Univerzita Karlova v Praze

Přírodovědecká fakulta

Studijní program: Biologie

Studijní obor: Botanika

Bc. Ondřej Staněk

Vliv vojenského managementu na krajinu a vegetaci Dokeska

Influence of military activities on vegetation diversity in Doksy region

Diplomová práce

Školitel: Mgr. Jaroslav Vojta, Ph.D.

Praha, 2013

Prohlášení:

Prohlašuji, že jsem závěrečnou práci zpracoval/a samostatně a že jsem uvedl/a všechny použité informační zdroje a literaturu. Tato práce ani její podstatná část nebyla předložena k získání jiného nebo stejného akademického titulu.

V Praze, 6. května 2013

Podpis

Chtěl bych zde poděkovat všem, kdo mi při vypracování mé diplomové práce jakkoliv pomáhali. Především školiteli Jaroslavu Vojtovi, dále Petru Petříkovi a Jiřímu Sádlovi za cenné rady při vymýšlení designu celé práce. Poděkování patří také Megan Ginder za obětavou pomoc při korektuře rukopisu v anglickém jazyce.

Děkuji.

1. Abstract

The thesis focuses on description of specific area of Doksy region, situated in northern Bohemia. This region was affected by fifty years of military management. Vegetation composition, species richness and several environmental characteristics were measured and statistically tested to determine the effect of military area on landscape and vegetation. No significant difference in species richness, but important changes in species composition were discovered. Also the environmental (soil) characteristics of the area were probably changed by the military history of landscape. There were no major changes in Beta diversity uncovered, probably because of different management leading to the same resulting changes applied in the landscape. Also four invasive plant species were found in high numbers present in the area connected with past military land-use.

Key words: Disturbance, Military management, Beta-diversity, Soil changes, Invasive plants

2. Abstrakt

Práce je důkladnou studií oblasti Dokeska na severu čech. Tato oblast byla v historii ovlivněna existencí vojenského prostoru Ralsko a po více než 50 let byla vystavena vojenskému managementu. Pro účely určení vlivu vojenského managementu byla sebrána data o složení vegeatce a druhovém bohatství a také o některých charakteristikách prostředí. Vše bylo prověřeno různými statistickými technikami. Nebyl objeven žádný signifikantní efekt vojenského využití v minulosti na počet druhů, ale byl prokázán efekt na složení vegetace. Také některé charakteristiky prostředí (především půd) stále nesou čitelné stopy vojenského zacházení. Žádné výrazné rozdíly v Beta diverzitě vojensky využívaných a nevyužívaných ploch zjištěny nebyly, zřejmě z důvodu různých procesů působících homogenizaci na úrovni beta diverzity. Také bylo zjištěno několik druhů ze seznamu invazních a expanzivních druhů MZE ČR vyskytujících se na území ve větším množství, pravděpodobně vázaných na vojensky obhospodařované plochy.

Klíčová slova: Disturbance, Vojenský management, Beta diversita, Půdní charakteristiky, Invazivní rostliny

3. Introduction

3.1. Man and disturbance in landscape

3.1.1. Forest and woodless islands

Woodless areas in the temperate continental landscape of central Europe and their persistence is a phenomenon that has been discussed by many scientists for years. There are, of course, generally known large temperate steppes in North America or in not so far Hungary and Ukraine. However the presence of woodless areas in the deep forests of the Holocene era has always been a question. There are different opinions on the persistence of such islands of woodless landscape in oceans of original forest (Olff *et al.* 1999). One thing that can hardly be doubted is the important role of man in creating and transforming the landscape. Since the Mesolitic era, with major development occurring in the Neolitic and continuing on until modern time, the pressure of human influence has been growing (Sádlo *et al.* 2005).

3.1.2. Human impact in landscape

People have always been using their environment for various activities necessary for life. Especially from the first settlements until the end of middle age a continuous deforestation took place up to relatively high mountain peaks. The impacts of such practices on the central-European landscape were rather severe. Deforestation was initiated for lumber harvesting, to free more arable soil or just for the feeling of safety among the inhabitants. The newly created woodless areas were then maintained by plowing, farming, animal grazing or human labor with other motivation. Some places were abandoned from time to time and underwent natural succession. Elsewhere new forest clearings were made creating a heterogeneous landscape mosaic. Human impact persists until today, when almost everything in the European landscape is driven by man-induced processes. Land management priorities are nowadays shifting from agricultural needs that are lowered because of high effectiveness and import from abroad to recreational, industrial and military uses.

3.1.3. Intermediate disturbance hypothesis

A classic British study describes the impact of different disturbance regimes on landscape diversity using the so called Intermediate Disturbance Hypothesis (Connell 1978). It states that disturbances of intermediate strength and extent, (on the scale from small local damages to massive catastrophes of large extent) are most beneficial to species diversity. This hypothesis has been tested in many studies (Malmivaara *et al* 2002; Rejmanek *et al* 2004) and nowadays is considered classic. It belongs to the basics of modern ecology.

3.2. Military areas and Military management

3.2.1. History

When discussing different types of landscape management in history It is necessary to mention a major phenomenon of modern history from the twentieth century. Especially in central Europe, many military training areas were created that occupied a considerable part of land. There are eight large training areas in Czech Republic including three abandoned in 1991, when the Soviet army left Czechoslovakia. This is also the case in Ralsko military area, which will be discussed further on in this thesis. In these military areas all civil inhabitants were removed and forbidden access to the area. Former villages were usually destroyed, and nowadays, barely visible ruins can be seen. This part of the land became different and started a new chapter in its development, separated from the surrounding cultural landscape. Instead of typical agricultural use, various kinds of military practices were applied, influencing the nature in a rather atypical way.

3.2.2. Major types of military management

The main interest of the study lies in changes triggered by management after the area was separated for military use only. How exactly were training grounds used and where can one get the information? According to historical sources, photographs and present army trainings the main activities can be assessed. Surely the most widespread and studied aspect of military land use is vegetation and soil trampling caused by tracked and wheeled vehicles. This is usually the major disturbance factor, but not the only one. Various kinds of ditches and trenches (including tank hideouts) were dug during training. In some specialized areas explosive ammunition (including aircraft ammunition) was tested, leaving craters with a diameter of several meters. There were also other kinds of disturbances, harder to identify nowadays because they have not damaged the soil or caused permanent visible changes. These could be due to foot trampling during training or marching soldiers or any increased human traffic in proximity of specialized facilities. Some of these facilities can be identified from historical photographs, such as military airport or accommodation quarters. These also had different effects on the land.

The human impact in military areas can be divided into two major groups: 1) severe disturbance causing vegetation destruction, soil compaction and terrain changes and (2) in contrary increased nutrient flow to the ecosystem at the proximity of military bases, combined with milder disturbances. These two are very different and need to be clearly separated in analyses or treated one at a time. This study will focus only on the first.

There are multiple ways to determine the exact military management practices in Ralsko. First, there is a relatively good record of aerial photographs, giving idea of actual land use practices in the area. Most of the damages to soil and major damages to vegetation are visible from the photographs. A second way of understanding is through simulation of actual impacts by similar machines still in use. Many studies have observed tank tracks and wheeled vehicles effects on soil and vegetation (Dickson *et al.* 2008; Althoff *et al.* 2009). Nevertheless studies quantifying other ways of military disturbance, such as bomb craters, fighting trenches or aircraft landing have not yet been done (as to authors knowledge).

