispersal, seeds of benefit plant species can be sown on this uncultivated strip (Kleijn et al. 1998).

1. 3. The objectives of the research

As it may be concluded from the preceding introduction, different species need different conditions for survival in agricultural landscapes and that diversity is affected by various spatio-temporal processes from local to regional scales. The planning strategies of agricultural landscape should consider the different dispersal mechanisms, behaviour, habitat requirement of species but also the cultural and historical identity of each landscape.

Serious ecological consequences of production-orientated management have forced policy makers of European Union (EU) to focus more on environmental issues of agricultural landscapes. Common Agricultural Policy (CAP) now includes many different agri-environmental schemes to maintain the existent biodiversity and to restore the lost species richness. Since 2000, Estonian Ministry of Agriculture has also supported Estonian farmers for the application of agri-environmental schemes. For example, organic farming, environmentally friendly production, the protection of environmentally sensitive areas and the afforestation of set-aside land are among the subsidised activities (Estonian Rural Development Plan 2004). However, recent studies have given ground to doubts whether the agri-environmental schemes applied in EU really enhance biodiversity or are they simply formal decisions that have no actual ecological justification (Kleijn et al. 2001, Kleijn and Sutherland 2003, Berendse et al. 2004). Therefore, despite of a number of studies carried out on this subject, there is still a need for wider understanding about species distribution in agricultural landscapes and factors affecting it.

Six landscape test sites were chosen from Estonia. The study sites differ in regard to land use intensity and landscape structure. The general objective of the present study is to analyse the relationships between plant species diversity, composition, landscape structure and land use intensity. The questions of particular interest are the following:

1) Do different management regimes, chemical application and landscape structure of the test sites affect the overall vegetation diversity of those landscapes?

2) Do semi-natural linear elements and small patches support the vegetation diversity of agricultural landscapes?

3) What are the main differences between different landscape element types in regard to plant diversity and species composition?

4) How does the species diversity and composition of vascular plants depend on the structural properties of a field margin?

2. MATERIALS AND METHODS

2. 1. Study sites

On the basis of preliminary survey and Estonian Basic Map, six landscape test sites were chosen for the research: Are, Vihtra, Viiratsi, Väike-Maarja, Ilmatsalu and Abja-Paluoja. Four of the test sites (Are, Vihtra, Viiratsi and Väike-Maarja) were chosen within the frames of the EU 5th Framework project "Greenveins". The main objective of the project "Greenveins" was to assess the vulnerability of biodiversity in the agro-ecosystem as influenced by greenveining and land use intensity. Among the participating countries were Estonia, Belgium, The Netherlands, Germany, Switzerland, France and Czech Republic. To obtain a more representative assemblage of agricultural landscapes for appropriate comparisons in Estonian scale, two additional study sites (Ilmatsalu and Abja-Paluoja) were selected for the present research.

Agriculture is the main land use type of all six landscape test sites. One of the main objectives of the current study was to evaluate the impact of land use intensity and landscape structure on plant diversity and composition. However, there are many other natural and human-caused factors that may influence the biodiversity. Therefore, the study areas had to satisfy certain criteria as close as possible to avoid the side effects of other factors influencing the patterns of vegetation diversity. Landscape test sites and their adjacency are homogenous and compact in regard to land use. They have similar geomorphologic characteristics and limited variation of relief. The proportion of natural and semi-natural communities is about 30 % or less. The area of each landscape test site is 4 x 4 km. The landscape test sites differ from each other in regard to agricultural land use intensity and percentage of "greenveining" (i.e. the proportion of natural and semi-natural communities). The study areas are located all over Estonian mainland (Figure 3).

Are study area is located in the south-western part of Estonia in Pärnu county (58° 29' N, 24° 35' E). Most of the agricultural area is used as rotational grassland and only some fields are arable, covered mostly by rape or cereals. Cattle breeding is one of the main agricultural activities. Leached soil is the dominant soil type (Estonian Soil Map).

Vihtra is located in the north-western part of Pärnu county in Vändra municipality (58° 33' N, 24° 00' E). Extensive land use has always been characteristic to this area. Similarly to Are study site, most of the agricultural land in Vihtra is covered by rotational grasslands and livestock raising is prevalent. The percentage of natural and semi-natural communities is the highest compared to other study areas. Glei is the dominant soil type (Estonian Soil Map).

Viiratsi is located in southern Estonia near the town of Viljandi (58° 20' N, 25 ° 39' E). Viiratsi is characterised by high land use intensity and high landscape fragmentation. Since 1974, Estonian largest pig farm "Ekseko" has been located in Viiratsi. The number of pigs in the farm was about 39 000 during the fieldwork. The manure originating from the pig farm has been actively used as additional fertiliser in the fields of the landscape test site and in the neighbouring fields. Additional nitrogen and phosphor loads have most probably influenced the nutrient balance of the soil. About half of the cultivated fields are croplands. Podsol is the prevalent soil type in Viiratsi (Estonian Soil Map).

Väike-Maarja is located in the north-eastern part of Estonia in Lääne-Virumaa county in the municipality of Väike-Maarja (59° 15' N, 26° 15' E). The area is characterised by comparatively high land use intensity. Most of the agricultural land is cropland. Main crops are barley and wheat. Besides crops, rape fields cover a considerable amount of agricultural land. The main soil type of Väike-Maarja landscape test site is glei (Estonian Soil Map).

Ilmatsalu is located in the south-eastern part of Estonia in the vicinity of Tartu (58° 23' N, 26° 35' E). The area has been intensively managed throughout the second half of the last century. The utilised agricultural land covers over 76 % of the area and the share of natural and semi-natural communities is the lowest in comparison with other study sites. Two large farms (Haage Suurtalu and Tartu Agro) are the main land-users and most of the agricultural land is under crops and short-term rotational grassland. Leached soils are prevalent (Estonian Soil Map).

Abja-Paluoja is located in southern Estonia in Viljandi county (58° 35' N, 25° 24' E). Most of the farmers in this landscape test site have applied for the support of environmentally friendly production scheme. According to this scheme, the maximum amount of nitrogen fertilisation may be up to 100 kg/N/ha (Estonian Rural Development

Plan 2004-2006). Therefore, there are practically no fields that are intensively managed. Most of the agricultural land is used as cropfields. Leached soil is the dominant soil type (Estonian Soil Map).

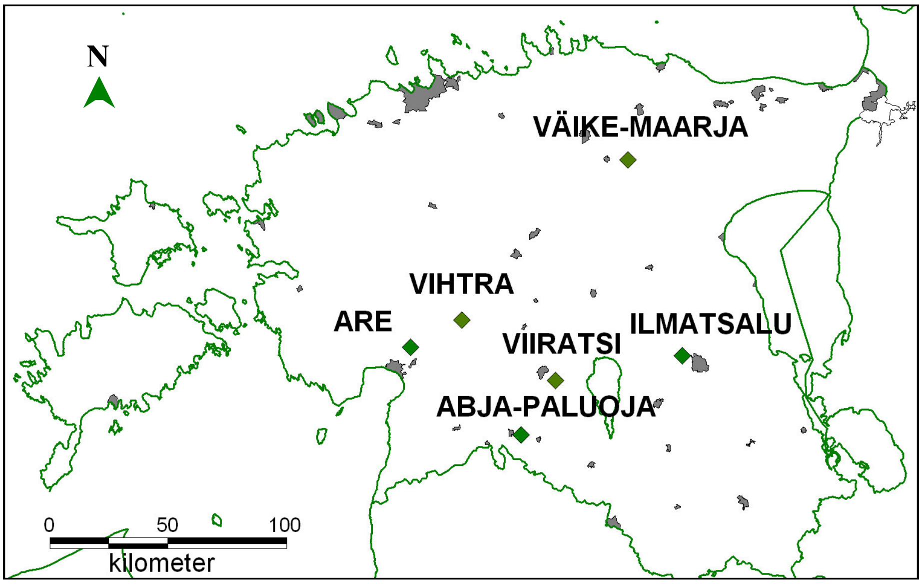


Figure 3. The location of landscape test sites

2. 2. Fieldwork and data collection

2. 2. 1. Vegetation data

Fieldwork was carried in 2001-2004. The area of each landscape test site was 4 x 4 km. Vegetation surveys comprised recordings from three main types of spatial elements:

- patches with natural or semi-natural vegetation;
- agricultural patches;
- semi-natural uncultivated linear elements.

Patches were defined as compact spatial elements representing natural, semi-natural or cultivated ecosystems (cropfields, cultural grasslands, pastures). According to the size, forest patches with an area of less than 1 ha were defined as small woodlands. Linear elements were defined as natural or semi-natural features being less than 10 meters and more than 0.5 meters wide – grassy field margins, ditch banks, road verges etc. Differentiation was made between edges (transition zones between cultivated area and natural vegetation patch) and corridors (adjacent land use on both sides of the element is the same). On the basis of fieldwork and maps, all the landscape elements were later classified according to the EUNIS classification (Table 2; Davies and Moss 2002).

Vegetation surveys were carried out in each landscape test site in two following years: Are, Vihtra, Viiratsi and Väike-Maarja were surveyed in 2001 and 2002 and Ilmatsalu and Abja-Paluoja in 2003 and 2004. Each landscape test site was divided into 16 quadrates of 1 km². In the first year of fieldwork, 9 plots were randomly sampled from each 1 km² quadrate following the scheme that the plots comprised 4 plots within natural or semi-natural patches, 4 plots within linear elements and 1 plot within agricultural patch. The sampling scheme in the next year was not so strict: 6-7 plots were surveyed on each 1 km² quadrate so that different landscape elements would be sampled proportionally to landscape structure and according to the representation of main habitat types in the dataset of the first year. The sampling scheme is presented in Figure 4.

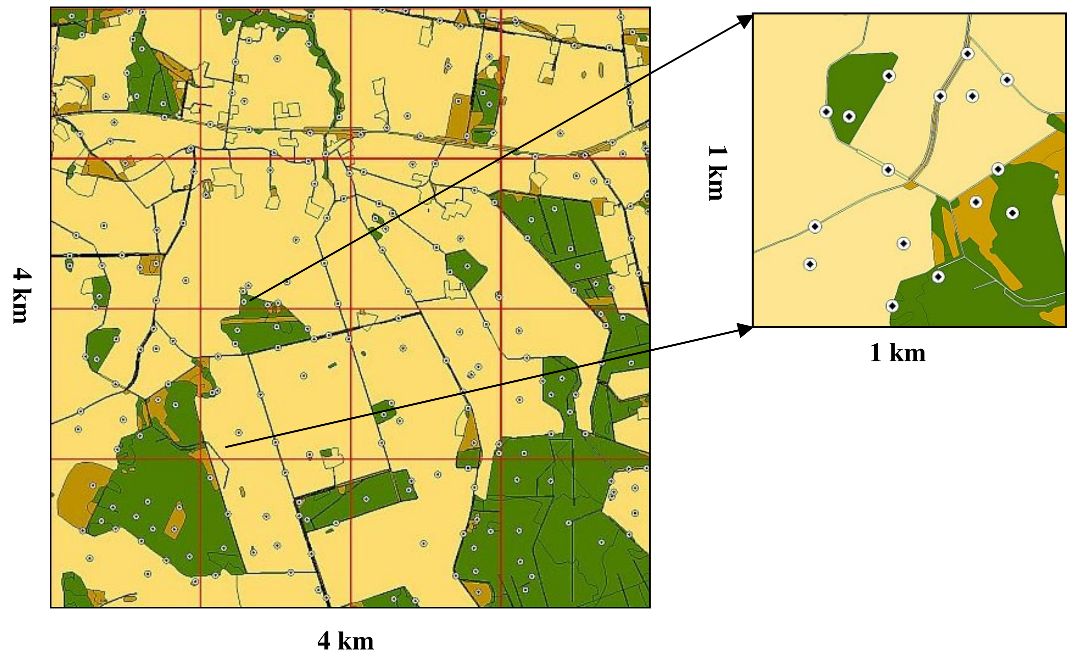


Figure 4. The sampling scheme of sample plots. Grey colours designate natural and semi-natural communities; light areas are covered by fields. Houses, roads and other elements under direct human influence are defined with lines. White rings with black dots denote the location of sample plots.

The size of one sample plot was 2 x 2 meters, with the exception of some very narrow linear elements where the size of 1 x 4 meters was more appropriate. Approximately 255-280 plots were described in each landscape test sites during two years. The overall number of plots in six landscape test sites was 1558.

The following parameters were recorded at each plot:

1) landscape element type ((semi-)natural patch, cultivated field, semi-natural linear element);

2) habitat type (community type);

3) the species composition, closure and upper height limit of tree layer within 20 x 20 meters around the 2 x 2 m plot (in the case of linear elements the mentioned parameters were recorded within the area of 10 x 40 m);

4) the species composition, cover and upper height limit of shrub layer (the scheme was similar to that of tree layer);

5) the species composition of vascular plants and the abundance of each species in the 2 x 2 m plot; species abundance was estimated according to the modified Braun-Blanquet scale (*1* - < 1%, a single plant; *2 – 1%...< 5%*, few plants; *3 – 5% ... < 25%*; *4 – 25% ... < 50%*; *5 – 50% ... < 75%*; *6 – 75% ... 100%*);

6) the overall abundance of vascular plants in the 2 x 2 m plot;

7) plant species composition in the surroundings of the plot within the landscape element type (local or habitat species pool);

8) the presence of ditch or road and other special features describing the surroundings of the plot.

The basic biodiversity index was plant species richness on 2 x 2 m plots. However, species richness *per se* may not be an appropriate indicator of actual habitat quality and species composition may be more informative (Burel et al. 1998, Kleyer 1999). Therefore, all plant species were classified roughly into two wide groups, agrotolerant species and nature-value species. Agrotolerant species were defined as the species that are common in arable fields and other anthropogenic habitats ("non-greenvein habitats"), i.e. species which can also survive in the landscape almost without natural or semi-natural habitats and have low threshold for natural habitats. A species was classified as an agrotolerant species if it was present in at least 10 % of the plots sampled in the agricultural fields or non-greenvein habitats. All the other species were classified as nature-values species. The species richness per plot and landscape was estimated for both groups separately.

Plant species were provided with Ellenberg ecological values of light, soil fertility, moisture and acidity. Ellenberg ecological value estimates the optimal position of a species along the particular environmental gradient (either the gradient of light, fertility, moisture or acidity) where the species should achieve its maximal abundance (Ellenberg et al. 1992). The mean abundance-weighted Ellenberg scores were calculated for each sample plot.

2. 2. 2. Spatial data

Maps of the landscape structure of Are, Vihtra, Viiratsi and Väike-Maarja were digitalised within the frames of the project "Greenveins" in Germany in Leipzig-Halle (partner of the "Greenveins" project) on the basis of aerial photos, Estonian Basic Map and cadastral maps using Arc-Info. The maps of Ilmatsalu and Abja-Paluoja were digitalised on the basis of Basic Map and cadastral map using program MapInfo Professional 6.5. Field checking of maps and habitats was done in all study sites to define and specify the habitat types. All landscape elements were provided with EUNIS code (Davies and Moss 2002). For further analyses, the original EUNIS classification was generalised into broader classes of habitats or landscape element types (Table 2). The following spatial parameters were calculated about each landscape test site from the maps: the proportion of natural and semi-natural communities, the mean area of natural and semi-natural patches and total edge density of natural and semi-natural habitats (Table 3). Natural and semi-natural habitats were further divided into semi-natural open habitats (i.e. grasslands) and wooded habitats (forests).