3.2.3. Impacts of military disturbance to soil and vegetation

There are basically two main approaches to studying military disturbance in connection with vegetation. Some studies are sustainability and land-management oriented (Prosser *et al* 2000; Althoff *et al.* 2009; Abella 2010). These are mainly financed by ministries of defense, and are, therefore, more focused on assessing the extent of vegetation loss and the time needed to restore the green cover in order to maintain the land usable and stable for more training. Some studies show interest in particular plant species (Prosser *et al.* 2000), evaluating their changes in abundance. Such studies are not usually concerned in species richness or vegetation composition, but soil compaction and erosion (Guretzky *et al* 2006). The other kind of studies, that are much less frequent, is focused on species richness changes following disturbance (Leis *et al.* 2005; Warren *et al.* 2007; Jentsch *et al.* 2009). These reveal that immediately after disturbance, species richness grows from low numbers up to high, sometimes even richer than original grassland before disturbance. The basic idea leads to the intermediate disturbance hypothesis (Connell 1978), tested on military grounds and suggesting intermediate military disturbance regime to increase plant diversity. Leis et al. (2005) also emphasizes the importance of intermediate strength of disturbance regime. Their data show diversity declines at high levels of disturbance. In contrary to this observation, Warren et al. (2007), based on experience from German training areas Grafenwöhr and Hohenfels, suggests his heterogenous disturbance hypothesis, emphasizing the variability in strength, duration and extent of disturbances, as the drivers of species richness.

In general, the idea of increasing the number of species in an ecosystem by creating patches of different successional stages seems logical. More niches in time and space are created and more specialists can be involved in the system. The question is: where do the new species enriching community come from? Some studies emphasize potential danger in the role of invasive plants in colonization of disturbed sites (Milchunas *et al* 2000). In the short-term perspective they might increase the number of species, but their colonization mechanisms can irreversibly damage the ecosystem outcompeting valuable native species. There have been studies focusing on immediate impact of military vehicles on soil and vegetation, but now the real questions are whether there are any permanent changes left after the army disturbances and how long it takes to regenerate. Considering the time dimension of these processes, some studies tried to quantify the extent of species richness recovery (Hirst *et al.* 2005) on grasslands of different age (time since disturbance) up to 50 years. Besides chronosequence (used in above mentioned study), other approaches of estimating past disturbance intensity were used such as measuring the amount of soil organic matter as approximation of past disturbance / vegetation removed (Leis *et al.* 2005). These studies describe the legacy of past disturbance in varying intensity and time of persistence on different kinds of soil. This thesis will add another perspective to the issue in of vegetation changes following disturbance and their stability in time and clarify the problem in Czech geographic and environmental conditions.

3.3. Processes on different spatial scales

When exploring disturbance in nature, it is important to notice that different kinds of processes can be responsible for changes in nature. Vast variability in causes also brings variability in sizes and intensity of plant community responses. Some patches can be colonized vegetatively from the nearest neighborhood. Some require such adaptations as resistant seeds, increased seed mobility or even some kind of specialized aimed transport by animals.

3.3.1. Scales of military disturbances

When considering military disturbance, different scales of observation might be appropriate. Some areas seem homogenized by tracked vehicles disturbing in the same way for hundreds of meters. In general they can be considered very homogenous for they usually consist of huge grassland, more or less regularly disturbed for half century. Microhabitats are also created during such activities. Besides general vehicular disturbance of bigger grain, smaller objects, such as bomb craters or tank trenches, are also created during training (Demarais *et al.* 1999). Such special features in the meadows create microhabitats with slightly or even vastly different conditions, mainly regarding wetness and light exposure (personal observation). This kind of mosaic-like heterogeneity in the landscape tends to promote species richness and higher quality of ecosystem services for all participants, including birds (Reif *et al.* 2011), insects and soil microfauna (Althoff *et al.* 2007). This idea of creating and sustaining irregular disturbance regime leading to such a mosaic is developed in the work of Warren et al. (2007). They argue that the main factor involved in increasing species richness is heterogeneity, not just regular disturbance.

3.4. Secondary succession of abandoned grasslands

3.4.1. Diversity loss by competition

Grasslands, in general, are not considered a climax stage of ecosystem in central Europe. They are, in most cases, kept in a dynamic state of ongoing succession, while regularly occurring disturbances hold the system from permanent change. As mentioned before, in the present time of massive regulation of natural processes, man plays the role of main disturbing agent. Since agricultural grasslands, pastures or military grounds have been abandoned recently, there is plenty of occasions to observe changes of community structure and even species richness of such meadows. In the study of the abandoned *Calthion* type hay meadow in Germany (Rosenthal 2010), a major increase of canopy height and litter cover was observed, excluding less competitive species. Especially when observed in smaller grain, strong competitive clonal grasses and high plants tend to rapidly overtake the dominance in community and form big patches of dense canopy leaving almost no light in the understory (Dupre & Diekmann 2001; Pottier & Evette 2010).

3.4.2. Time factor of succession

In cases like this, time dimension of such successional changes is important knowledge for the general understanding of the system and potentially for successful conservation management. After mowing ceased in wet meadows, it took only cca four years for major canopy height to increase and another four years to loose about half of the species present (Rosenthal 2010). Compared to the study from the Sonoran desert (USA), focused on military use connected to disturbance, the wet meadow succession progressed much faster. In this extremely arid, desert, grassy environment, the vegetation cover loss was distinguishable even after 56 years (Kade & Warren 2002). Such vast differences show the necessity of better knowledge of the system and also the need of thorough study on this topic in many different environments.

3.4.3. Calamagrostis epigejos

One of the competitive clonal grasses expanding in grasslands and various ruderal habitats is *Calamagrostis epigejos*. Despite its native status in Czech Republic, it tends to spread expansively, changing (light) conditions and occupying whole patches of land (Rebele & Lehmann 2001). It seems to favor all kinds of patches without established grassland community, which are abandoned and left to succession. Than, it spreads vigorously and reduces species richness (Pottier & Evette 2010). Mowing study showed its relative sensitivity to this kind of management allowing radical lowering of its cover after eight years of treatment (Házi *et al.* 2011). However, the decrease started after two years. On spots with eradicated *C. epigejos* species diversity rose again.

3.5. Military area Ralsko

One of the suitable environments for such studies is the military area Ralsko, situated in northern Bohemia, Czech Republic. With its temperate continental climate the conditions are somewhere in between the above-mentioned cases, not very humid and not too dry. The area was subject to intensive use by Czechoslovak and Soviet armies in the past hundred years and abandoned twenty years ago.

The military disturbed grasslands are surrounded by deep forests in the middle of sandstone pseudokarst area. The forest is considered to be the south-westernmost relict of boreal taiga in central Europe (Novák *et al* 2012). One of the factors responsible for the taiga-like character of nature might be the nutrient poor sandy soils found in the area. Therefore, the impact of these soils on the grassland vegetation should be studied, and whether it is truly so restricted in nutrients as thought.