Around the vegetation sample plot, four additional presence-absence indicators of trees or shrubs, ditch, road and the vicinity of agricultural land were observed during fieldworks. The parameters were later updated from maps in the radius of 10 meters with the exception of the neighbourhood of agricultural land (Table 3). It was presumed that some habitats experience more severe agricultural disturbance in comparison with other habitats. Therefore, a broad distinction was made between the habitats in the vicinity of agricultural field and habitats that were considerably distant from agricultural land. Semi-natural linear elements, stone piles and small woodlots were classified as habitats in the proximity of agricultural land. Larger patches of forest and semi-natural grassland were considered to have internal part (core area) which is not under direct agricultural pressure. This indice and the three before-mentioned presence-absence indicators should give an overview of local small-scale landscape structure around the sample plot.

2. 2. 3. Data about land use intensity

To assess the land use intensity, a group of land users from each landscape test site was interviewed (Herzog et al. (in press)). The number of farmers was selected according to the representative proportion of the agricultural land within the landscape test site. The interview included questions about the area of utilised agricultural land, main crops, fertilisation, stocking rates, use of pesticides, herbicides, fungicides, crop successions, melioration etc (Table 3). The mean area-weighted values of nitrogen fertilisation, pesticide application, density of livestock units, percentage of intensively managed fields and average number of crops for each study area were calculated.

2.3. Data analyses

Principal Component Analyses (PCA) was performed to describe the general distribution of landscape test sites in regard to the parameters of landscape structure and land use intensity. The landscape test sites were ordinated in the space of land use intensity indices (the load of nitrogen fertilisation, pesticide application, livestock density, the share of intensively managed fields and the average number of crops in rotation) and the indices of landscape structure (the percentage of natural and semi-natural communities, the proportional area of woody and herbaceous communities, edge density and the mean size of woody patches and semi-natural grasslands). Spearman rank correlation was carried out to investigate the relationship between the variables of land use and landscape structure.

The impact of the main indices related to landscape structure and land use on the overall number of nature-value species of study sites (gamma diversity) was analysed using regression analysis. Analysis of Variance (ANOVA) was performed to describe the differences in the mean values of agrotolerant and nature-value species richness between different landscape element types. The analyses were carried out in Statistica 6.0.

The effect of landscape structure, agricultural land use intensity and habitat conditions on species richness of linear elements and woodland patches was analysed using General Linear Model (GLM). The factors for the model were chosen with backward stepwise procedure. The repeated measures design was used to take into account the sampling of the richness of nature-value and agrotolerant species richness in the same plot. The analysis was performed in SAS.

Detrended Correspondence Analyses (DCA) was performed in PC-Ord (ver 4.36) to describe the composition patterns of vegetation in forests and semi-natural linear elements. The explanatory variables in the analysis of forest vegetation were the following: the total species richness of a plot, the species richness of agrotolerant species, the species richness of nature-value species, the closure of tree layer, Ellenberg ecological values of light, soil fertility, moisture and acidity. In order to interpret the results of the analysis of the vegetation composition of linear elements, the following explanatory variables were used to correlate with ordination axes: the total species richness of a plot, the species richness of agrotolerant species, the species richness of nature-value species, Ellenberg ecological values of light, soil fertility, moisture and acidity, the presence/absence of ditch, the presence/absence of road, the presence/absence of tree-bush layer. The species that were recorded in at least 4 sample plots were included in the ordination of woodland patches. The species that occurred in at least 6 sample plots were included in the analysis of the vegetation of linear elements. In total, 152 species from 400 plots were used for the ordination of woodland patches and 195 species from 957 plots were used for the ordination of linear elements.

Indicator species analysis (Legendre and Legendre 1998) was performed in PC-Ord to estimate characteristic species of woodland patches. Species that were present in at least 4 sample plots were included in the indicator analysis of woodland vegetation. The same analysis was carried out to define species that prefer particular linear elements as main habitat type. Species occurring in at least 10 sample plots were included in the indicator analysis of linear elements – i.e. 159 species. In this analysis every species has been given an indicator value according to average abundance and occurrence frequency in a particular habitat type. Monte Carlo test of significance was used to evaluate the randomness of species indicative properties. The threshold value for meaningful indication was set to be at least 20 units.

Table 2. The classification of landscape element types according to EUNIS classification and the generalised version of EUNIS classification.

Landscape element type	Generalised EUNIS	EUNIS
Arable land	**I**	**I10** – arable land
Woodlands	**G1** – broadleaved deciduous woodlands **G3** – coniferous woodlands **G4** – mixed deciduous and coniferous woodlands	**G10** – broadleaved deciduous woodlands **G30** – coniferous woodlands **G40** – mixed deciduous and coniferous woodlands
Small spatial elements ("stepping stones")	**G5 –** small woodlands	**G52 –** small broadleaved deciduous woodlands **G54 –** small coniferous woodlands **G55 –** small mixed deciduous and coniferous woodlands
Semi-natural grasslands	**M**	**E10** – dry grasslands **E20** – mesic grasslands **E30** – seasonally wet and wet grasslands
Linear elements	**C2G** – grassy margins of surface and temporary running water **I1G** – grassy field margins **J4V** – road verges **F** – corridors with hedge or tree line	**C2G** – grassy margins of surface and temporary running water **I1G** – grassy field margins **H30** – inland cliffs, rock pavements and outcrops **J4V** – road verges **FAB** – broadleaved hedgerows **FAC** – coniferous hedgerows **FAM** – mixed deciduous and coniferous hedgerows **GT0** – solitary trees **GL0** – line of trees **GLB** – line of broadleaved trees **GLC** – line of coniferous trees **GLM** – mixed line of broadleaved and coniferous trees

Table 3. The list of variables used in analyses and the abbreviations of variables.

Variables	Abbreviation	Units/Categories	Source
Vegetation variables			
General plant species richness	SR	no / 4 m²	Fieldwork
The species richness of nature-value species	NV	no / 4 m²	Fieldwork
The species richness of agrotolerant species	AT	no / 4 m²	Fieldwork
Categorical variable to differentiate between nature-value and agrotolerant species	AT_NV	AT - agrotolerants NV - nature-value species	
Ellenberg ecological values of light	Light		
Ellenberg ecological values of soil fertility	Fertility		
Ellenberg ecological values of moisture	Moisture		
Ellenberg ecological values of acidity	pH		
Local structural variables			
Tree/bush layer	Tree	0 – absent 1 – present	Fieldwork/map
Road	Road	0 – absent 1 – present	Fieldwork/map
Ditch	Ditch	0 – absent 1 – present	Fieldwork/map
Closure of tree layer (if present)	Closure	0….1	Fieldwork
The vicinity of agricultural field	Agri	Agri- (absent) Agri+ (present)	Fieldwork/map Fieldwork/map
Generalised EUNIS	EUNIS	See Table 2	Fieldwork/map
Spatial variables			
Utilised agricultural area	UAA	ha	Map/Interview
Percentage of natural and semi-natural patches	GV%	%	Map
Percentage of forests	GVw%	%	Map
Percentage of herbaceous patches	GVh%	%	Map
Edge density of (semi-)natural habitats	ED	m/km²	Map
Mean area of patches with natural and semi-natural vegetation	MGV	ha	Map
Mean area of forests	MW	ha	Map
Mean size of herbaceous patches	MH	ha	Map
Variables about land use intensity			
Mean nitrogen fertilisation on two major crops	N-fert	kg/ha	Interview
Intensively managed arable land – percentage of UAA that receives more than 150 kg/N/ha in year	IA	%	Interview
Pesticide treatement	PT	no of applications	Interview
Livestock units per area unit	LU	livestock units/ha	Interview
Average number of crops	Crops	no	Interview
Percentage of drained UAA	Drainage	%	Interview

3. RESULTS

3.1. The landscape structure and land use intensity of study sites

The six landscape test sites represent a wide range of values of land use intensity and landscape structure (Table 4). Among the variables of land use intensity, mean nitrogen application varies from 34 kg/ha in Vihtra to 319 kg/ha in Viiratsi. The percentage of intensively managed land differs – in Vihtra there are no intensively managed fields while in Viiratsi 67 % of agricultural area receives more than 150 kg/N/ha. Livestock density is the highest in Are landscape test site (1.6 LU/ha) and the lowest in Abja-Paluoja (0.1 LU/ha). Landscape test sites differ in regard to the proportion of (semi-)natural communities – the percentage of greenveining is the highest in Vihtra landscape test site (33.6 %) and the lowest in Ilmatsalu (17 %). The mean size of (semi-)natural patches is the highest in Are study site (6.1 ha) and the lowest in Ilmatsalu (2.3 ha). The edge density of natural and semi-natural communities varies from 12 974 m/km² in Väike-Maarja landscape test site to 36 945 m/km² in Vihtra.

The distribution of study sites among the gradient of different landscape and land use indices is visualised on PCA (Prinsipal Component Analysis) ordination diagrams (Figure 5 (a) and (b)). The first two PCA axes describe 71 % of variance. One set of variables related to the first axis encompasses the parameters of land use intensity – nitrogen fertilisation, the percentage of intensively cultivated land and the number of crops (Figure 5 (a)). Correlation analysis revealed that nitrogen application and the percentage of intensively managed land are significantly correlated with each other ($r_{Spearman} = 0.899$, $P < 0.05$; Table 5). Figure 5 (b) shows that the complex of land use characteristics of Ilmatsalu landscape test site is a good illustrator for this: mean nitrogen application is 150 kg/ha, the share of intensively managed land is over 40 % and the number of crops is also the highest (Table 4). The second set of parameters correlated to the first axis and contrasting to land use indices is related to landscape structure – the percentage of greenveining and the mean area of semi-natural and natural patches. Vihtra test site distinguishes from other study sites because of the highest proportion of greenveining – the percentage of overall greenveining is 33.6 % and the proportion of total area covered by forest is 27.7 %. The mean patch area of woodlands is the highest in

Are test site (6.1 ha). The second axis of PCA correlates the factors related to livestock density and mean area of semi-natural grasslands on one hand and parameters of edge density and percentage of semi-natural grasslands on another hand. According to correlation analysis, the percentage of semi-natural grasslands and livestock density are negatively correlated ($r_{Spearman}$ = -0.899, $P < 0.05$). The highest livestock density (1.6 LU/ha) and low proportion of herbaceous semi-natural patches (3.8 %) is characteristic to Are landscape test site. The values of mentioned parameters are similar in Väike-Maarja (0.9 LU/ha and 2.7 %, respectively) but this study area distinguishes from Are due to higher land use intensity. The proportion of greenveining and edge density were significantly correlated ($r_{Spearman}$ = 0.829, $P < 0.05$). As the share of greenveining is the highest in Vihtra test site but also in Viiratsi, those areas are characterised also by higher edge density compared to other landscape test sites (36 945 m/km² and 23 165 m/ km², respectively). Abja-Paluoja is distinguished from other study sites mainly in regard to higher pesticide use (2.72 appl/year) and higher share of semi-natural grasslands (5.7 %).

Table 4. The land use intensity (a) and landscape structure (b) of landscape test sites according to the results of interviews and map analysis. Abbreviations are explained in Table 3.

(a)

	UAA (ha)	**IA (%)**	**N-fert (kg/ha)**	**LU (lu/ha)**	**PT (nr.)**	**Crops (nr.)**	**Drained (%)**
Are	1046	13	38	1.6	0.04	1.8	90
Vihtra	952	0	34	0.2	0.57	3.3	95
Viiratsi	971	67	319	0.3	1.11	4.5	63
Väike-Maarja	1182	48	168	0.9	0.93	5.3	1
Ilmatsalu	1218	43	150	0.7	1.96	7.7	98
Abja-Paluoja	1084	0	102	0.1	2.72	4.2	93

(b)

	GV%	**GVw%**	**GVh%**	**MGV (ha)**	**MW (ha)**	**MH (ha)**	**ED (m/km²)**
Are	30.5	26.7	3.8	6.1	4.3	0.7	23 124
Vihtra	33.6	27.7	5.8	3.2	2.6	0.5	36 945
Viiratsi	29.5	24	5.5	3	1.4	0.7	23 165
Väike-Maarja	23.5	20.6	2.7	3.5	1.7	0.8	12 974
Ilmatsalu	17	12.3	4.7	2.3	3.8	0.5	14 527
Abja-Paluoja	25.7	19.9	5.7	2.6	2.5	0.4	22 896

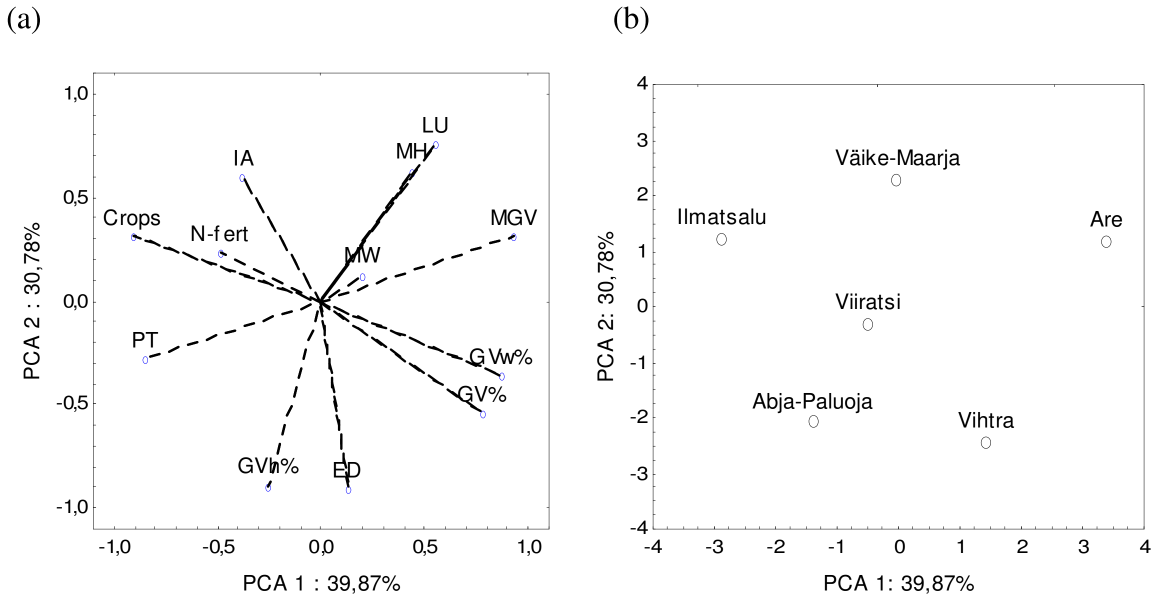


Figure 5. Ordination diagrams of Principal Component Analysis (PCA) about the variables of land use intensity and landscape structure (a) and the position of landscape test sites in relation to the variables (b). Abbreviations are explained in Table 3.

Table 5. Spearman rank correlation matrix of the variables of land use intensity and landscape structure. Significant values ($P < 0.05$) are in bold. Abbreviations are explained in Table 3.

	GV%	**GVw%**	**GVh%**	**MGV**	**MW**	**MH**	**ED**	**PT**	**N-fert**	**Crops**	**LU**
GV%	1										
GVw%	**0.943**	1									
GVh%	0.486	0.257	1								
MGV	0.543	0.714	-0.429	1							
MW	-0.026	-0.143	-0.143	0.029	1						
MH	0.086	0.371	-0.600	0.657	-0.543	1					
ED	**0.829**	0.714	0.771	0.143	-0.429	-0.029	1				
P	-0.657	**-0.826**	0.257	**-0.886**	-0.143	-0.543	-0.200	1			
N-fert	-0.600	-0.486	-0.429	-0.257	-0.600	0.486	-0.314	0.429	1		
Crops	**-0.886**	-0.771	-0.314	-0.600	-0.314	0.086	-0.600	0.600	0.714	1	
LU	-0.143	0.086	**-0.886**	0.600	0.314	0.600	-0.600	-0.600	0.143	0.029	1
IA	-0.406	-0.203	-0.580	0.029	-0.522	0.725	-0.319	0.029	**0.899**	0.580	0.464

3.2. General vegetation characteristics and large-scale species richness

Altogether 471 vascular plant species were recorded in the sample plots of six study sites. The overall species number including the species from species pool recorded from the surroundings of the sample plots was 573 species. Only 8 protected species were found in the sample plots. The numbers of vascular plant species per each landscape test site are presented in Table 6. Altogether 37 plant species from the group of agrotolerant species (i.e. species that occurred in at least 10 % of sample plots) were recorded (Figure 7). *Taraxacum officinale* and *Elymus repens* were the most frequent species occurring in 58 % and 56 % of sample plots in agricultural land, respectively. Other species were less frequent occurring in less than 40 % of sample plots in arable land. The general species richness (i.e. gamma diversity) was the highest in Are landscape test site (291 species) and the lowest in Ilmatsalu landscape test site (245 species). The number of agrotolerant species did not vary notably in different landscape test sites ranging from 33 species in Are and Vihtra test sites to 37 species in other study sites.