4.Scientific questions

1. Is there any difference in species richness between military training grounds and undisturbed grassland?

2. What is the floristic difference between military grounds and managed grasslands?

3. What are the main gradients present in vegetation structure? What might be the most important drivers?

4. Are there any differences in vegetation structure and species richness observed on different spatial scales? What processes might be involved?

5. What is the variability of soil properties in connection with military management? Could the soil be somehow influenced?

6. What is the effect of past disturbance on invasive plants?

7. Is *Calamagrostis epigejos* bound to military disturbed grasslands, or are there any patterns in its distribution?

5.Methods

5.1. Study site

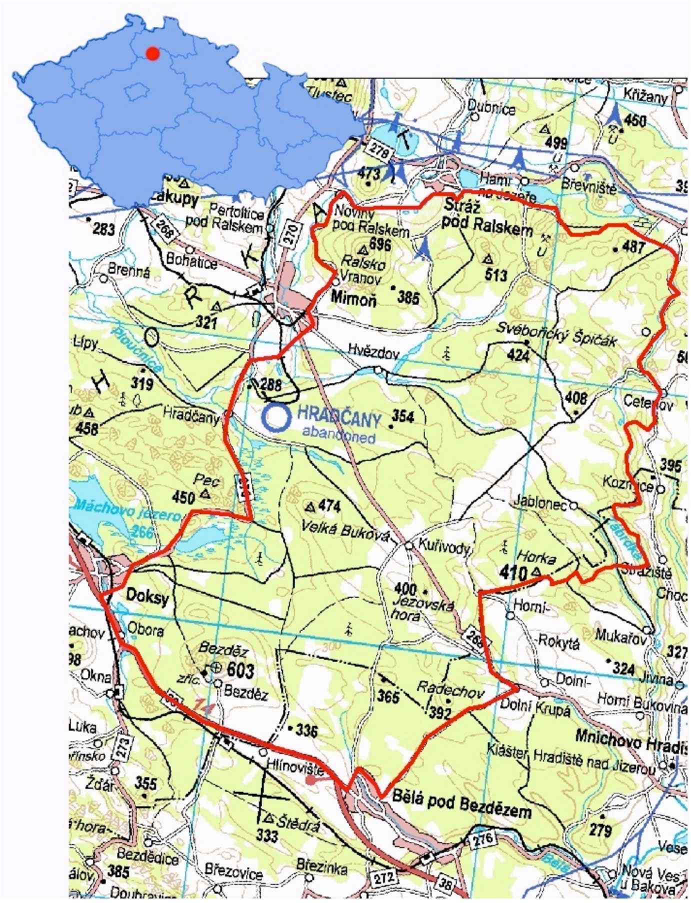

Fig. 1. Map of military area Ralsko.

The study took place in northern Bohemia, Czech Republic in the Doksy area close to Mimoň and Doksy (Fig. 1). The object of study, the military area Ralsko, covers an area of approximately 250 square kilometers. It is a rather flat plateau with large areas of pine forests. Mean annual precipitation is 635 mm, but only 364 mm in the growing season. Mean annual air temperature is 7.3°C, and the climate is of continental character with hot summers and harsh cold winters (Novák *et al.* 2012).

The military training area was officially founded in 1950 but had been used for training purposes and aircraft landing by German army during World War II. In 1968, the area was overtaken by occupying Soviet forces. Houses, garages and ammunition storages were built for approximately 20,000 soldiers. The Red army left the area in 1991, and the military area was officially abolished (zanikleralsko.cz). Since that time, the landscape has been left mainly unmanaged. In 2001, the game preserve Židlov was established in part of the area.

5.2. Sampling design

Vegetation data were collected by sampling triplets of reléves located on points generated in ArcGIS (ESRI 2011). The triplet design of sampling points distribution was chosen to cover vegetation variability on multiple spatial scales. A similar sampling design was used in the master thesis of Miloš Kubát (2010). First, I picked all the military grasslands in the area based on characteristics visible on aerial photographs from 2001. These area points were randomly distributed with constrains assuring even distribution in smaller grassland polygons. To assure even distribution of control points on grasslands not used for training purposes, they were generated as paired to those from former training ground in distance up to 1500 meters. A few (up to ten) points were additionally generated (required as a substitute for some unsuitable sampling localities such as bushes, inaccessible areas, unexpected forests etc.). Afterwards the distribution of points and their management category (training ground, undisturbed meadow) were checked according to aerial photographs from three different times in history (years 1953, 1971 and 1989), covering the whole military history of the area.

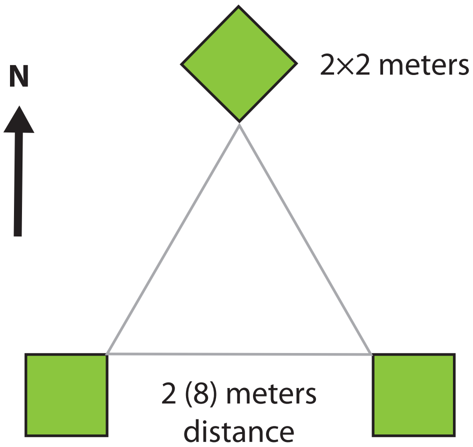

Fig.2. Triplet sampling design. Green squares – sampled plots, grey lines show distances between each sample. A triplet like this was placed on each sampled point.

The reléve triplets of each sampling locality were in a triangular pattern oriented to North, West and East (fig. 2) with inner distances between reléves of two or eight meters. The reléves area was four square meters. Species list was made with percentage cover values (estimated by single person sampling), 252 species of herbs and juvenile trees. These were determined using the nomenclature of Kubát et al (2002). For each sample, recent disturbances, slope angle, percentage cover of rock and of anthropogenic waste / rubble were also noted. Overall 273 reléves were sampled, 147 on training grounds and 126 on unmanaged grasslands. The two levels of inter sample distance were 46 and 45 triplets with a distance of two and eight meters combined in both types of management. For spatial analysis use, data points were divided into 10 spatial clusters (Fig. 3.) based on proximity and similarity of conditions.

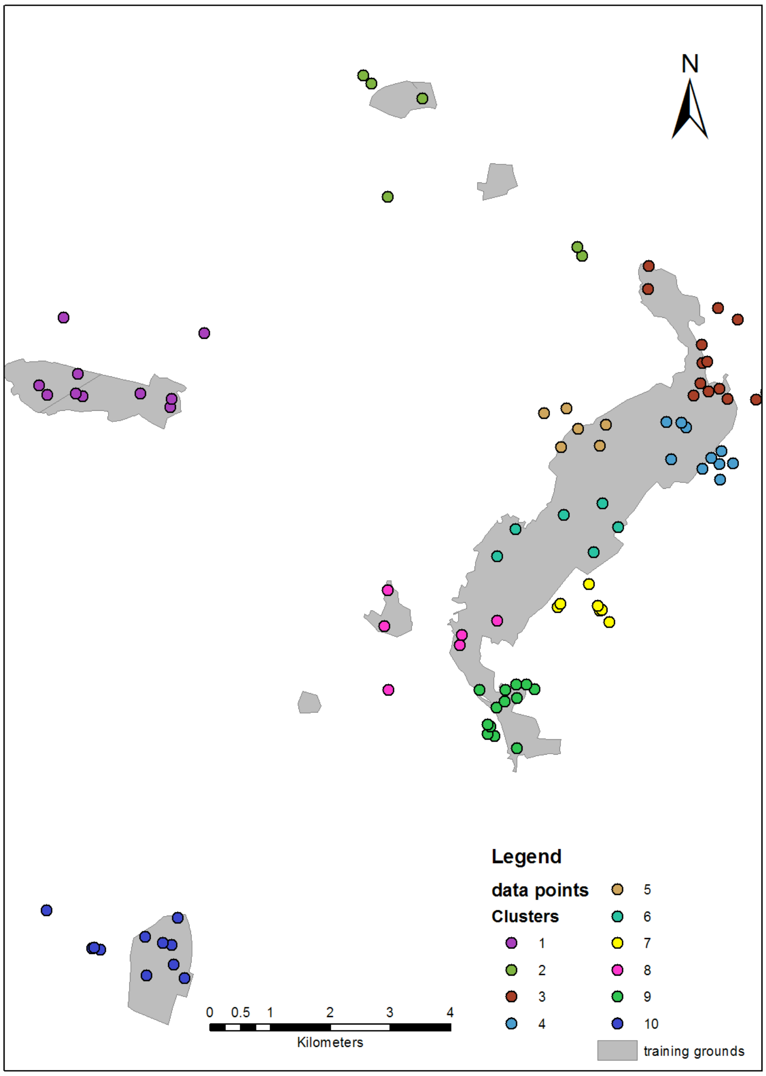

Fig. 3. Sampled points divided into 10 clusters created an arbitrary base of proximity of points. Points situated in the grey field are training ground points. The rest are meadow points.

More environmental data was calculated from elevation maps and aerial photographs using ArcGIS (ESRI 2011). The elevation data was transformed into a digital elevation model (DEM) Based on this information, the topographical wetness index was calculated using GRASS GIS 6.3. (GRASS Development Team 2008). The values of the wetness index were interpolated for points from the model.

The level of disturbance was also quantified using historical aerial photographs from 1989 (two years before abandonment). Inspired by Hirst et al. (2000) The raster was classified for two levels (disturbance and undisturbed, Fig. 4.) and then calculated the sum of cell values in buffer zones 20 meters from each data point. This method corrects for possible mistakes in assigning points to past military land-use class and quantifies the level of disturbance.

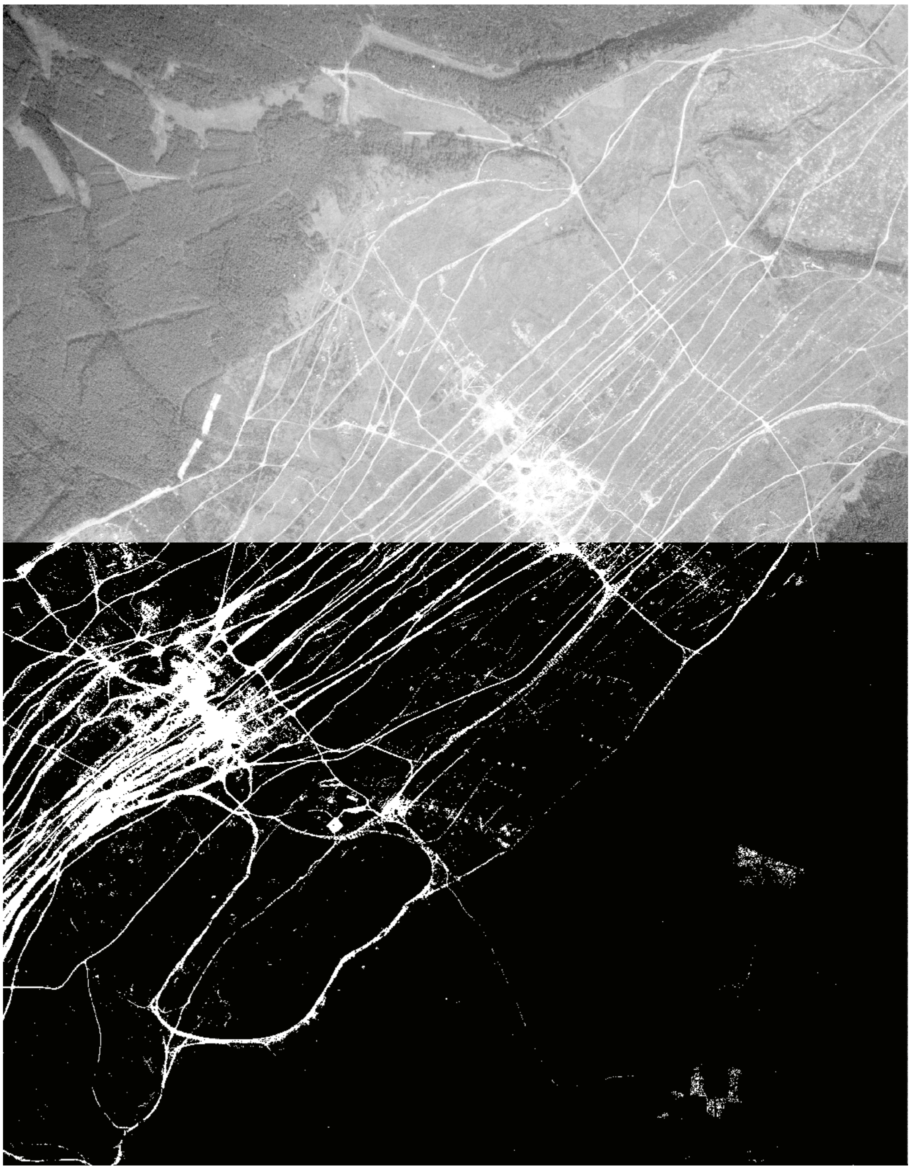

Fig. 4. Classified raster (lower half) used to quantify actual disturbance from aerial photographs from 1989 (upper half).

For some analyses, subsets were used because of incomplete datasets for soil analyses, data point exclusion, or loss from various reasons.

5.3. Soil Chemistry

From 80 points 240 soil samples were collected; one sample collected from the center of each reléve square. Soil samples were taken approximately 15 cm bellow the surface. Back in the laboratory, samples were dried and sieved to 2 mm particles, part of the soil to 0.1mm. In the

Department of Botany's laboratory soil reaction was measured in a solute of 0.1 M potassium chloride (KCl) using calibrated electrode (WUW, type: SenTix 41). For the rest of the analyses, soil samples were sent to the Analytic Laboratory of the Institute of Botany ASCR.

For C and N elemental analyses, a known quantity of soil was burned in a stream of clear oxygen (temperature 1020°C) in the presence of Cr_20_3 catalyzer, using Carlo Erba NC 2500 analyzer. Created oxides of carbon and nitrogen were lead through a reduction tube (650°C, filled with Cu) to a separation column where water and carbon dioxide are separated using helium as a medium gas. The amount of separated oxides is assessed by a conductivity detector. For evaluation, Clarity Lite fy CE Instruments software was used.

For an assessment of exchange, a phosphorus soil sample was extracted with Me III solute (5g of soil to 50ml). After filtration the assessment was done using Olsen's method (Olsen 1982). Based on the reaction of phosphates with $(NH_4)_2MoO_4$ using a reaction mixture with sulphuric acid, ascorbic acid and antimony potassium tartrate. Absorbance of achieved color was measured by UV-vis spectrometer Unicam UV-400 at 630 nm.