Table 6. The vascular plant species richness of study areas. List of more frequent species are in Appendix 1 and 2.

Landscape test site	**Total species number**	**Number of nature-value species**	**Number of agrotolerant species**
Are	291	258	33
Vihtra	277	244	33
Viiratsi	269	232	37
Väike-Maarja	246	209	37
Ilmatsalu	245	208	37
Abja-Paluoja	256	219	37

Regression analysis that was performed to specify the impact of landscape structure and land use intensity on large-scale species richness revealed that higher nitrogen fertilisation decreases the overall number of nature-value species (P = 0.02; R^2 = 0.88; Figure 6 (a)). The increase in the percentage of greenveining significantly increases the large-scale species richness (P = 0.03; R^2 = 0.65; Figure 6 (b)).

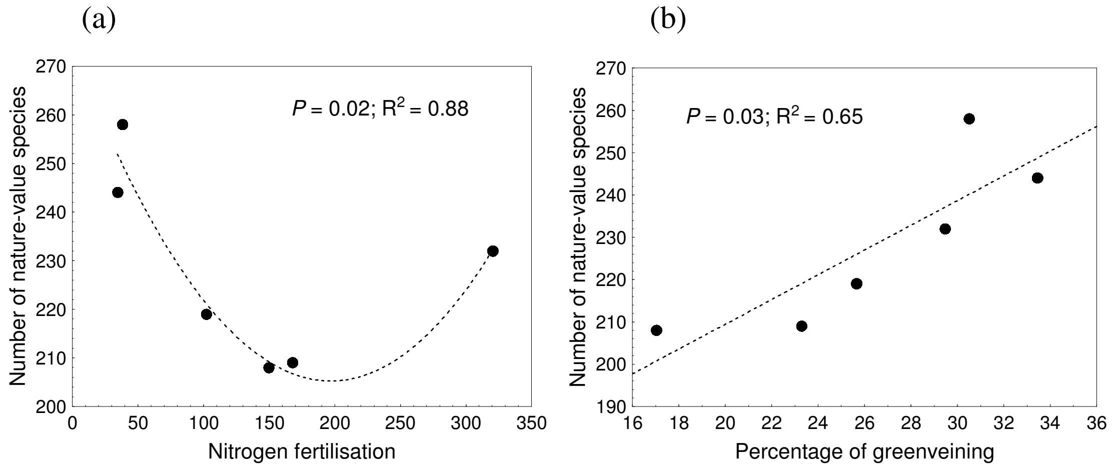


Figure 6. The influence of (a) nitrogen fertilisation and (b) greenveining on large-scale nature-value species richness.

Significant differences in mean nature-value and agrotolerant species richness per sample plots were determined between different landscape element types (Table 7; Figure 8) The mean agrotolerant species richness was significantly higher in agricultural land, linear elements and in (semi-)natural patches than in large (semi-)natural patches (semi-natural grassland, deciduous/coniferous/mixed forests). The mean richness of nature-value species was the lowest in cultivated fields (Figure 8).

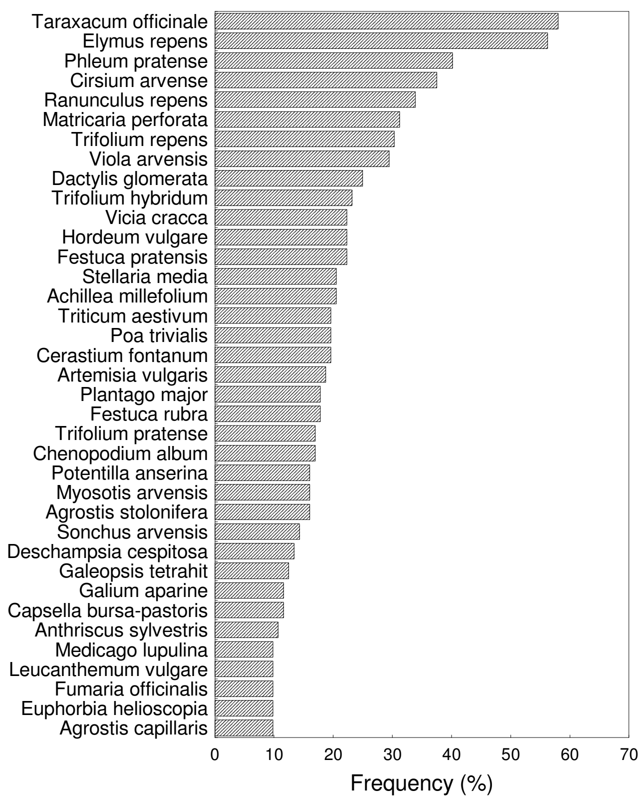


Figure 7. The frequency of agrotolerant species in the sample plots of agricultural land.

Table 7. The results of Analyses of Variance (ANOVA) about the differences of mean agrotolerant and nature-value species richness between different landscape elements. Abbreviations: d.f. – degree of freedom, F – Fisher's statistic, *P* – level of significance. The abbreviations of the factors are explained in Table 3.

Factor	d.f.	F	*P*
Intercept	1	3465.039	0.001
EUNIS	6	67.152	0.001
AT_NV	1	407.636	0.001
EUNIS*AT_NV	6	183.730	0.001

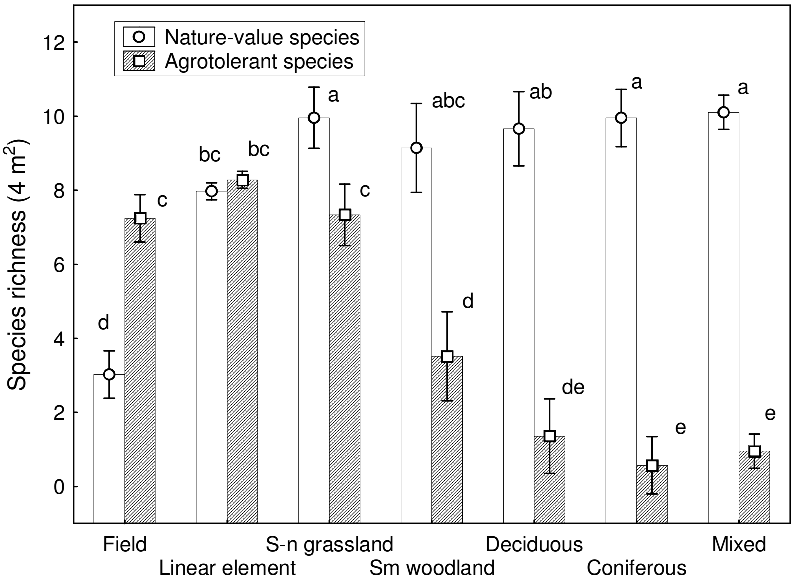


Figure 8. The differences in nature-value and agrotolerant species richness between different landscape element types. Vertical bars – 95 % confidence interval, letters – the homogenous groups of Tukey HSD test. "S-n grassland" – semi-natural grassland, "Sm woodland" – small woodland, "Deciduous" – deciduous forest, "Coniferous" – coniferous forest, "Mixed" – mixed forest.

3.3. The determinants of small-scale species richness

General Linear Model was carried out to investigate the impact of large- and local-scale factors of landscape structure and land-use intensity on small-scale plant species richness (Table 8). The results reveal that the species richness of agrotolerants and nature-values species generally did not differ significantly (factor: "AT_NV"). It was differentiated between small/linear (semi-)natural elements near arable land and larger (semi-)natural patches assuming that small and linear elements experience greater disturbance of agricultural activities than the vegetation cover of large patches. According to the model, the vicinity of agricultural land does not influence the overall species richness (factor: “Agri”). The adjacency of agricultural land has a significant effect on the small-scale diversity if agrotolerant and nature-value species are observed separately (factor: “AT_NV*Agri”; $P < 0.029$; Figure 9(a)). The richness of nature-value species is affected negatively by the vicinity of arable field while agrotolerant species richness, on the contrary, increases near agricultural land. The increase in nitrogen fertilisation causes the decrease in species richness in general (factor: “N-fert”; $P < 0.001$) but particularly strong negative effect was observed in the plots adjacent to agricultural land (factor: “N-fert*Agri”; slope estimate: -0.009; $P < 0.001$) compared to large patches (slope estimate: -0.002; $P = 0.168$).

Among the factors of large-scale landscape structure, the percentage of woody patches increases small-scale species richness (factor: “GVw%”; $P < 0.001$) and the richness of nature-value species (factor: “GV%w*AT_NV”; slope estimate: 0.204; $P < 0.001$) is more enhanced than the richness of agrotolerants (slope estimate: 0.082; $P < 0.001$). The percentage of herbaceous semi-natural communities does not significantly affect the general small-scale species richness (factor: “GVh%”) but the significance of the factors interactions between the percentage of herbaceous communities and agrotolerant and nature-value species diversity reveals that the increase in the percentage of herbaceous semi-natural communities causes a significant increase in the richness of agrotolerant species (factor: “GV%h*AT_NV”; slope estimate: 0.269; $P = 0.017$) in comparison with nature-value species richness (slope estimate -0.09; $P = 0.262$).

Local structural variables significantly influence the small-scale species diversity. The diversity of nature-value species is increased when ditch is present, but the richness of agrotolerants remains unchanged (factor: “AT_NV*Ditch”, $P < 0.001$; Figure 9 (b)). The presence of tree or shrub layer decreases the number of agrotolerant species but does not affect the richness of nature-value species (factor: “AT_NV*Tree-shrub”, $P < 0.001$; Figure 9 (c)). The neighbourhood of road significantly increases the richness of agrotolerants (factor: “AT_NV*Road, $P < 0.001$; Figure 9 (d)). The changes in the closure of tree and shrub canopy significantly affect species richness (factor: “Closure”; $P < 0.001$; Figure 10). The increase in closure decreases the species richness of agrotolerants both in the vicinity of field and in natural and semi-natural patches (factor: “Closure*AT_NV*Agri“; parameter estimates: -0.066 and -0.027, resp.; $P < 0.001$; Figure 10).

Table 8. The results of the General Linear Model (GLM) about the effect of land use intensity and landscape structure on small-scale plant species richness. Slopes are presented for significant factors or factors interactions. Abbreviations: d.f. – degrees of freedom, F – Fisher's statistic, SE – standard error, *P* – level of significance; significant factors are in bold font. The abbreviations of the factors are explained in Table 3.

Effect	d.f.	F	*P*	Factor	Slope	SE	*P*
AT_NV	1;1420	1.14	0.286				
Agri	1;1420	1.69	0.194				
AT_NV*Agri	**1;1420**	**4.8**	**0.029**		see Figure 9 (a)		
Ditch	**1;1420**	**19.17**	**0.001**				
AT_NV*Ditch	**1;1420**	**29.6**	**0.001**		see Figure 9 (b)		
Tree-shrub	**1;1420**	**36.28**	**0.001**				
AT_NV*Tree-shrub	**1;1420**	**12.49**	**0.001**		see Figure 9 (c)		
Road	**1;1420**	**21.35**	**0.001**				
AT_NV*Road	**1;1420**	**44.05**	**0.001**		see Figure 9 (d)		
N-fert	**1;1420**	**42.92**	**0.001**				
N-fert*AT_NV	1;1420	2.11	0.147				
N-fert*Agri	**1;1420**	**15.5**	**0.001**	Agri-	-0.002	0.002	0.168
				Agri+	**-0.009**	**0.001**	**0.001**
N-fert*AT_NV*Agri	1;1420	0.02	0.885				
GVw%	**1;1420**	**53.19**	**0.001**				
GVw%*AT_NV	**1;1420**	**13.35**	**0.001**	**NV**	**0.204**	**0.021**	**0.001**
				AT	**0.082**	**0.021**	**0.001**
GVw%*Agri	1;1420	2.58	0.109				
GVw%*AT_NV*Agri	1;1420	0.07	0.789				
GVh%	1;1420	0.97	0.326				
GVh%*AT_NV	**1;1420**	**5.67**	**0.017**	NV	-0.090	0.081	0.262
				AT	**0.269**	**0.081**	**0.001**
GVh%*Agri	1;1420	1.3	0.255				
GVh%*AT_NV*Agri	1;1420	2.11	0.147				
Closure	**1;1420**	**45.2**	**0.001**				
Closure*AT_NV	**1;1420**	**72.27**	**0.001**				
Closure*Agri	**1;1420**	**14.18**	**0.001**				
Closure*AT_NV*Agri	**1;1420**	**7.42**	**0.007**	NV, Agri-	-0.004	0.006	0.566
				NV, Agri+	0.008	0.006	0.207
				AT, Agri-	**-0.066**	**0.006**	**0.001**
				AT, Agri+	**-0.027**	**0.006**	**0.001**

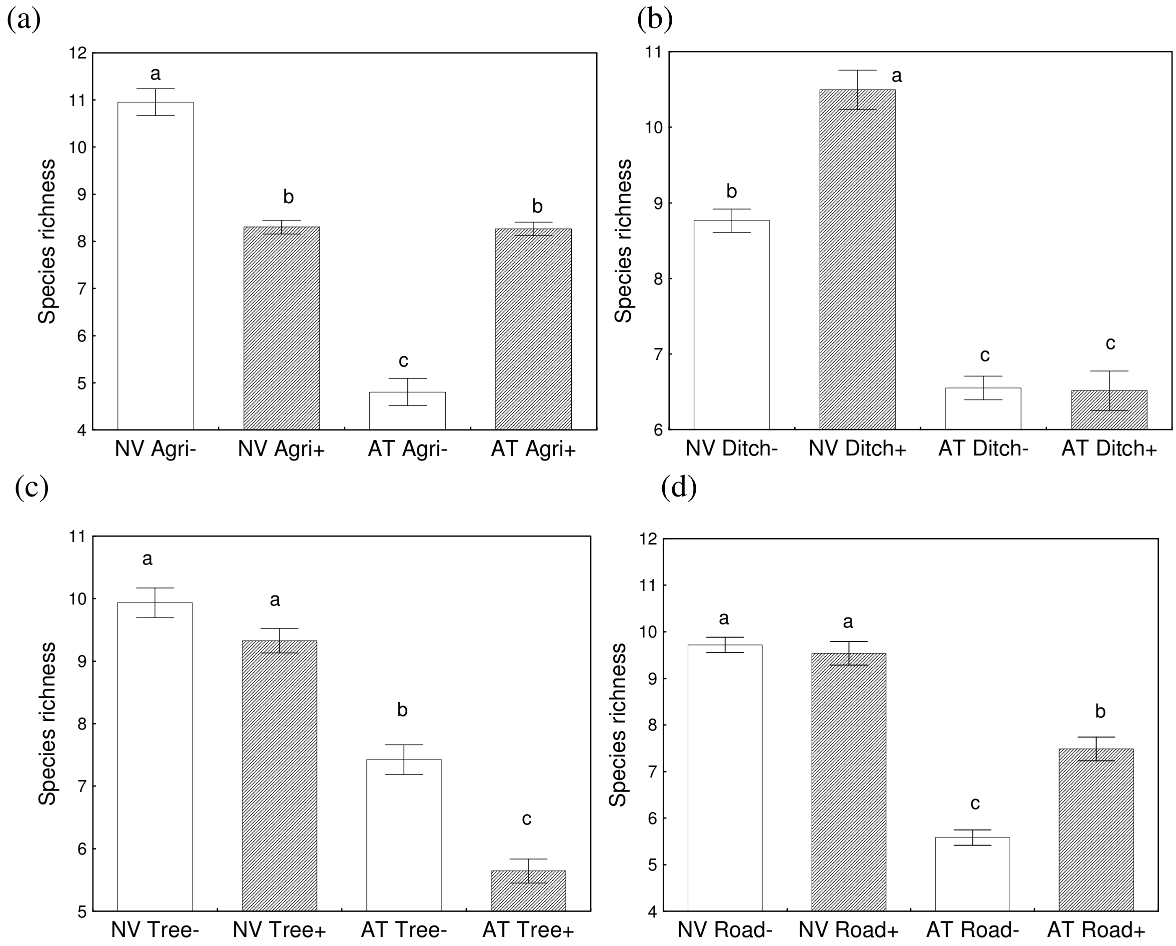


Figure 9. The species richness of nature-value (NV) and agrotolerant species (AT) (a) in the absence of agricultural adjacency (Agri-) and in the vicinity of agricultural land (Agri+), (b) in the absence of ditch (Ditch-) and in the presence of ditch (Ditch+), (c) in the absence or tree or/and bush layer (Tree-) and in the presence of tree or/and bush layer (Tree+), (d) in the absence of road (Road-) and in the presence of road (Road+). Whiskers - standard error; letters – the homogenous groups of Tukey-Kramer HSD test.