All analyses results were recalculated for the dry matter of the soil sample.

5.4. Statistical Analyses

To answer the basic question of how plant diversity is influenced by military land management, different parts of diversity as Alpha and Beta diversity needed to be explored. For Alpha, a plain number of species per sample and Shannon's index were used and then tested for the influence of past management. For calculating Beta diversity, many different approaches have been discussed in the last decades (Tuomisto 2010a; b; Anderson 2011).They are either based on Whittaker's original multiplicative relationship of diversity partitions (Whittaker 1960) or on more recent additive relationship (Lu *et al.* 2007). The third main way to quantify Beta diversity is vegetation distance indices. The Jaccard index and the Bray-Curtis index were chosen since they are easily interpretable and suitable to assess beta diversity in a triplet. For each triplet of reléves the average value of both indices and the classical Beta diversity sensu Whittaker ($\beta = \alpha / \gamma$) were calculated. One-way ANOVA was employed to compare the training grounds and unmanaged grasslands in Alpha and Beta diversity.

To examine species fidelity in areas with different kinds of historical management, their frequency in both types of habitats was used. Fidelity was calculated as the difference between the expected and the observed species frequency and was tested by Chi^2 test.

In order to describe vegetation composition and to discover some of the gradients present in the data, the R-package vegan was used (Oksanen *et al.* 2013) to perform two kinds of ordinations. First, canonical correspondence analysis was done using measured environmental constraining variables. The second ordination was DCA with displayed sites and centroids of the two management groups to show how distant or overlapping they are. The third ordination was DCA with fitted Ellenberg Indicator values. The fit of values was tested by a permutation test (with 999 permutations).

Assessments concerning the proper observation scale for processes affecting the area needed taking a closer look at on three different scales. The first scale concerned clusters of data points based on spatial proximity. Differences in species richness and Beta diversity amongst them were tested using ANOVA and Tukey's Honestly Significant Difference test. These tests assessed which are the clusters differing from others. Beta diversity of clusters was also explored with Kruskal-Wallis test (because of non-normal data distribution).

Secondly, statistical testing of different sized of sample triplets (there were 2m distances and 8m distances amongst samples) for their overall species richness was done using Gamma diversity in triplet and ANOVA. Exploring relationships on different spatial scales was also done by comparing the vegetation distance matrix with geographic distance matrix of the points, using Mantel's test.

For soil analyses results, the Multiple-way ANOVA model was fitted using stepwise selection of variables (both forward and backward) to determine main predictors of species richness amongst soil characteristics. The soil reaction and its correlation with species richness was tested using a linear regression model. To understand the variability partitioning, the linear models of soil properties explained by geographic points were examined and R squared was used to quantify variability explained by triplet and the rest (between triplets variability).

Based on a list of invasive and expansive species from the Czech Ministry of Agriculture (MZE ČR 2005), four invasive species were determined and tested for their frequency on the training grounds as well as for correlation with disturbance intensity. This was done using Kruskal-Wallis rank sum test.

Graminoid plants were also tested using Kruskal-Wallis test. It was compared, what percentage of all species consisted of grasses in samples from training grounds and from meadows.

For a summary of all tested variables and their relationships, correlation coefficients were calculated. Spearman's rank correlation coefficient was used because of its suitability even for data with non-normal distribution.

6. Results

6.1. Species diversities

Plant species richness of grasslands with different management history does not show any significant difference in Alpha diversity or Beta diversity (Fig 5. and 6.). The three indices used to quantify Beta diversity show slightly different results, but neither one shows a difference in the two datasets.

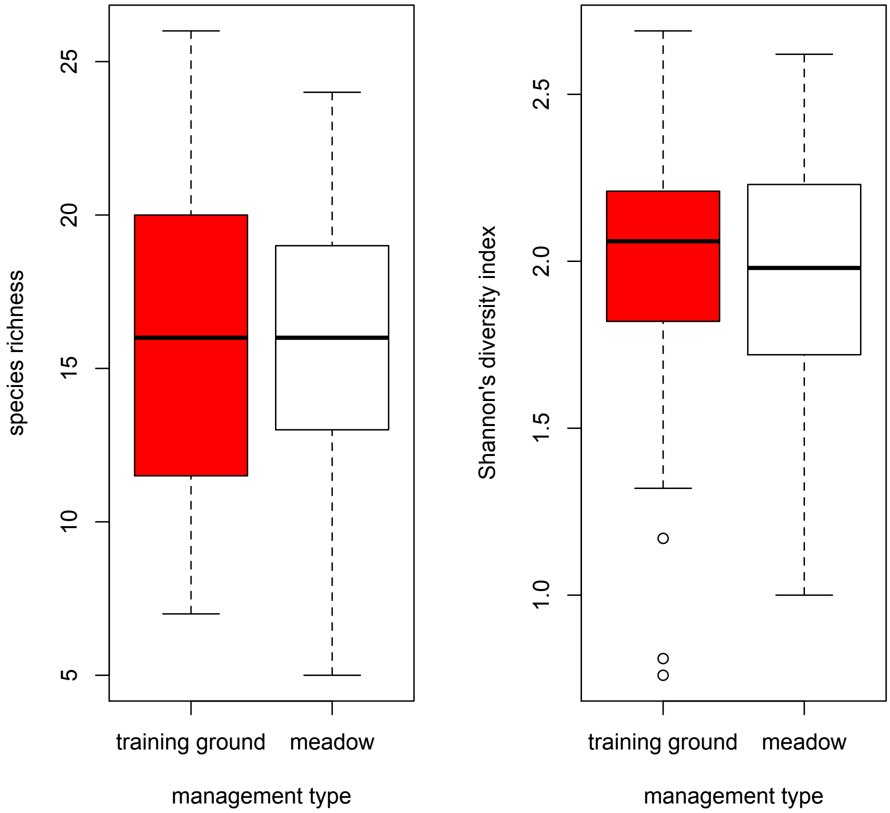

Fig. 5. Alpha diversity for different habitat types. Plain number of species per sample (left boxplot) and Shannon's diversity index (right boxplot) were used. Neither of them is significantly different.

Besides the two management categories, the linear regression of the three diversities (Alpha, Beta and Gamma, according to Whittaker's concept) and disturbance intensity index was done. The statistical testing (Kruskal-Wallis) did not show any significant relationship with either one of the three diversities (Fig. 7.).