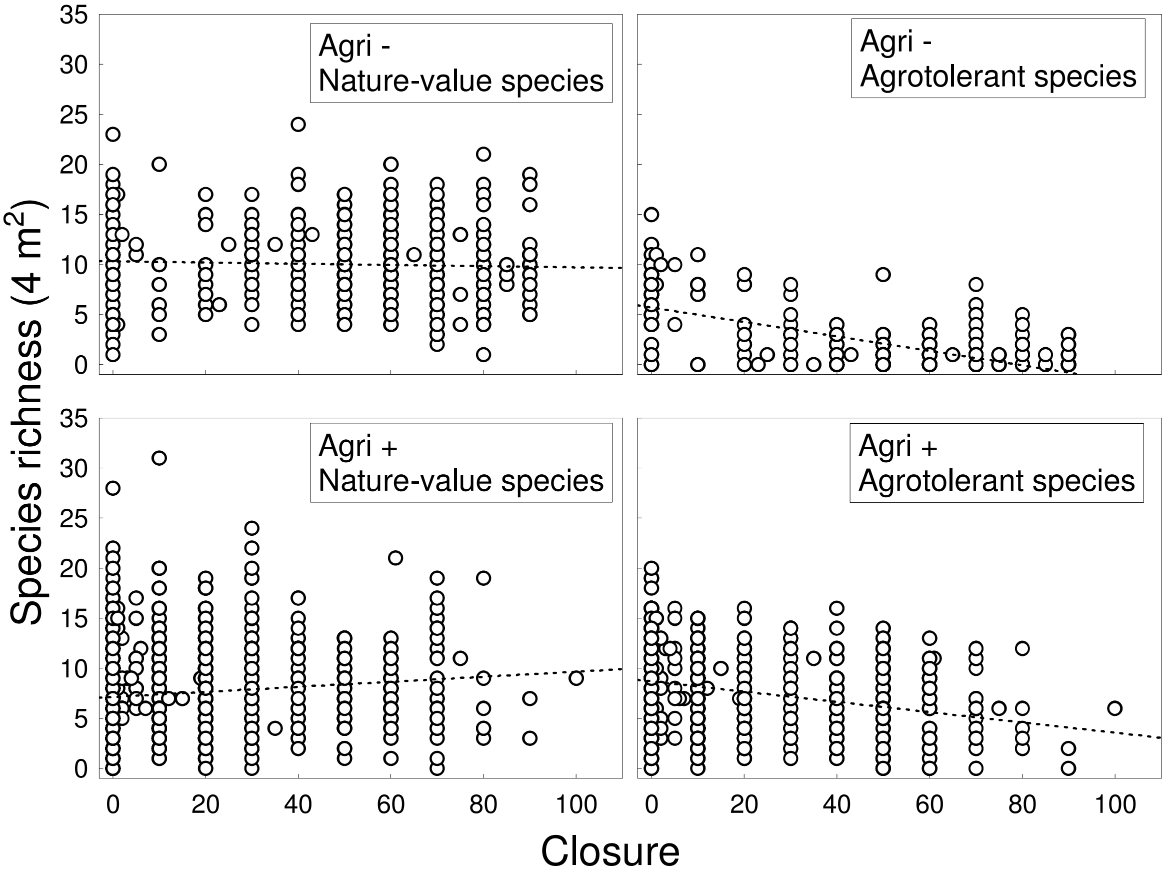


Figure 10. The influence of closure on the species richness of agrotolerant and nature-value species without the adjacency of agricultural land (Agri-) and in the vicinity of agricultural land (Agri+). Slope estimates and level of significance are presented in Table 8.

3.4. Vegetation composition

3.4.2. The vegetation composition of woodland patches

The results of Detrended Correspondence Analysis (DCA) reveals overlapping of the species composition of different forest types (deciduous, coniferous and mixed forests) (Figure 11 (a)) with the distinction of the group of small woodlands. Most of the small woodlots are aggregated on the top of the ordination diagram. The first axis represents the gradient of the Ellenberg ecological value of fertility from higher scores to lower ones ($r_{Spearman}$ = -0.819; $P < 0.001$; Table 9). The species ordination diagram (Figure 11 (b)) confirms the result as the beginning of this gradient is characterised by species with high requirements for soil fertility. These species are mostly typical of boreo-nemoral forests – *Galeobdolon luteum*, *Hepatica nobilis*, *Stachys sylvatica*, *Impatiens parviflora* and *Stellaria holostea*. At the end of the first axis one can notice species characteristic to nutrient-poor soils – *Vaccinium myrtillus*, *Deschampsia flexuosa* and *Vaccinium vitis-idaea*. The Ellenberg ecological value of light and agrotolerant species richness is strongly correlated to the second axis ($r_{Spearman}$ = 0.509 and $r_{Spearman}$ = 0.400, resp.; P < 0.001) implying that the growth in Ellenberg value of light is partly accompanied by the increase in the number of agrotolerant species. Most of the sample plots recorded in small woodland patches are located at the end of this gradient (Figure 11 (a)). Species ordination diagram reveals that species favoured by the conditions in small patches are graminoids like *Poa pratensis*, *Phleum pratense*, *Dactylis glomerata*, *Alopecurus pratensis*, *Festuca rubra*, and other light-demanding species – *Galium boreale*, *Tussilago farfara*, *Ranunculus acris*, *Vicia cracca*, *Galium album* and *Alchemilla* sp. (Figure 11 (b)). The Ellenberg ecological value of soil acidity has a strong positive correlation with the second axis ($r_{Spearman}$ = 0.749; P < 0.001). The beginning of this gradient is characterised by species with acid soil requirements (mostly species of coniferous forests) – *Maianthemum bifolium*, *Trientalis europaea*, *Picea abies* and *Lycopodium annotinum*.

Indicator species analysis was carried out to determine the typical species of each forest type (Appendix 3). The results indicate that the EUNIS classification of forests into deciduous, coniferous and mixed types is too rough for such analyses as the indicative value of the species characteristic to these forest types is relatively low, although some species showed significant indication level (P < 0.05). *Oxalis acetosella* was the most characteristic and frequent species in coniferous forests. *Dryopteris carthusiana* was most common in mixed forests (Appendix 3). Surprisingly, the total number of species typical of small woodland patches was the highest (26 species). Most of those species are characterised by higher light requirements and also belong to the group of agrotolerant species – e.g. *Achillea millefolium*, *Galium boreale*, *Agrostis capillaris*, *Aegopodium podagraria*, *Cirsium arvense*, *Anthriscus sylvestris* and *Elymus repens*.

Table 9. Spearman correlations between the explanatory variables of the vegetation composition of forests and the three DCA axes. * - P < 0.001

Variable	Axis 1	Axis 2	Axis 3
General species richness	0.356*	0.070	-0.120
Nature-value species richness	0.276*	-0.106	-0.096
Agrotolerant species richness	0.414*	0.400*	-0.070
Closure	-0.276*	0.005	0.131
Ellenberg value of fertility	-0.819*	0.416*	0.373*
Ellenberg value of moisture	0.371*	0.223*	0.401*
Ellenberg value of light	0.603*	0.509*	-0.012
Ellenberg value of acidity	-0.547*	0.749*	0.385*

(a)

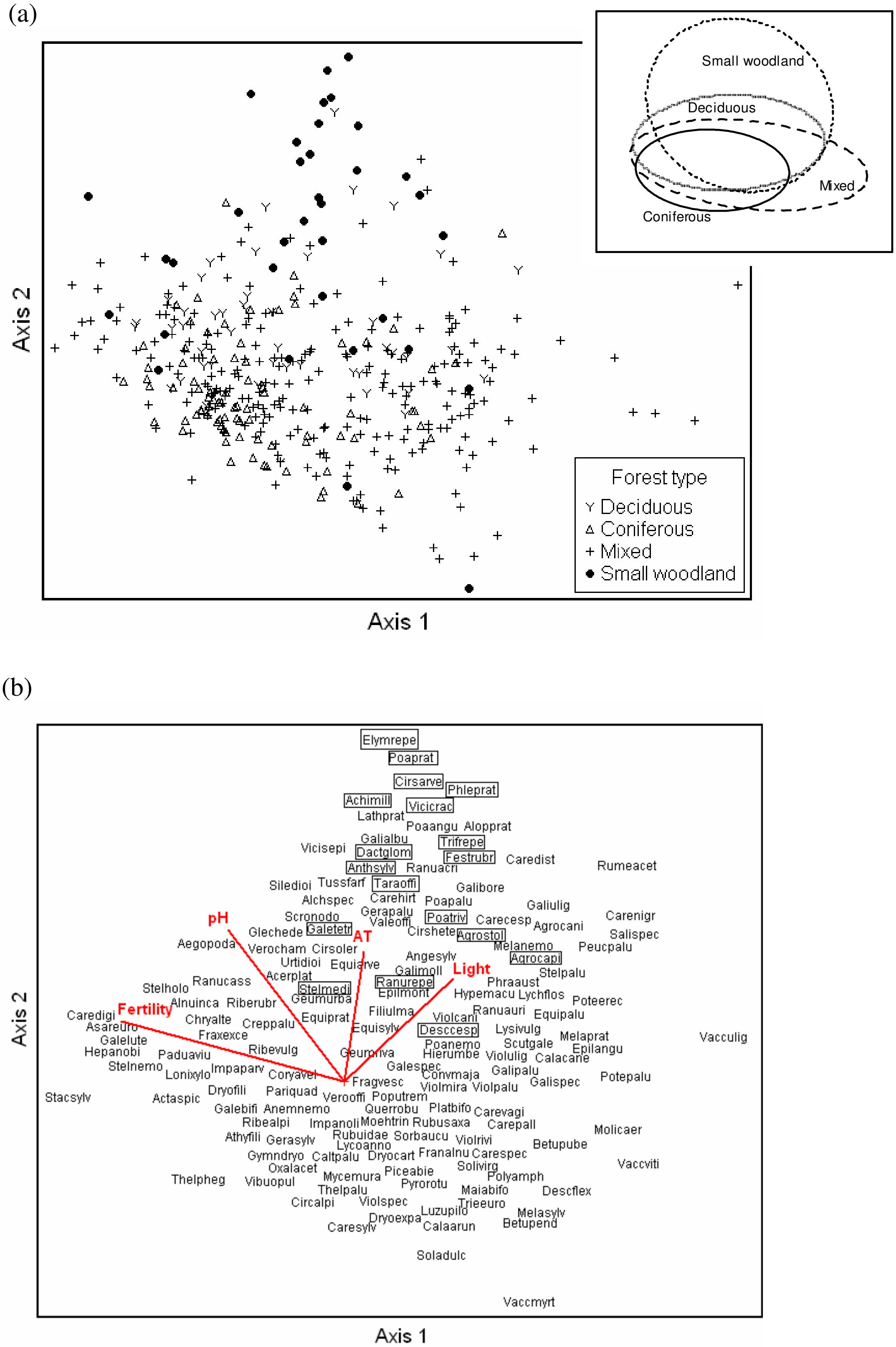


Figure 11. Ordination diagrams of the first two DCA axes with 400 forest sample plots: (a) the position of sample plots; (b) the position of species. Agrotolerant species are surrounded by black frames. Explanations for the abbreviations of explanatory variables are in Table 3. Full names of the abbreviated species names are presented in Appendix 1. Ellipses in Figure (a) denote the area on ordination diagram where the plot sampled in particular forest type should incur with the probability of 75 %.

3.4.1. The vegetation composition of semi-natural linear elements

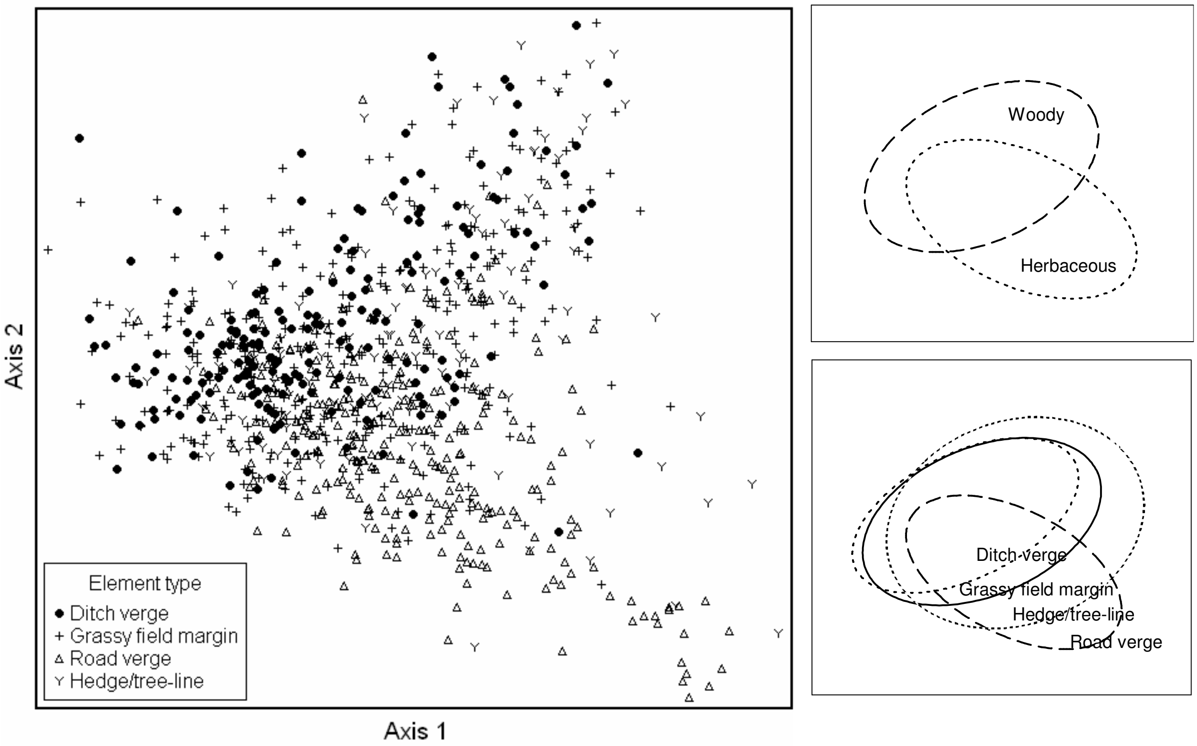
The results of Detrended Correspondence Analysis (DCA) of the vegetation of linear elements (Figure 12 (a) and (b)) and Spearman correlation coefficients between explanatory variables and DCA axes (Table 10) indicate that the species compositional pattern is correlated to land use intensity and landscape structure. The ordination analysis revealed partial differences between the vegetation composition of different EUNIS types. The vegetation of road and ditch verges is more clustered and distinguishable from other element types (Figure 12 (a)). The Ellenberg ecological value of fertility is positively correlated to the first axis ($r_{Spearman} = 0.843$; $P < 0.001$; Table 10). The species at the end of the fertility gradient on the species diagram are characteristic to fertile soils of field boundaries adjacent to intensively managed fields – e.g. *Galeopsis tetrahit, Artemisia vulgaris, Arctium tomentosum, Triticum aestivum, Matricaria perforata, Bunias orientalis, Chenopodium album, Sonchus arvensis, Thlaspi arvense, Lapsana communis* and *Fumaria officinalis* (Figure 12 (b)). The scores of the plots are negatively correlated to the presence of ditch ($r_{Spearman} = -0.51$; $P < 0.001$; Table 10). Species typical of ditch verges are located in the beginning of this gradient - e.g. *Juncus effusus, Galium palustre, Peucedanum palustre* and different species of *Carex* sp. One protected orchid species can be found from this species group as well, i.e. *Platanthera bifolia*. The richness of nature-value species decreases also along the first axis ($r_{Spearman} = -0.616$; $P < 0.001$). The second axis separates the survey plots with different light conditions ($r_{Spearman} = -0.539$; $P < 0.001$) – plots where tree or bush layer is present are located in the upper part of the graph, while plots of opened habitats (e.g. road verges) and species with higher light requirements are aggregated at the bottom of the diagram. There is also a strong positive correlation between moisture and the second axis ($r_{Spearman} = 0.542$; $P < 0.001$). Characteristic species tolerating shade and moisture are e.g*., Elymus caninus, Oxalis acetosella, Scirpus sylvatica, Moehringia trinervia*, and woody species like *Salix* sp. and *Alnus incana*. At the lower part of the species diagram there are drought-tolerant species characteristic to opened habitats, mostly road verges – e.g. *Potentilla anserina, Achillea millefolium, Cerastium fontanum, Festuca rubra, Trifolium repens* and *Polygonum aviculare*.