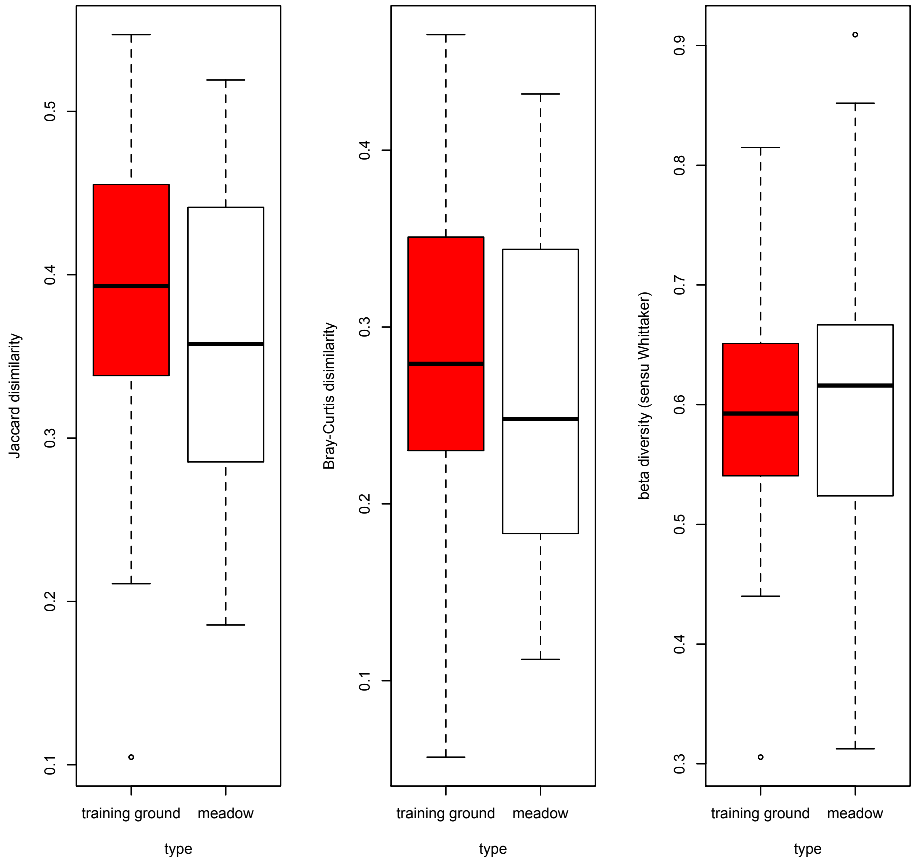

Fig. 6. The three indices of Beta diversity (Jaccard and Bray-Curtis dissimilarity and classical Whittaker's Beta diversity). The differences between past managements are not significant.

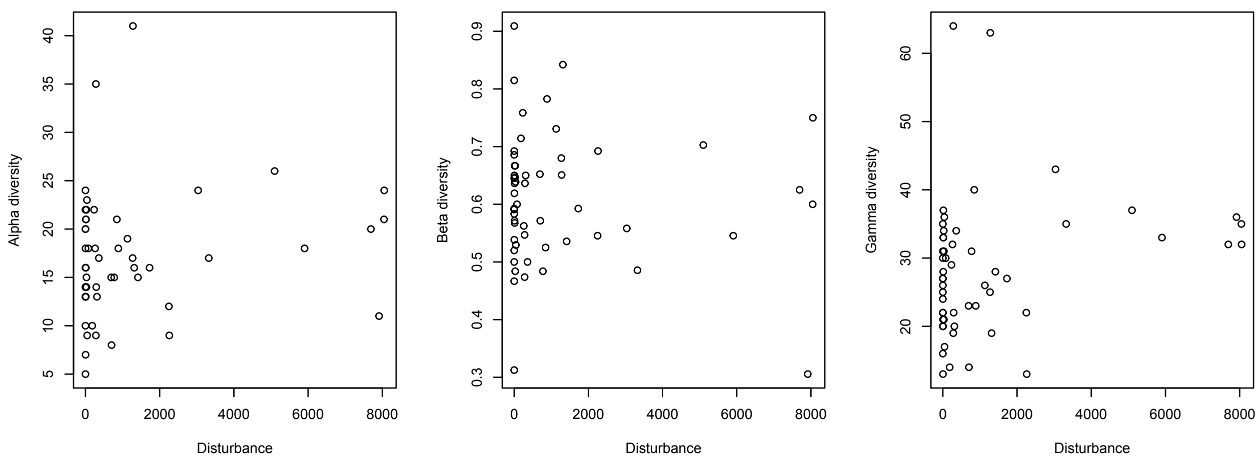

Fig. 7. The three diversities plotted against disturbance intensity in training grounds and meadows together. They yield no significant correlation (tested with Kruskal-Wallis nonparametric test).

6.2. Floristic characteristics

In training grounds and undisturbed meadows some species are more frequent. They may be considered bound to this kind of habitat. Species fidelity to a certain type was calculated as the difference between expected and observed occurrence (Fig. 7.). The distribution of species and their fidelity was tested by Chi^2 test ($p < 0.001$). Some of the species with the highest values bound to training grounds were *Calamagrostis epigejos, Galium album* or *Lupinus polyphyllus* (with only one occurrence on undisturbed meadow!). On the other side of the gradient, such species as *Hypochaeris radicata, Crepis biennis or Trifolium repens* can be found.