Indicator species analysis of the vegetation of the four habitat types of linear elements brought out a number of species with significant indicative properties (Appendix 4). However, as most of the indication values are below 20, which was set as a critical value (Legendre and Legendre 1998), the results do not let us to make far-reaching conclusions about those species. According to the results, typical roadside species that have high significant indicative value were *Taraxacum officinale*, *Dactylis glomerata*, *Achillea millefolium*, *Artemisia vulgaris* and *Plantago major*. *Geranium palustre* is a characteristic species of ditch banks.

Table 10. Spearman correlations between explanatory variables of the vegetation composition of linear elements and the three DCA axes. * - $P < 0.001$

Variable	**Axis 1**	**Axis 2**	**Axis 3**
General species richness	-0.467*	-0.391*	-0.087
Nature-value species richness	-0.616*	-0.017	-0.023
Agroltolerant species richness	-0.101*	-0.644*	-0.133*
Ditch	-0.510*	0.149*	-0.132*
Tree-shrub	-0.249*	0.448*	-0.068
Road	0.088	-0.466*	0.086
Ellenberg ecological value of fertility	0.843*	0.287*	-0.087
Ellenberg ecological value of moisture	-0.282*	0.542*	-0.431*
Ellenberg ecological value of light	0.085	-0.539*	-0.215*
Ellenberg ecological value of acidity	0.356*	0.075	0.001

(a)



(b)

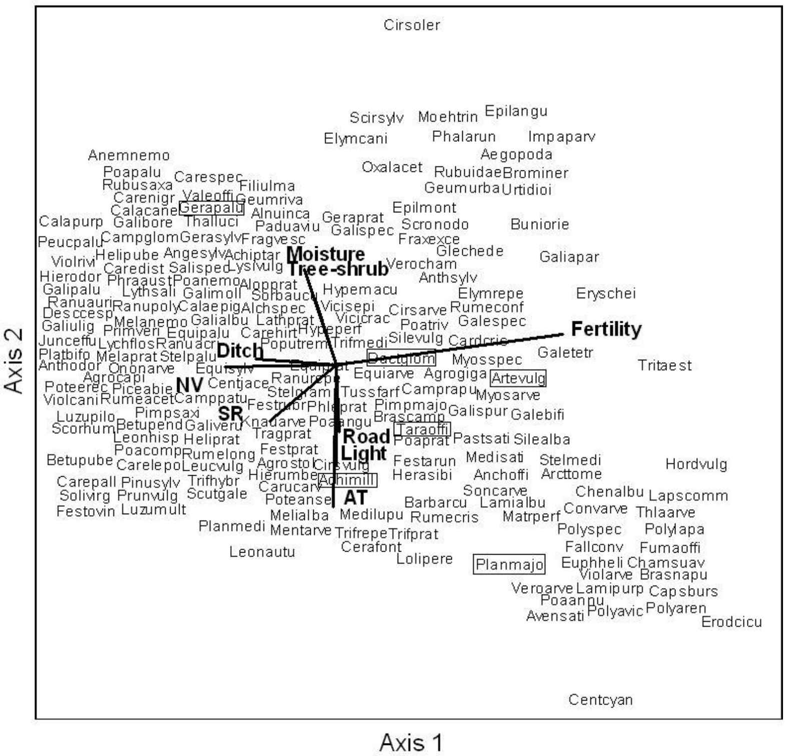


Figure 12. Ordination diagram of first two DCA axes with 957 survey plots of linear elements: (a) position of survey plots (grouping variable – element type); (b) position of species, full names of the abbreviated species names are in Appendix 2; indicator species are surrounded with black frames. Ellipses in Figure (a) denote the area on ordination diagram where the plot sampled in woody/herbaceous linear element or habitat type should occur with the probability of 75 %.

4. DISCUSSION

Measures of plant species richness

Species richness has been one of the most commonly used and accepted measures of biodiversity (Purvis and Hector 2000, Büchs 2003). However, several researches have indicated that species richness *per se* does not adequately demonstrate the actual status of biodiversity in agricultural landscapes because different taxa respond to changes in agricultural intensification and greenveining differently (Burel et al. 1998, Jeanneret et al. 2003). It has been suggested that species richness of different functional types should rather be considered as a reference of ecological conditions of agricultural landscapes – i.e. species with similar ecological traits (Lavorel et al. 1997, Hoffmann 1998, Kleyer 1999, Gondard et al. 2003, Van Diggelen et al. 2005). The presence of rare or Red List species has also been used as one of the possible indicators for the evaluation of biodiversity status but as contemporary agricultural landscapes seldom host rarities, this approach is impractical in agroecosystems. In the present study I observed the opposite aspect. I distinguished agrotolerant and nature-value species with the presumption that the richness of species frequent in arable land and nature-value species would react differently to the increase/decrease in land use intensity and percentage of natural and semi-natural communities, especially in the habitats adjacent to fields that experience more severe pressure of agricultural activities.

Geertsema and colleagues (2002) divided species in agricultural landscapes according to seed dispersal abilities and seed bank persistence. The long-dispersing species with persistent seed bank would be dominant in landscapes characterised by intensive management, low proportion of natural habitats and scattered small patches of natural habitats. Indeed, Geertsema and colleagues analysed the species from arable, grassland and forest habitats and found that almost three quarters of species from arable environments possessed the ability for long distance dispersal and long-term survival of seed bank. Species like *Matricaria perforata*, *Viola arvensis*, *Chenopodium album, Galeopsis tetrahit, Cirsium arvense* and *Galium aparine* in the list of agrotolerants of the present study are common disturbance-tolerant weeds on arable land, most of which are sharing the characteristics described by Geertsema and colleagues (2002). Possessing competitive strategy and resource capturing abilities is also one possibility to persist in arable landscape, e.g. *Elymus repens* (the second frequent species in the list of agrotolerants) and *Cirsium arvense*. *Vicia cracca*, *Ranunculus repens*, *Cerastium fontanum*, *Festuca rubra*, *Leucanthemum vulgare* are perennials typical of grasslands and pastures. All those species are characterised by high light requirement and are therefore common either in arable fields and rotational grasslands. Their proportion in woodlands is significantly lower in comparison to nature-value species. Thus, the richness of species with mentioned strategies compared to the proportion of species characteristic of natural and semi-natural habitats should be a representative indicator for illustrating the impact of land use parameters and landscape structure on the quality of vascular plants.

Gamma diversity, landscape structure and land use intensity

The results of regression analyses revealed that nitrogen input and the percentage of natural and semi-natural communities significantly influence the landscape-level species richness of nature-value species (i.e. gamma diversity). The increase in the percentage of natural and semi-natural communities affects large-scale species richness positively. In general, the increase in nitrogen fertilisation decreases the species number (Figure 6 (a)). The influence of land use intensity on species richness has been demonstrated in numerous studies. However, most of the works have been focused on the relationship between land use and small-scale species diversity (Kleijn and Snoeijing 1997, Schippers and Joenje 2001, Fédoroff et al. 2005); the studies of correlation between land use and landscape-level species richness are rare (Luoto et al. 2003, Zechmeister et al. 2003).

Mean nitrogen application and the percentage of greenveining influenced general species richness in opposite ways. Nitrogen application was correlated to the percentage of intensively managed land (i.e. the area of fields that receive more than 150 kg/N/ha). Higher fertilisation rates of a study area indicate that crop-growing is the main land use type (Roschewitz et al. 2005). Intensive fertilisation implies to higher disturbance on the vegetation adjacent to fields resulting from the mechanical pressure as well as from the altered conditions of soil chemistry. Such conditions cause the loss of species that are more sensitive to agricultural activities (Zechmeister et al. 2003). Intensive management is often accompanied by more coarse-grained landscape structure – small fields have been joined into larger ones and linear landscape features like ditches and hedges are removed to simplify the movement of agricultural machinery and as a result landscape structure becomes more homogenised (Ihse 1995, Hietala-Koivu 2002).

The relationship between large-scale species richness and nitrogen fertilisation showed a polynomial dependence. Mean nitrogen application is the highest in Viiratsi landscape test site (319 kg/N/ha), but the large-scale species richness in Viiratsi is not as low as it would be expected in the case of linear relationship. In fact, the number of nature-value species is much higher in Viiratsi (232) than in less intensively fertilised areas. Concurrently, the percentage of natural and semi-natural communities and the edge density of (semi-)natural habitats are comparatively high in Viiratsi – 29.5 % and 23 165 m/km², respectively. These results suggest that higher percentage of greenveining may partly compensate the effect of intensive fertilisation via larger total area of natural-vegetation habitats, higher proximity and connectivity between communities, higher buffering capabilities in regard to agricultural pressure and other compensative mechanisms that may contribute to higher landscape-scale biodiversity. However, testing of this hypothesis needs further thorough researches to make more certain conclusions.

Small woodlands versus large forests

As the results of General Linear Model revealed, the small-scale species richness of agrotolerants and nature-value species in forest patches is negatively influenced by the increase in the use of nitrogen fertilisers. The plant diversity and composition in the communities adjacent to agricultural land (e.g. small woodlots) are especially susceptible to changes in nitrogen application. Mikk and Mander (1995) demonstrated the relationship between plant species diversity and the frequency and intensity of disturbance (mainly nitrogen fertilisation) of forest islands in agricultural landscapes. They concluded that smaller patches are more sensitive to external disturbances. They also noticed the predominance of nitrophilous plant species in small woodlots. This result is confirmed by the present study as on the ordination graph the location of plots described in small woodlands are related to the position of species typical of productive habitats – e.g. *Cirsium arvense*, *Anthriscus sylvestris*, *Elymus repens* and *Galeopsis tetrahit* (Figure 11).

The Ellenberg ecological value of light was related to the distribution of sample plots recorded in small woodlots indicating that there are differences in the closure of small woodlands and large forests. Honnay and colleagues (2002) demonstrated that the gradient of photosynthetically active radiation in the forest edges is directly correlated to the proportion of light-demanding plant species. Consequently, the vegetation composition in the edge of the forest may be completely different from the composition in the core area of the woodland. High frequency of graminoids in the species composition of small woodlots confirms the latter – e.g. *Festuca rubra*, *Dactylis glomerata*, *Phleum pratense* and *Poa angustifolia* are typical species of those habitats (Figure 11 (b)).

The vegetation of small woodlots in Estonian agricultural landscapes seems to be strongly influenced by edge effect. The influence of edge effect and its extension into the forest interior in regard to light conditions and the movement of agrochemicals are important determinants of habitat quality of small woodlots. The decrease in the area of a community is accompanied by the increase in edge effect. The importance of small woodlands as stepping stones and refugia for plant species whose habitats have disappeared due to the expansion of fields has been pointed out in several studies. There is an ongoing discussion in the field of nature conservation whether a large number of small patches or few patches with large area should be preferred (Forman 1995, Whittaker 1998, Honnay et al. 1999, Dumortier et al. 2002, Honnay et al. 2002, Piessens et al. 2005). However, the present study indicates that large natural-vegetation woodland patches in agricultural landscapes are crucial for the maintenance of suitable conditions for habitat specialists.

The influence of land use intensity on small-scale plant species richness and composition

I chose mean nitrogen application as a surrogate variable for the overall land use intensity in the analysis of the determinants of small-scale species richness as it has been reported in many studies that nitrogen fertilisation is a good indicator of land use intensity (Le Coeur et al. 1997, Tilman et al. 2001, Schippers and Joenje 2002). This parameter had strong correlation with the percentage of intensively managed land as well. The strongest gradient among explanatory variables in the ordination analysis of semi-natural linear elements is related to the Ellenberg ecological value of soil fertility (Figure 12 (b)). According to the results of General Linear Model, the increase in nitrogen fertilisation causes significant decrease in species richness, especially in the adjacency of agricultural land.

Linear elements (i.e. road and ditch verges, forest edges, tree-lines and hedgerows) and small woodlots in the fields are usually under the strongest influence of agricultural activities. Field boundaries are often subject to direct misplaced fertiliser and are indirectly influenced via nutrient runoff from the field. The highest species richness is observed at the intermediate levels of production (Grime 1979) but the level of soil productivity is often above the intermediate in field margins. Additional nutrients in the soil increase the biomass production causing the asymmetrical competition for light and the dominance of species with highly competitive strategy. As a result, the species richness decreases (Tilman and Pacala 1993). Frequent disturbance (i.e. mechanical pressure) is the second important factor affecting field margin flora. Such conditions favour the persistence of disturbance-tolerant species with R-strategy that germinate in a vacant nutrient-rich gap where competition is low, and quickly produce a large number of propagules (Grime 1988).

The results of the present study show that the diversity of agrotolerant species is significantly higher and the richness of nature-value species is reduced in the vicinity of agricultural land (Figure 9 (a)). Kleijn and Verbeek (2000) demonstrated that the cover of *Elymus repens* and other weedy annuals in the margin flora is correlated to the management intensity of adjacent land. Indeed, in the present study *Elymus repens* was the most frequent agrotolerant species, occurring in 56 % of the sample plots in agricultural land. On the species ordination diagram of linear elements (Figure 12 (b)), this species belongs to the group of species with high Ellenberg value of fertility. *Elymus repens* is characteristic C-strategist in nutrient-rich habitats with frequent disturbance regime (Grime 1988). Interviews with farmers also revealed that *Elymus repens* is the most problematic weed species whose high disturbance-tolerance forces to apply higher amounts of herbicides. According to the ordination analysis of linear elements, common ruderal species characteristic to field margins with high soil fertility are *Galium aparine*, *Convolvulus arvensis*, *Galeopsis tetrahit*, *Matricaria perforata* and *Thlaspi arvense* (see also Grime 1988, Moonen and Marshall 2001). Species that are adapted to nutrient-rich soils but require moderate shade characterise the species composition of woody linear elements (i.e. tree-lines and forest edges) - *Impatiens parviflora*, *Angelica sylvestris*, *Urtica dioica*, *Bunias orientalis* and *Scrophularia nodosa*.