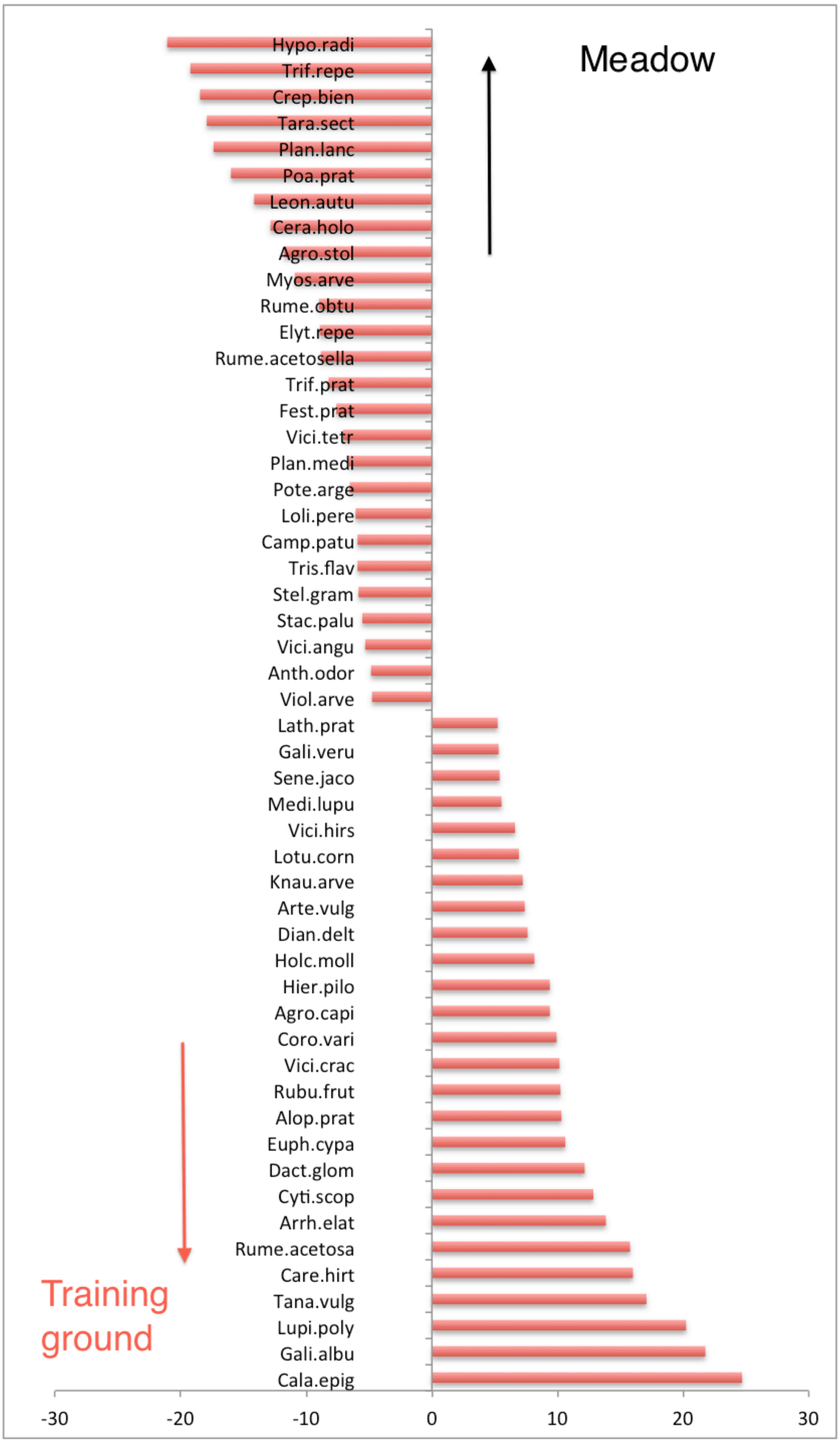

Fig. 8. Species fidelity plot. Top twenty-six species with highest fidelity for each type of samples are shown.

6.3. Vegetation gradients

Describing gradients present in the nature of Doksy region and the former military area Ralsko using ordination methods yielded some interesting information. Canonical correspondence analysis showed the main environmental predictors in composition of grassland vegetation. The first two (constrained) axes in CCA explained 4.3 % and 3.0 % variability in data. The first unconstrained axis explained 8.3 % variability (Fig. 9).

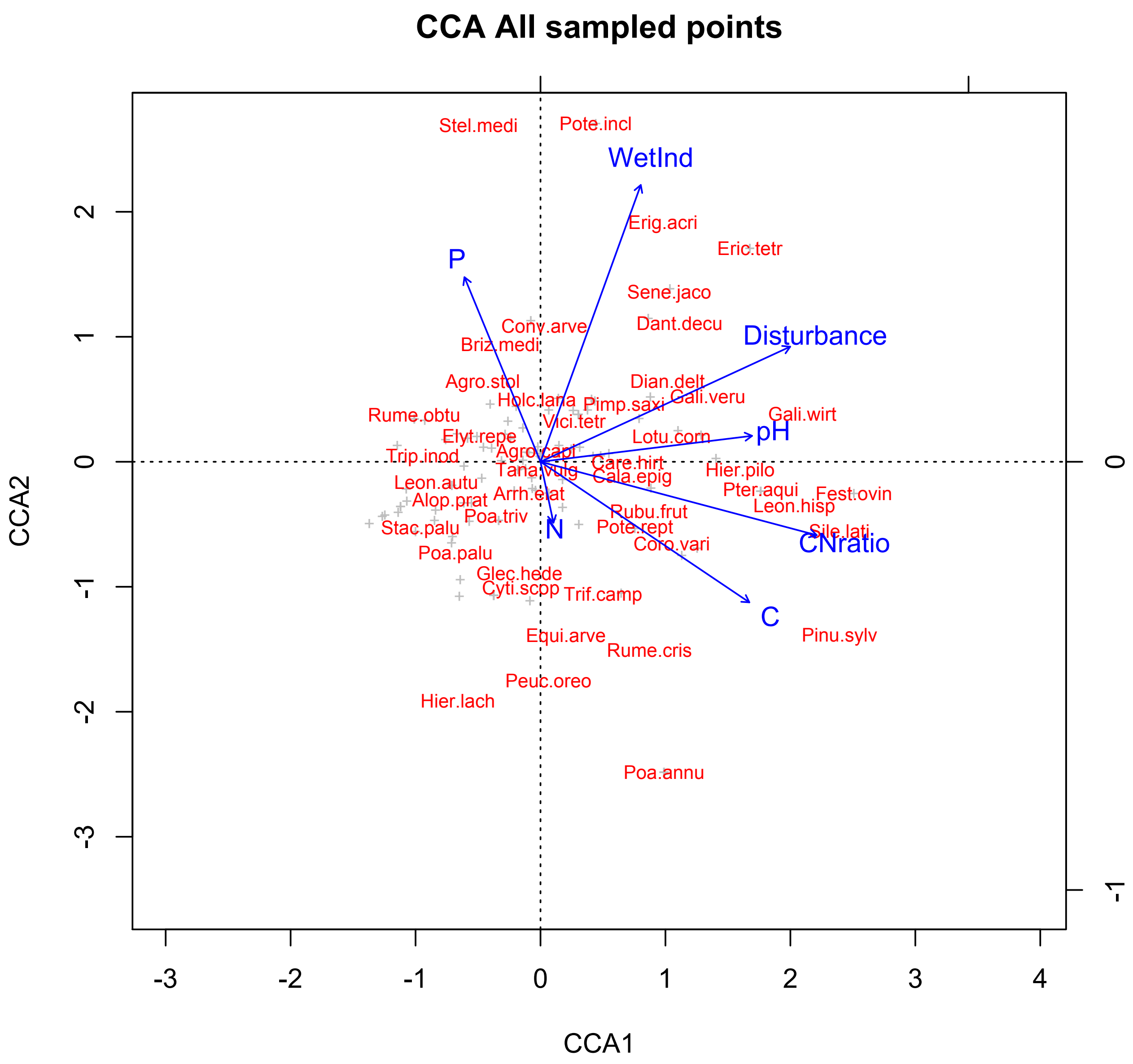

Fig. 9. CCA ordination of vegetation data. Most frequent species are displayed in red font, less frequent are displayed as grey "+" (for better readability of plot). First (constrained) axis explained 4.3 % of variability and first unconstrained explained 8.3 %.

For comparison the results of the same CCA analysis for the subset of samples from the training grounds only are shown (Fig. 10).