The before-mentioned species are typical of the field boundaries adjacent to intensively managed cropfields. High nitrogen fertilisation, intensive management and crop-growing are characteristic to the landscape test sites of Ilmatsalu and Väike-Maarja. In the beginning of the fertility gradient of the ordination diagram of linear elements, on the contrary, there is a set of species that were found in the margins of rotational grasslands – for, example *Anthoxanthum odoratum*, *Helictotrichon pubescens*, *Primula veris*, *Lychnis flos-cuculi* and *Galium boreale*. One protected species also belongs to this group – i.e. an orchid *Platanthera bifolia* (Figure 12 (b)). In general, the richness of nature-value species is correlated to the first axis in the opposite direction compared to fertility gradient. High percentage of permanent or long-term grasslands is characteristic to Are and Vihtra landscape test sites where the overall species richness is also higher. The effect of adjacent land use practises causing the differentiation of plant species richness and composition of semi-natural linear elements has been reported in several studies (Cummins and French 1994, Le Coeur et al. 1997, Cherrill et al. 2001, Le Coeur et al. 2002). Firstly, as it was mentioned before, margins adjacent to crop fields and short-term grasslands experience the effect of higher quantities of fertilisers or other agrochemicals and frequent disturbances that alter the ecological properties of the margin. Secondly, it has been demonstrated that the cropfield itself may act as a source of weedy annual species, i.e. agrotolerant species, which change the composition of field margin flora (McAdam et al. 1994, Aude et al. 2003). The management of permanent and long-term rotational grasslands is less intensive compared to cropfields and therefore the field boundaries of grasslands and pastures may host species with lower disturbance-tolerance and competition abilities.

Cummins and French (1994) differentiated between four main associations of vascular plants related to field margins depending on the adjacent management regimes: 1) the vegetation of field boundaries adjacent to intensively managed cropfields; 2) vegetation adjacent to intensively managed cultural grasslands; 3) vegetation adjacent to extensively managed grasslands and pastures; 4) the association of shade-tolerant species in the forest edges adjacent to fields. Mentioned classification of habitats is applicable in the present research as well while the vegetation assemblages on ordination diagram and the explanatory variables related to it quite well illustrate the pattern of the before-mentioned associations.

The misplacement of additional nitrogen, phosphor, pesticides and leaching of nutrients from adjacent fields into field margins should be avoided to maintain the merits of those linear features as habitats for the preservation of biodiversity in agricultural landscapes. Schippers and Joenje (2002) modelled the effect of fertilisers on plant diversity and showed that already very slight changes in nitrogen amount may cause notable changes in species richness and composition. Field margins are often treated as sources of weeds to adjacent fields and are therefore sprayed with herbicides. But several experiments have shown the contrary effect – species-rich field boundary vegetation composed of perennial grassland species may prevent and even decrease the dispersal of weedy annuals (Moonen and Marshall 2001). The development of such vegetation may be enhanced by sowing seeds of "useful" plant species (Kleijn et al. 1998). Diverse field margin vegetation may host insects who control the pest populations of the adjacent cropfield (Marshall and Moonen 2002). Diverse flora affects the habitat conditions for other invertebrates (Mänd et al. 2002), small mammals (Tew 1994) and birds (Jobin et al. 2001) as well.

The influence of landscape structure on plant species diversity and composition

The importance of the structural features of semi-natural linear habitats influencing vegetation composition and diversity has been emphasised in several studies (Boatman et al. 1994, Le Coeur et al. 1997, Cherrill et al. 2001). Therefore I analysed the impact of structural variables separately, although the parameters describing environmental conditions (the Ellenberg ecological values of light, moisture and fertility) are partly related to the presence or absence of these features. The analysis of landscape factors influencing species richness showed that the presence of ditch and road in the neighbourhood increase the overall small-scale species richness while the presence of tree and shrub layer lowers the number of species (Table 8). The structural features related to linear elements affect the richness of agrotolerant and nature-value species very differently (Figure 9). Indicator species analysis of field margin habitats brought out only a few plant species with high indicative value for particular landscape features, implying that a large portion of those species are generalists whose occurrence does not depend of certain ecological conditions (see also Appendix 4). However, the ordination analysis based on the abundance of plant species in field margins revealed that the species composition is still clearly affected by small-scale structural features of the landscape.

The presence of ditch significantly increases the proportion of nature-value species (Figure 9 (b)). This result is confirmed by the ordination analysis where the gradients of the richness of nature-value species and the ditch being present have almost the similar trend (Figure 12 (b)). Indeed, the species composition of many ditch banks considered in the present study is similar to the species assemblages typical of semi-natural grasslands. It may be partly the result of intermediate disturbance level. In comparison with margins adjacent to roads there is no such mechanical pressure but most of the ditch verges are mown once per few years. The decreased disturbance level has enabled the development of diverse plant association composed mainly of perennials common in permanent grasslands and weedy annuals do not have possibilities to colonise the ditch bank community. Milsom and colleagues (2004) demonstrated that suitable management regime (i.e. mowing and dredging) significantly increases the richness of ditch banks. The same was confirmed by Blomqvist and colleagues (2003) who emphasised the importance of combining moderate management and reduction of nutrients to maintain and enhance the diversity of ditch banks. The presence of ditches is especially influential to aquatic plants and phreatophytes (Deckers et al. 2004). Species that were characteristic to ditch verges according to species ordination were *Lychnis flos-cuculi*, *Galium palustre*, *Juncus effusus*, *Hierochloe odorata* and *Peucedanum palustre* (Figure 12 (b)).

The presence of tree or/and shrub layer significantly reduces the proportion of agrotolerant species. This is also consistent to the result that closure affects the diversity and composition of different landscape elements – denser tree and shrub layer decreases the agrotolerant species richness in the vicinity of agricultural land as well as in patches with natural and semi-natural vegetation. The richness of nature-value species decreases in patches with higher closure but increases in semi-natural linear elements and small woodlots adjacent to agricultural areas in comparison with agrotolerants. Most of the agrotolerants are opportunistic annuals that exhibit high light requirements and are replaced by shade-tolerant species in conditions where the available amount of light is decreased. On the ordination graph (Figure 12 (b)) one can notice typical forest species like *Oxalis acetosella* and *Anemone nemorosa*. The presence of species characterised by high productivity and competitive abilities like *Urtica dioica* and *Anthriscus sylvestris* is also positively related to the conditions created by tree-shrub layer indicating on higher nutrient level in those margins. The dominance of these species in the field boundaries cause the additional decrease in light and may therefore displace slow-growing and small-sized species (Boatman et al. 1994). The ordination analysis of linear elements revealed that the presence of tree or bush layer is accompanied by the frequent occurrence of species with higher requirements for moisture (i.e. the Ellenberg ecological value of moisture). Trees and bushes decrease the overall evaporation and thus significantly influence the microclimate of the development of herb layer (Boatman et al. 1994). The combination of two structural variables – i.e. the presence of both tree layer and ditch – seems to favour the growth of *Valeriana officinalis*, *Carex* sp., *Thalictrum lucidum*, *Geum rivale*, *Angelica sylvestris* and *Lychnis flos-cuculi*.

Field margins adjacent to roads are characterised by significantly higher richness of agrotolerant species and according to the ordination analyses are favoured by plants with higher light requirements (Figure 12 (b)). Roads are subject to intensive anthropogenic disturbance: the bushes and trees of the verges of larger roads are usually cut down, road verges are frequently mown and the vegetation in the nearest vicinity of the road is affected by mechanical disturbance caused by vehicles. Therefore, those habitats are often characterised by extreme ecological conditions caused by ample light, drought, and sedimentation of mineral nutrients from roads as well as from adjacent fields. One of the main features of roadside plant communities is great instability and disturbance-tolerant species tend to dominate (Ullmann and Heindl 1989, Forman and Alexander 1998). Ullmann and Heindl determined a clear zonation of roadside plant communities depending on the level of disturbance and vicinity of the road. Communities nearest to the road are dominated by *Polygonum aviculare*, *Poa annua*, *Plantago major* - species that are dependent on the presence of road according to the results of the present study as well. Other species typical of roadside species composition according to the indicator species analysis and consistently to the studies of Ullmann and Heindl (1989) are *Artemisia vulgaris*, *Dactylis glomerata*, *Achillea millefolium, Taraxacum officinale, Festuca rubra, Trifolium repens* and *Poa pratensis.* Unfortunately, in some landscape test sites of the present study, especially in intensively managed landscapes, the mentioned zone remained to be the only vegetation strip between road and crop field. As most of the species typical of this zone brought out by Ullmann and Heindl (1989) and confirmed by the present study belong to the list of agrotolerants, the function of such road verges as alternative habitats and dispersal corridors for semi-natural grassland species seems questionable. However, if the road verge is wider, encompasses different zones of vegetation and is combined with other structural elements like tree-lines and ditches, these landscape features may still be important habitats for a high number of species (Cherrill et al. 2001, Tikka et al. 2001).

The percentage of woody communities among landscape-scale structural variables affects the overall small-scale species richness positively. The increase in the percentage of semi-natural herbaceous communities is accompanied by significant increase in small-scale richness of agrotolerant species. This is consistent to the study of Le Coeur and colleagues (1997) who showed that the predominance of species characteristic to woody patches significantly decreased on the gradient of land use intensification and shade-tolerant species became replaced by light-demanding grassland species. The increased percentage of herbaceous communities may account for the higher small-scale richness of agrotolerants indicating on the agricultural land use effect on those grasslands via using fertilisers, particularly manure. Indeed, correlation analysis revealed that the mean patch size of semi-natural communities is negatively related to the percentage of semi-natural grasslands (Table 5) implying that those habitats are influenced by edge effect and are therefore more prone to external effects. The loss of suitable habitats due to agricultural intensification accompanied by enlargement of fields has been one of the major causes of the decrease in biodiversity of agricultural landscapes (Brokaw 1998, Priorr 2003). A set of landscape parameters may be related to these factors – connectivity, distances between patches with natural vegetation and other variables that may account for the changes in small-scale species richness as well, but these parameters are beyond the scope of the present research.

5. CONCLUSIONS

The results of this study show that land use intensity and landscape structure influence vascular plant species diversity in landscape scale as well as small-scale species richness and composition. However, the relationships between mentioned parameters differ if the tolerance of different species to agricultural disturbance is considered. Although the distinction between agrotolerant and nature-value species is quite rough, the differential response of two species groups to land use and structural variables imply that species richness *per se* is not an accurate indicator of biodiversity status, at least in semi-natural linear elements and small woodlots. The species composition and abundance in the habitats of agricultural landscapes depend on species ecological traits and this aspect should be more thoroughly studied and considered in the evaluation of biodiversity of agroecosystems.

Small woodlots in Estonian agricultural landscapes are habitats mainly for generalists and agrotolerant species implying that the ecological conditions of small woodlands are strongly influenced by edge effect. This result as well as the significance of the percentage of natural and semi-natural communities determining landscape- and small-scale species richness refer that the amount of natural-vegetation patches with appropriate ecological conditions is essential for maintaining the diversity of habitat specialists.

The higher richness of nature-value species in the presence of ditch and tree-bush layer indicates that the diverse structure of field margins is one of the presumptions for the development of diverse herb layer. The maintenance of the local structure of field boundaries should be combined with decreased use of fertilisers and other agrochemicals near the field margin to reduce the alteration of soil conditions.

SUMMARY

The expansion of fields, mechanisation, intensive use of different chemicals and fertilisers – these are the keywords that characterise the agricultural revolution in the second half of the 20^{th} century. Mentioned activities have become serious factors affecting the biodiversity of agricultural landscapes through fragmentation and decreasing quality of habitats. It is presumed that biodiversity still might persist due to greenveining of agricultural areas if we knew enough about the species responses along the gradient of land-use intensity and landscape structure, so we could act according to our knowledge. The objective of the present research was to assess what are the general characteristics of the vegetation of Estonian agricultural landscapes and what are the main factors influencing the landscape-level as well as small-scale species diversity.

Six landscape test sites that were chosen for the research differ in regard to land use intensity and percentage of greenveining. Data collection included vegetation sampling from different landscape elements, working with maps and interviewing farmers about the land use intensity. The diversity of species that occurred frequently in the plots of cultivated land (i.e. agrotolerants) was distinguished from the diversity of nature-value species. General Linear Model (GLM) was used to evaluate the factors affecting small-scale vegetation diversity. Ordination (DCA) and indicator species analysis were performed to describe the species composition of field boundaries and forest patches.

Land use intensity had a significant effect on large- and small-scale species richness. The increase in nitrogen fertilisation decreases the landscape-scale and small-scale species richness. Large-scale landscape structure and local structure influence the species richness of agrotolerants and nature-value species differently. The increase in the proportion of (semi-)natural communities is positively correlated to the landscape-scale species richness. The species richness of agrotolerant is higher in the vicinity of agricultural land and in the neighbourhood of roads while the proportion of nature-value species is positively affected by the presence of ditch and tree-line/hedgerow and. The results indicate that the vegetation of the small woodlots in the fields are dominated mainly by generalist and agrotolerant species.

Field boundaries with additional structural elements (ditch, tree-line) that are not subject to fertilisers and herbicides might some-what compensate the effect of the loss in the area of semi-natural grasslands and large woodlands. The management and habitat quality of field boundaries is also an important indicator of aesthetic, historical and cultural value of agricultural landscapes. However, patches with larger area and stable environmental conditions in agricultural landscapes are essential to maintain the diversity of habitat specialists.

KOKKUVÕTE

20. sajandi teisel poolel hoogustunud intensiivse põllumajandusega kaasnenud põldude suurenemine, põllutöö mehhaniseerimine ja väetiste ning muude agrokemikaalide laiaulatuslik kasutamine saagikuse tõstmise eesmärgil on liikide kasvukohtade ja elupaikade killustumise ning kvaliteedi languse kaudu kujunenud tõsisteks põllumajandusmaastike bioloogilist mitmekesisust mõjutavateks faktoriteks. Põllumajandusmaastike bioloogilise mitmekesisuse säilitamine eeldab teadmisi selle kohta, kuidas muutused maakasutuse intensiivsuses ja maastiku struktuuris erinevaid liike mõjutavad. Käesoleva uurimustöö eesmärgiks oli kirjeldada Eesti põllumajandusmaastike taimkatet üldisemas plaanis ning analüüsida, kuidas ning mil määral maakasutuse intensiivuse ja maastiku struktuuri tegurid mõjutavad soontaimede suure- ning väikeseskaalalist liigirikkust.

Uurimuse tarbeks valiti kuus prooviala, mis erinevad üksteisest maakasutuse intensiivsuse ning maastiku struktuuri poolest. Andmete kogumine hõlmas taimkatteruutude kirjeldusi, tööd kaartidega ning talunike küsitlemist maakasutuse intensiivsuse kohta. Taimeliigid jagati sõltuvalt põldudel esinemise sagedusest agrotolerantseteks ja n-ö. loodusväärtuslikeks liikideks ning analüüsiti vaadeldavate faktorite mõju kummagi liigirühma väikeseskaalalisele liigirikkusele eraldi. Väikeseskaalalist liigirikkust mõjutavate tegurite analüüsiks kasutati üldist lineaarset mudelit (GLM). Põlluservade ja metsaeraldiste liigilist koosseisu uuriti ordinatsioonanalüüsi (DCA) ning indikaatorliikide analüüsi abil.

Maakasutuse intensiivsus mõjutab oluliselt nii suure- kui väikeseskaalalist liigirikkust. Lämmastikväetise koguse suurenemine vähendab nii maastiku kui prooviruutude liigirikkust. Nii struktuur maastiku skaalas kui ka lokaalsed struktuurielemendid mõjutavad agrotolerantsete ja loodusväärtuslike liikide mitmekesisust erinevalt. (Pool-)looduslike koosluste osakaalu suurenemisega kaasneb maastiku liigirikkuse tõus. Põllu läheduses ning tee naabruses suureneb agrotolerantsete liikide osakaal. Liituvuse suurenemine, puu-ja/või põõsarinde olemasolu ning kraavi lähedus tõstavad loodusväärtuslike liikide mitmekesisust. Töö tulemused viitavad sellele, et väikesed metsaeraldised põldudel on kasvukohtadeks peamiselt generalistidele ning agrotolerantsetele liikidele.

Põllumajandusmaastike avatud ja pool-avatud joonelemendid (põllu- ja teeservad) võivad mõningal määral kompenseerida suuremate metsaeraldiste ja pool-looduslike koosluste kadumisest tulenevat kasvukohtade hävinemist, kui pööratakse tähelepanu põlluservade majandamisele, mis eeldab lisaks struktuurilise kasvukohtade mitmekesisuse säilitamisele ka väiksemat väetiste ja herbitsiidide suunamist põlluservadele. Hooldatud põlluservad on ka põllumajandusmaastike kultuurilis-ajaloolise ning esteetilise väärtuse indikaatoriks. Siiski on ka suurema pindalaga stabiilsemat kasvukohta pakkuvate looduslike eraldiste säilitamine põllumajandusmaastikel oluline kasvukohaspetsialistide jaoks.

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Maps:

Estonian Basic Map (1:10 000) – Estonian Land Board (Licence ST-A1 nr. 00046)

Cadastral Map (1:10 000) – Estonian Land Board

Digitalised maps of Are, Vihtra, Viiratsi, Väike-Maarja. Augenstein, I. UFZ Centre for Environmental Research Leipzig-Halle, Germany.

Estonian Soil Map – Institute of Geography, University of Tartu

Appendix 1. The abbreviations and Latin names of species (152) used in the ordination analysis of woodland patches.

Abbreviation	Latin name
Acerplat	*Acer platanoides*
Achimill	*Achillea millefolium*
Actaspic	*Actaea spicata*
Aegopoda	*Aegopodium podagraria*
Agrocani	*Agrostis canina*
Agrocapi	*Agrostis capillaris*
Agrostol	*Agrostis stolonifera*
Alchspec	*Alchemilla species*
Alnuinca	*Alnus incana*
Alopprat	*Alopecurus pratensis*
Anemnemo	*Anemone nemorosa*
Angesylv	*Angelica sylvestris*
Anthsylv	*Anthriscus sylvestris*
Asareuro	*Asarum europaeum*
Athyfili	*Athyrium filix-femina*
Betupend	*Betula pendula*
Betupube	*Betula pubescens*
Calaarun	*Calamagrostis arundinacea*
Calacane	*Calamagrostis canescens*
Caltpalu	*Caltha palustris*
Carecesp	*Carex cespitosa*
Caredigi	*Carex digitata*
Caredist	*Carex disticha*
Carehirt	*Carex hirta*
Carenigr	*Carex nigra*
Carepall	*Carex pallescens*
Carespec	*Carex species*
Caresylv	*Carex sylvatica*
Carevagi	*Carex vaginata*
Chryalte	*Chrysosplenium alternifolium*
Circalpi	*Circaea alpina*
Cirsarve	*Cirsium arvense*
Cirshete	*Cirsium heterophyllum*
Cirsoler	*Cirsium oleraceum*
Convmaja	*Convallaria majalis*
Coryavel	*Corylus avellana*
Creppalu	*Crepis paludosa*
Dactglom	*Dactylis glomerata*
Desccesp	*Deschampsia cespitosa*
Descflex	*Deschampsia flexuosa*
Dryocart	*Dryopteris carthusiana*
Dryoexpa	*Dryopteris expansa*
Dryofili	*Dryopteris filix-mas*
Elymrepe	*Elymus repens*
Epilangu	*Epilobium angustifolium*
Epilmont	*Epilobium montanum*
Equiarve	*Equisetum arvense*
Equipalu	*Equisetum palustre*
Equiprat	*Equisetum pratense*

Abbreviation	Latin name
Equisylv	*Equisetum sylvaticum*
Festrubr	*Festuca rubra*
Filiulma	*Filipendula ulmaria*
Fragvesc	*Fragaria vesca*
Franalnu	*Frangula alnus*
Fraxexce	*Fraxinus excelsior*
Galebifi	*Galeopsis bifida*
Galelute	*Galeobdolon luteum*
Galespec	*Galeopsis speciosa*
Galetetr	*Galeopsis tetrahit*
Galialbu	*Galium album*
Galibore	*Galium boreale*
Galimoll	*Galium mollugo*
Galipalu	*Galium palustre*
Galispec	*Galium species*
Galiulig	*Galium uliginosum*
Gerapalu	*Geranium palustre*
Gerasylv	*Geranium sylvaticum*
Geumriva	*Geum rivale*
Geumurba	*Geum urbanum*
Glechhede	*Glechoma hederacea*
Gymndryo	*Gymnocarpium dryopteris*
Hepanobi	*Hepatica nobilis*
Hierumbe	*Hieracium umbellatum*
Hypemacu	*Hypericum maculatum*
Impanoli	*Impatiens noli-tangere*
Impaparv	*Impatiens parviflora*
Lathprat	*Lathyrus pratensis*
Lonixylo	*Lonicera xylosteum*
Luzupilo	*Luzula pilosa*
Lychflos	*Lychnis flos-cuculi*
Lycoanno	*Lycopodium annotinum*
Lysivulg	*Lysimachia vulgaris*
Maiabifo	*Maianthemum bifolium*
Melanemo	*Melampyrum nemorosum*
Melaprat	*Melamyrum pratense*
Melasylv	*Melampyrum sylvaticum*
Moehtrin	*Moehringia trinervia*
Molicaer	*Molinia caerulea*
Mycemura	*Mycelis muralis*
Oxalacet	*Oxalis acetosella*
Paduaviu	*Padus avium*
Pariquad	*Paris quadrifolia*
Peucpalu	*Peucedanum palustre*
Phleprat	*Phleum pratense*
Phraaust	*Phragmites australis*
Piceabie	*Picea abies*
Platbifo	*Platanthera bifolia*

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Appendix 1 continues

Abbreviation	Latin name
Poaangu	*Poa angustifolia*
Poanemo	*Poa nemoralis*
Poapalu	*Poa palustris*
Poaprat	*Poa pratensis*
Poatriv	*Poa trivialis*
Polyamph	*Polygonum amphibium*
Poputrem	*Populus tremula*
Poteerec	*Potentilla erecta*
Potepalu	*Potentilla palustris*
Pyrorotu	*Pyrola rotundifolia*
Querrobu	*Quercus robur*
Ranuacri	*Ranunculus acris*
Ranuauri	*Ranunculus auricomus*
Ranucass	*Ranunculus cassubicus*
Ranurepe	*Ranunculus repens*
Ribealpi	*Ribes alpinum*
Riberubr	*Ribes rubrum*
Rubuidae	*Rubus idaeus*
Rubusaxa	*Rubus saxatilis*
Rumeacet	*Rumex acetosa*
Salispec	*Salix species*
Scronodo	*Scrophularia nodosa*
Scutgale	*Scutellaria galericulata*
Siledioi	*Silene dioica*
Soladulc	*Solanum dulcamara*
Solivirg	*Solidago virgaurea*
Sorbaucu	*Sorbus aucuparia*
Stacsylv	*Stachys sylvatica*
Stelholo	*Stellaria holostea*
Stelmedi	*Stellaria media*
Stelnemo	*Stellaria nemorum*
Stelpalu	*Stellaria palustris*
Taraoffi	*Taraxacum officinale*
Thelpalu	*Thelypteris palustris*
Thelpheg	*Thelypteris phegopteris*
Trieeuro	*Trientalis europaea*
Trifrepe	*Trifolium repens*
Tussfarf	*Tussilago farfara*
Urtidioi	*Urtica dioica*
Vaccmyrt	*Vaccinium myrtillus*
Vacculig	*Vaccinium uliginosum*
Vaccviti	*Vaccinium vitis-idaea*
Valeoffi	*Valeriana officinalis*
Verocham	*Veronica chamaedrys*
Verooffi	*Veronica officinalis*
Vibuopul	*Viburnum opulus*
Vicicrac	*Vicia cracca*
Vicisepi	*Vicia sepium*
Violcani	*Viola canina*
Violmira	*Viola mirabilis*
Violpalu	*Viola palustris*
Violrivi	*Viola riviniana*
Violspec	*Viola species*
Violulig	*Viola uliginosa*

Appendix 2. The abbreviations and Latin names of species (195) used in the ordination analysis of linear elements.

Abbreviation	Latin name
Achimill	*Achillea millefolium*
Achiptar	*Achillea ptarmica*
Aegopoda	*Aegopodium podagraria*
Agrocapi	*Agrostis capillaris*
Agrogiga	*Agrostis gigantea*
Agrostol	*Agrostis stolonifera*
Alchspec	*Alchemilla species*
Alnuinca	*Alnus incana*
Alopprat	*Alopecurus pratensis*
Anchoffi	*Anchusa officinalis*
Anemnemo	*Anemona nemorosa*
Angesylv	*Angelica sylvestris*
Anthodor	*Anthoxanhtum odoratum*
Anthsylv	*Anthriscus sylvestris*
Arcttome	*Arctium tomentosum*
Artevulg	*Artemisia vulgaris*
Avensati	*Avena sativa*
Barbarcu	*Barbarea arcuata*
Betupend	*Betula pendula*
Betupube	*Betula pubescens*
Brascamp	*Brassica campestris*
Brasnapu	*Brassica napus*
Brominer	*Bromus inermis*
Buniorie	*Bunias orientalis*
Calacane	*Calamagrostis canescens*
Calaepig	*Calamagrostis epigeios*
Calapurp	*Calamagrostis purpurea*
Campglom	*Campanula glomerata*
Camppatu	*Campanula patula*
Camprapu	*Campanula rapunculoides*
Capsburs	*Capsella bursa-pastoris*
Cardcrisp	*Carduus crispus*
Caredist	*Carex disticha*
Carehirt	*Carex hirta*
Carelepo	*Carex leporina*
Carenigr	*Carex nigra*
Carepall	*Carex pallescens*
Carespec	*Carex species*
Carucarv	*Carum carvi*
Centcyan	*Centaurea cyanus*
Centjace	*Centaurea jacea*
Cerafont	*Cerastium fontanum*
Chamsuav	*Chamomilla suaveolens*
Chenalbu	*Chenopodium album*
Cirsarve	*Cirsium arvense*
Cirsoler	*Cirsium oleraceum*
Cirsvulg	*Cirsium vulgare*
Concarve	*Convolvulus arvensis*

Abbreviation	Latin name
Dactglom	*Dactylis glomerata*
Desccesp	*Deschampsia cespitosa*
Elymcani	*Elymus caninus*
Elymrepe	*Elymus repens*
Epilangu	*Epliobium angustifolium*
Epilmont	*Epilobium montanum*
Equiarve	*Equisetum arvense*
Equipalu	*Equisetum palustre*
Equiprat	*Equisetum pratense*
Equisylv	*Equisetum sylvaticum*
Erodcicu	*Erodium cicutarium*
Eryschei	*Erysimum cheiranthoides*
Euphheli	*Euphorbia heliocopia*
Fallconv	*Fallopia convolvulus*
Festarun	*Festuca arundinacea*
Festovin	*Festuca ovina*
Festprat	*Festuca pratensis*
Festrubr	*Festuca rubra*
Filiulma	*Filipendula ulmaria*
Fragvesc	*Fragaria vesca*
Fraxexce	*Fraxinus excelsior*
Fumaoffi	*Fumaria officinalis*
Galebifi	*Galeopsis bifida*
Galespec	*Galeopsis speciosa*
Galetetr	*Galeopsis tetrahit*
Galialbu	*Galium album*
Galiapar	*Galium aparine*
Galibore	*Galium boreale*
Galimoll	*Galium mollugo*
Galipalu	*Galium palustre*
Galispec	*Galium species*
Galispur	*Galium spurium*
Galiulig	*Galium uliginosum*
Galiveru	*Galium verum*
Gerapalu	*Geranium palustre*
Geraprat	*Geranium pratense*
Gerasylv	*Geranium sylvaticum*
Geumriva	*Geum rivale*
Geumurba	*Geum urbanum*
Glechhede	*Glechoma hederacea*
Heliprat	*Helictotrichon pratense*
Helipube	*Helictotrichon pubescens*
Herasibi	*Heracleum sibiricum*
Hierodor	*Hierochloe odorata*
Hierumbe	*Hieracium umbellatum*
Hordvulg	*Hordeum vulgare*
Hypemacu	*Hypericum maculatum*
Hypeperf	*Hypericum perforatum*

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Appendix 1 continues

Abbreviation	Latin name
Impaparv	*Impatiens parviflora*
Junceffu	*Juncus effusus*
Knauarve	*Knautia arvensis*
Lamialbu	*Lamium album*
Lamipurp	*Lamium purpureum*
Lapscomm	*Lapsana communis*
Lathprat	*Lathyrus pratensis*
Leonautu	*Leontodon autumnalis*
Leonhisp	*Leontodon hispidus*
Leucvulg	*Leucanthemum vulgare*
Lolipere	*Lolium perenne*
Luzumult	*Luzula multiflora*
Luzupilo	*Luzula pilosa*
Lychflos	*Lychnis flos-cuculi*
Lysivulg	*Lysimachia vulgaris*
Lythsali	*Lythrum salicaria*
Matrperf	*Matricaria perforata*
Medilupu	*Medicago lupulina*
Medisati	*Medicago sativa*
Melanemo	*Melampyrum nemorosum*
Melaprat	*Melampyrum pratense*
Melialba	*Melilotus alba*
Mentarve	*Mentha arvensis*
Moehtrin	*Moehringia trinervia*
Myosarve	*Myosotis arvensis*
Myosspec	*Myosotis species*
Ononarve	*Ononis arvensis*
Oxalacet	*Oxalis acetosella*
Paduaviu	*Padus avium*
Pastsati	*Pastinaca sativa*
Peucpalu	*Peucedanum palustre*
Phalarun	*Phalaris arundinacea*
Phleprat	*Phleum pratense*
Phraaust	*Phragmites australis*
Piceabie	*Picea abies*
Pimpmajo	*Pimpinella major*
Pimpsaxi	*Pimpinella saxifraga*
Pinusylv	*Pinus sylvestris*
Planmajo	*Plantago major*
Planmedi	*Plantago media*
Platbifo	*Platanthera bifolia*
Poaangu	*Poa angustifolia*
Poaannu	*Poa annua*
Poacomp	*Poa compressa*
Poanemo	*Poa nemoralis*
Poapalu	*Poa palustris*
Poaprat	*Poa pratensis*
Poatriv	*Poa trivialis*
Polyaren	*Polygonum arenastrum*
Polyavic	*Polygonum aviculare*
Polylapa	*Polygonum lapathifolium*
Polyspec	*Polygonum species*

Abbervation	Latin name
Poputrem	*Populus tremula*
Poteanse	*Potentilla anserina*
Poteerec	*Potentilla erecta*
Primveri	*Primula veris*
Prunvulg	*Prunella vulgaris*
Ranuacri	*Ranunculus acris*
Ranuauri	*Ranunculus auricomus*
Ranupoly	*Ranunculus polyanthemos*
Ranurepe	*Ranunculus repens*
Rubuidae	*Rubus idaeus*
Rubusaxa	*Rubus saxatilis*
Rumeacet	*Rumex acetosa*
Rumeconf	*Rumex confertus*
Rumecris	*Rumex crispus*
Rumelong	*Rumex longifolius*
Salispec	*Salix species*
Scirsylv	*Scirpus sylvaticus*
Scorhumi	*Scorzonera humilis*
Scronodo	*Scrophularia nodosa*
Scutgale	*Scutellaria galericulata*
Silealba	*Silene alba*
Silevulg	*Silene vulgaris*
Solivirg	*Solidago virgaurea*
Soncarve	*Sonchus arvensis*
Sorbaucu	*Sorbus aucuparia*
Stelgram	*Stellaria graminea*
Stelmedi	*Stellaria media*
Stelpalu	*Stellaria palustris*
Taraoffi	*Taraxacum officinale*
Thalluci	*Thalictrum lucidum*
Thlaarve	*Thlaspi arvense*
Tragprat	*Tragopogon pratensis*
Trifhybr	*Trifolium hybridum*
Trifmedi	*Trifolium medium*
Trifprat	*Trifolium pratense*
Trifrepe	*Trifolium repens*
Tritaest	*Triticum aestivum*
Tussfarf	*Tussilago farfara*
Urtidioi	*Urtica dioica*
Valeoffi	*Valeriana officinalis*
Veroarve	*Veronica arvensis*
Verocham	*Veronica chamaedrys*
Vicicrac	*Vicia cracca*
Vicisepi	*Vicia sepium*
Violarve	*Viola arvensis*
Violcani	*Viola canina*
Violrivi	*Viola riviniana*

Appendix 3. The list of species that have significant variation of indicator value among groups ($P < 0.05$) according to the results of indicator species analysis of the forest patches. The indication value (IV) and frequency (FR; %) in particular forest type is presented; species whose indication value is at least 20 are marked in bold. "Forest" – forest type where the particular species has the highest indicative value, "Decid." – deciduous forest, "Conif." – coniferous forest, "Mixed" – mixed forest, "Sm.woodl." – small woodland.

Species	Forest	Decid.		Conif.		Mixed		Sm.wood		*P*
		IV	(FR)	IV	(FR)	IV	(FR)	IV	(FR)	
Fraxinus excelsior	Decid.	18	(39)	1	(10)	3	(14)	4	(17)	0.002
Filipendula ulmaria	Decid.	15	(35)	0	(1)	9	(26)	4	(17)	0.012
Cirsium oleraceum	Decid.	9	(15)	0	(0)	0	(3)	3	(9)	0.013
Poa nemoralis	Decid.	9	(13)	0	(2)	0	(3)	0	(3)	0.010
Valeriana officinalis	Decid.	6	(11)	0	(0)	0	(3)	3	(9)	0.046
Carex cespitosa	Decid.	5	(7)	0	(0)	0	(0	1	(3)	0.020
Scrophularia nodosa	Decid.	4	(7)	0	(1)	0	(0	1	(3)	0.049
Oxalis acetosella	**Conif.**	6	(39)	**46**	**(82)**	12	(49)	0	(9)	**0.001**
Mycelis muralis	Conif.	2	(13)	16	(31)	5	(17)	0	(3)	0.007
Dryopteris filix-mas	Conif.	0	(2)	15	(20)	1	(5)	0	(0)	0.001
Sorbus aucuparia	Conif.	3	(17)	14	(38)	6	(26)	5	(23)	0.049
Paris quadrifolia	Conif.	6	(20)	14	(31)	4	(16)	0	(0)	0.011
Lonicera xylosteum	Conif.	1	(7)	14	(19)	0	(1)	0	(0)	0.001
Athyrium filix-femina	Conif.	3	(13)	11	(24)	3	(13)	0	(3)	0.045
Circaea alpina	Conif.	1	(4)	11	(20)	2	(7)	0	(0)	0.010
Gymnocarpium dryopteris	Conif.	0	(0)	11	(12)	0	(1)	0	(0)	0.001
Ribes rubrum	Conif.	0	(0)	8	(12)	0	(1)	1	(6)	0.004
Geranium sylvaticum	Conif.	0	(0)	9	(10)	0	(0)	0	(0)	0.001
Actaea spicata	Conif.	1	(2)	5	(7)	0	(0)	0	(0)	0.030
Ribes alpinum	Conif.	0	(0)	5	(7)	0	(0)	1	(3)	0.030
Dryopteris carthusiana	Mixed	6	(28)	13	(38)	19	(45)	0	(6)	0.029
Trientalis europaea	Mixed	2	(11)	7	(21)	15	(31)	0	(6)	0.038
Molinia caerulea	Mixed	0	(0)	0	(1)	7	(8)	0	(0)	0.025
Dactylis glomerata	**Sm.woodl.**	1	(9)	0	(0)	0	(3)	**30**	**(37)**	**0.001**
Festuca rubra	**Sm.woodl.**	0	(0)	0	(2)	0	(2)	**25**	**(29)**	**0.001**
Poa angustifolia	**Sm.woodl.**	0	(2)	0	(1)	0	(1)	**24**	**(29)**	**0.001**
Anthriscus sylvestris	**Sm.woodl.**	1	(9)	0	(5)	0	(3)	**23**	**(34)**	**0.001**
Taraxacum officinale	**Sm.woodl.**	5	(20)	1	(7)	1	(7)	**21**	**(37)**	**0.001**
Phleum pratense	**Sm.woodl.**	0	(2)	0	(0)	0	(1)	**20**	**(23)**	**0.001**
Vicia cracca	Sm.woodl.	1	(4)	0	(0)	0	(1)	18	(23)	0.001
Poa pratensis	Sm.woodl.	0	(0)	0	(0)	0	(0)	17	(17)	0.001
Aegopodium podagraria	Sm.woodl.	4	(20)	3	(18)	3	(16)	16	(37)	0.005
Galium album	Sm.woodl.	0	(2)	1	(5)	0	(0)	16	(20)	0.001
Elymus repens	Sm.woodl.	0	(0)	0	(0)	0	(0)	14	(14)	0.001
Ranunculus acris	Sm.woodl.	0	(2)	0	(2)	0	(2)	13	(17)	0.001
Ranunculus repens	Sm.woodl.	1	(9)	1	(6)	2	(9)	11	(20)	0.010
Cirsium arvense	Sm.woodl.	0	(2)	0	(1)	0	(0)	11	(14)	0.001
Silene dioica	Sm.woodl.	0	(0)	0	(0)	0	(0)	11	(11)	0.001
Equisetum pratense	Sm.woodl.	2	(7)	0	(1)	2	(8)	9	(20)	0.019
Carex hirta	Sm.woodl.	0	(0)	0	(0)	0	(0)	8	(9)	0.005
Agrostis capillaris	Sm.woodl.	0	(2)	1	(6)	1	(7)	8	(14)	0.025
Rumex acetosa	Sm.woodl.	0	(0)	0	(0)	0	(1)	8	(9)	0.004
Galium boreale	Sm.woodl.	0	(2)	0	(0)	0	(1)	7	(9)	0.005

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Appendix 3 continues

Species	**Forest**	**Decid.**		**Conif.**		**Mixed**		**Sm.wood**		***P***
		IV	FR	IV	FR	IV	FR	IV	FR	
Achillea millefolium	Sm.woodl.	0	(2)	0	(0)	0	(0)	7	(9)	0.002
Alopecurus pratensis	Sm.woodl.	0	(0)	0	(0)	0	(0)	7	(9)	0.002
Alchemilla species	Sm.woodl.	2	(7)	1	(5)	0	(1)	6	(11)	0.030
Galium uliginosum	Sm.woodl.	0	(0)	0	(0)	0	(2)	5	(6)	0.023
Trifolium repens	Sm.woodl.	0	(0)	0	(0)	0	(1)	5	(6)	0.014

Appendix 4. The list of species that have significant variation of indicator value among groups ($P < 0.05$) according to the results of indicator species analysis of linear elements. The indication value (IV) and frequency (FR; %) in particular element type is presented; species whose indication value is at least 20 are marked in bold. “Element” – linear element type where the particular species has the highest indicative value, “Ditch” – ditch verge, “Margin” – grassy field margin, “Road” – road verge, “Tree-bush” – tree-line or hedgerow.

Species	**Element**	**Ditch**		**Margin**		**Road**		**Tree-bush**		***P***
		IV	FR	IV	FR	IV	FR	IV	FR	
Geranium palustre	**Ditch**	**20**	**(41)**	7	(23)	1	11)	2	(13)	**0.001**
Lathyrus pratensis	Ditch	14	(44)	3	(22)	6	(28)	13	(40)	0.004
Filipendula ulmaria	Ditch	14	(25)	2	(8)	0	(6)	2	(10)	0.001
Galium album	Ditch	12	(37)	4	(23)	7	(29)	7	(31)	0.017
Angelica sylvestris	Ditch	12	(29)	6	(21)	1	(8)	3	(14)	0.001
Centaurea jacea	Ditch	11	(29)	3	(14)	4	(16)	3	(14)	0.003
Aegopodium podagraria	Ditch	10	(28)	4	(18)	1	(9)	8	(27)	0.005
Melampyrum nemorosum	Ditch	10	(21)	4	(12)	1	(6)	1	(5)	0.001
Galium boreale	Ditch	10	(16)	1	(3)	0	(2)	1	(4)	0.001
Lysimachia vulgaris	Ditch	9	(25)	6	(21)	1	(10)	3	(14)	0.008
Ranunculus acris	Ditch	9	(21)	2	(11)	1	(7)	4	(14)	0.002
Alchemilla species	Ditch	7	(18)	3	(13)	1	(7)	2	(11)	0.009
Campanula patula	Ditch	6	(14)	3	(9)	0	(2)	3	(9)	0.009
Stellaria palustris	Ditch	6	(12)	1	(4)	1	(4)	0	(2)	0.001
Ranunculus auricomus	Ditch	5	(11)	2	(7)	0	(2)	1	(3)	0.005
Valeriana officinalis	Ditch	3	(8)	1	(4)	0	(2)	1	(3)	0.038
Peucedanum palustre	Ditch	3	(5)	0	(2)	0	(1)	0	(2)	0.019
Leontodon hispidus	Ditch	3	(4)	0	(1)	0	(0)	0	(0)	0.004
Solidago virgaurea	Ditch	2	(3)	1	(2)	0	(0)	0	(0)	0.038
Tragopogon pratensis	Ditch	2	(3)	0	(0)	1	(2)	0	(0)	0.044
Ranunculus repens	Margin	5	(21)	13	(33)	5	(21)	2	(15)	0.002
Deschampsia cespitosa	Margin	8	(23)	8	(22)	1	(7)	2	(13)	0.022
Rubus idaeus	Margin	1	(5)	6	(15)	0	(3)	4	(11)	0.018
Agrostis capillaris	Margin	3	(10)	5	(13)	0	(4)	1	(6)	0.032
Prunella vulgaris	Margin	4	(10)	5	(10)	0	(2)	0	(3)	0.015
Viola canina	Margin	2	(6)	5	(8)	0	(1)	0	(0)	0.005
Juncus effusus	Margin	1	(3)	4	(7)	0	(0)	0	(1)	0.004
Lychnis flos-cuculi	Margin	2	(4)	3	(6)	0	(0)	0	(1)	0.028
Mentha arvensis	Margin	0	(2)	3	(6)	0	(2)	1	(4)	0.041
Populus tremula	Margin	0	(1)	3	(5)	0	(1)	0	(2)	0.008
Pinus sylvestris	Margin	0	(1)	2	(3)	0	(0)	0	(1)	0.021
Oxalis acetosella	Margin	0	(1)	2	(3)	0	(0)	0	(0)	0.023
Taraxacum officinale	**Road**	12	(58)	14	(61)	**30**	**(85)**	12	(58)	**0.001**
Dactylis glomerata	**Road**	11	(51)	9	(45)	**24**	**(70)**	11	(51)	**0.001**
Achillea millefolium	**Road**	13	(51)	7	(37)	**25**	**(69)**	10	(47)	**0.001**
Artemisia vulgaris	**Road**	3	(23)	4	(24)	**20**	**(56)**	15	(46)	**0.001**
Plantago major	**Road**	1	(6)	2	(10)	**20**	**(34)**	1	(10)	**0.001**
Festuca rubra	Road	9	(33)	4	(22)	14	(42)	7	(31)	0.011
Poa pratensis	Road	5	(22)	3	(17)	11	(32)	6	(25)	0.007
Matricaria perforata	Road	1	(8)	3	(13)	12	(31)	5	(16)	0.001
Potentilla anserina	Road	4	(18)	4	(17)	10	(28)	2	(12)	0.011

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Appendix 4 continues

Species	**Element**	**Ditch**		**Margin**		**Road**		**Tree-bush**		***P***
		IV	FR	IV	FR	IV	FR	IV	FR	
Poa annua	Road	0	(2)	0	(2)	12	(18)	1	(3)	0.001
Festuca arundinacea	Road	2	(11)	3	(13)	11	(26)	2	(10)	0.002
Medicago lupulina	Road	1	(5)	1	(5)	10	(21)	4	(12)	0.001
Trifolium repens	Road	2	(10)	3	(14)	9	(23)	3	(16)	0.007
Melilotus alba	Road	0	(4)	0	(3)	9	(17)	2	(8)	0.001
Capsella bursa-pastoris	Road	0	(1)	0	(1)	8	(13)	2	(6)	0.001
Chamomilla suaveolens	Road	0	(0)	0	(2)	8	(10)	0	(3)	0.001
Poa angustifolia	Road	3	(15)	2	(11)	8	(22)	4	(17)	0.028
Trifolium pratense	Road	1	(7)	1	(6)	8	(16)	1	(7)	0.001
Viola arvensis	Road	0	(1)	0	(2)	7	(10)	0	(3)	0.001
Arctium tomentosum	Road	0	(3)	1	(5)	6	(13)	2	(8)	0.006
Chenopodium album	Road	0	(3)	1	(6)	5	(15)	4	(9)	0.035
Heracleum sibiricum	Road	0	(3)	0	(2)	5	(9)	1	(5)	0.012
Carum carvi	Road	1	(4)	1	(3)	4	(8)	0	(1)	0.020
Convolvulus arvensis	Road	0	(2)	0	(1)	3	(6)	1	(3)	0.019
Leontodon autumnalis	Road	0	(2)	0	(1)	3	(5)	1	(3)	0.042
Lamium purpureum	Road	0	(1)	0	(1)	3	(4)	0	(0)	0.009
Fumaria officinalis	Road	0	(0)	0	(0)	3	(4)	1	(3)	0.015
Pastinaca sativa	Road	0	(1)	0	(0)	2	(3)	0	(0)	0.019
Polygonum arenastrum	Road	0	(0)	0	(1)	2	(3)	0	(0)	0.017
Urtica dioica	Tree-bush	6	(29)	10	(37)	3	(21)	17	(47)	0.002
Epilobium angustifolium	Tree-bush	1	(5)	2	(7)	0	(2)	6	(11)	0.003
Silene alba	Tree-bush	0	(3)	0	(3)	1	(6)	5	(9)	0.008
Lamium album	Tree-bush	0	(1)	0	(0)	0	(2)	4	(6)	0.001
Sorbus aucuparia	Tree-bush	0	(1)	0	(2)	0	(0)	3	(4)	0.015
Fraxinus excelsior	Tree-bush	1	(3)	0	(1)	0	(1)	2	(4)	0.049
Luzula multiflora	Tree-bush	0	(2)	0	(1)	0	(0)	2	(3)	0.042