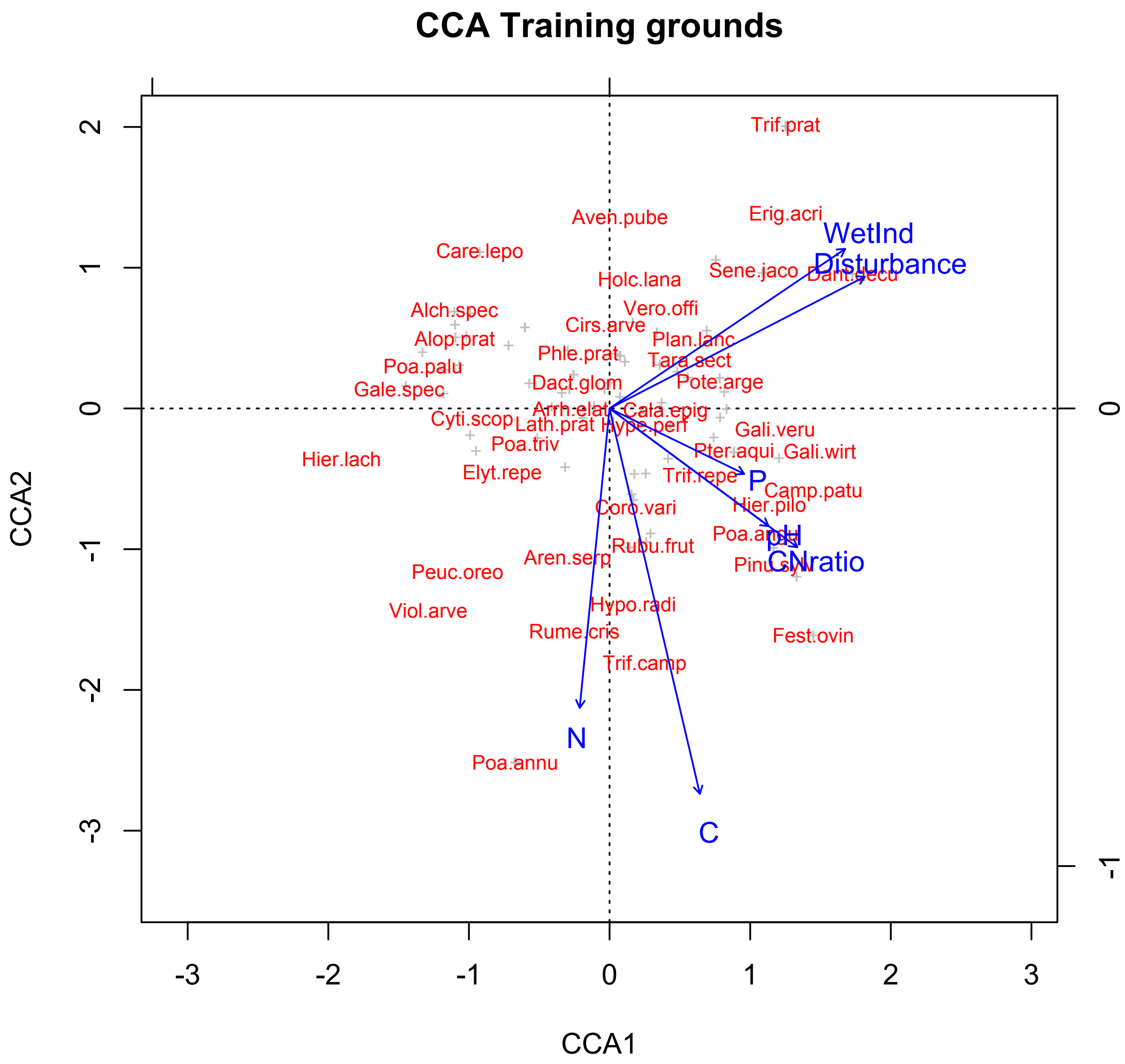

Fig. 10. CCA ordination of vegetation data. Most frequent species are displayed in red font, less frequent are displayed as grey "+" (for better readability of plot). First (constrained) axis explained 6.8 % variability and first unconstrained explained 7.1 %.

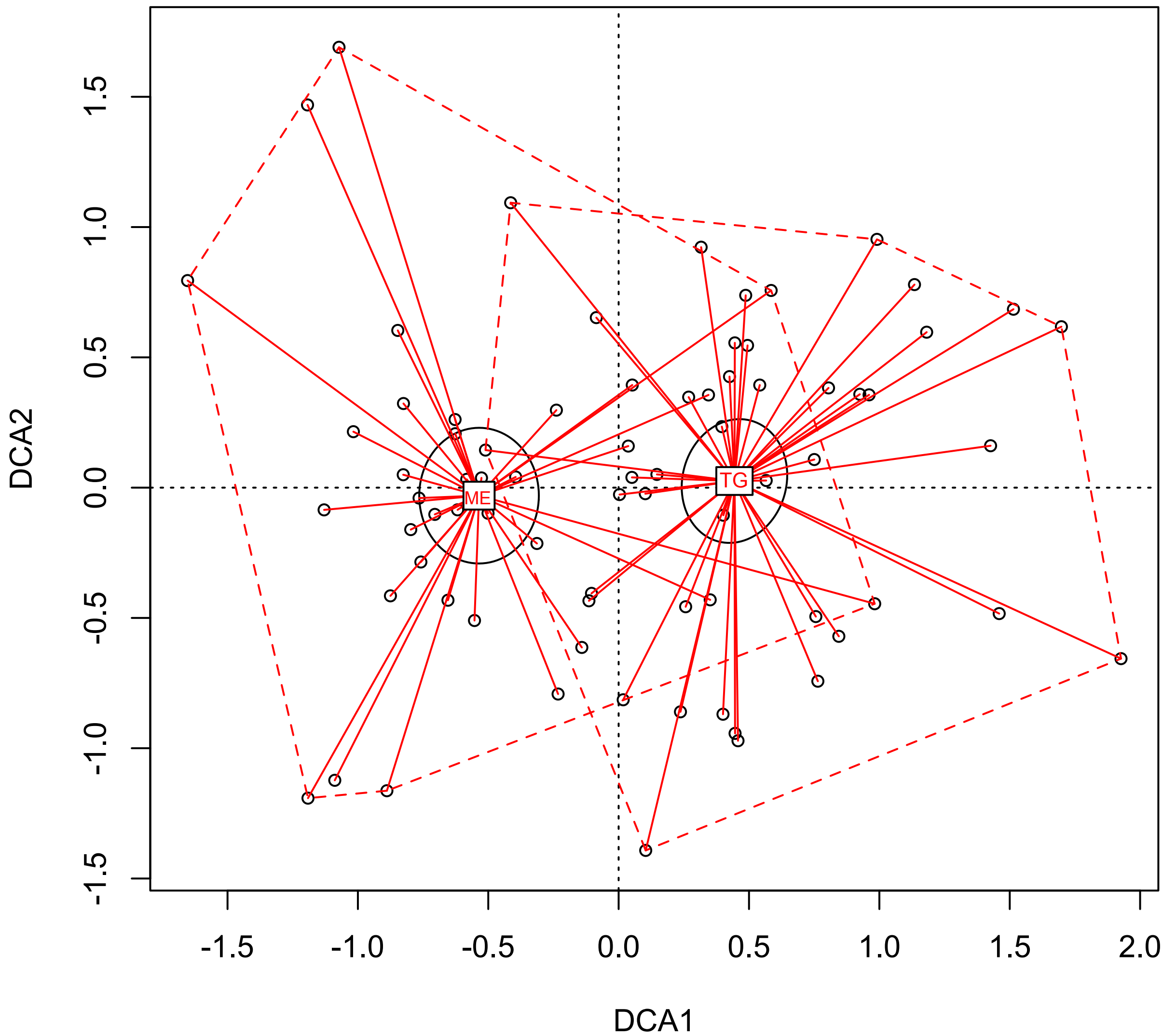

Fig. 11. DCA ordination shows sites of two management types: TG – training grounds and ME – meadows. Centroids of the two groups are displayed with their standard errors (black ovals). The management as the projected variable is significant (p = 0.001).

It was also tested for the effect of military management on vegetation structure by fitting the environmental variable (management factor) on DCA ordination with square root transformation (Fig. 11.). The goodness of fit was tested by a permutation test with 999 permutations yielding p-value 0.001. The two centroids of vegetation groups are not overlapping, and the groups differ significantly.

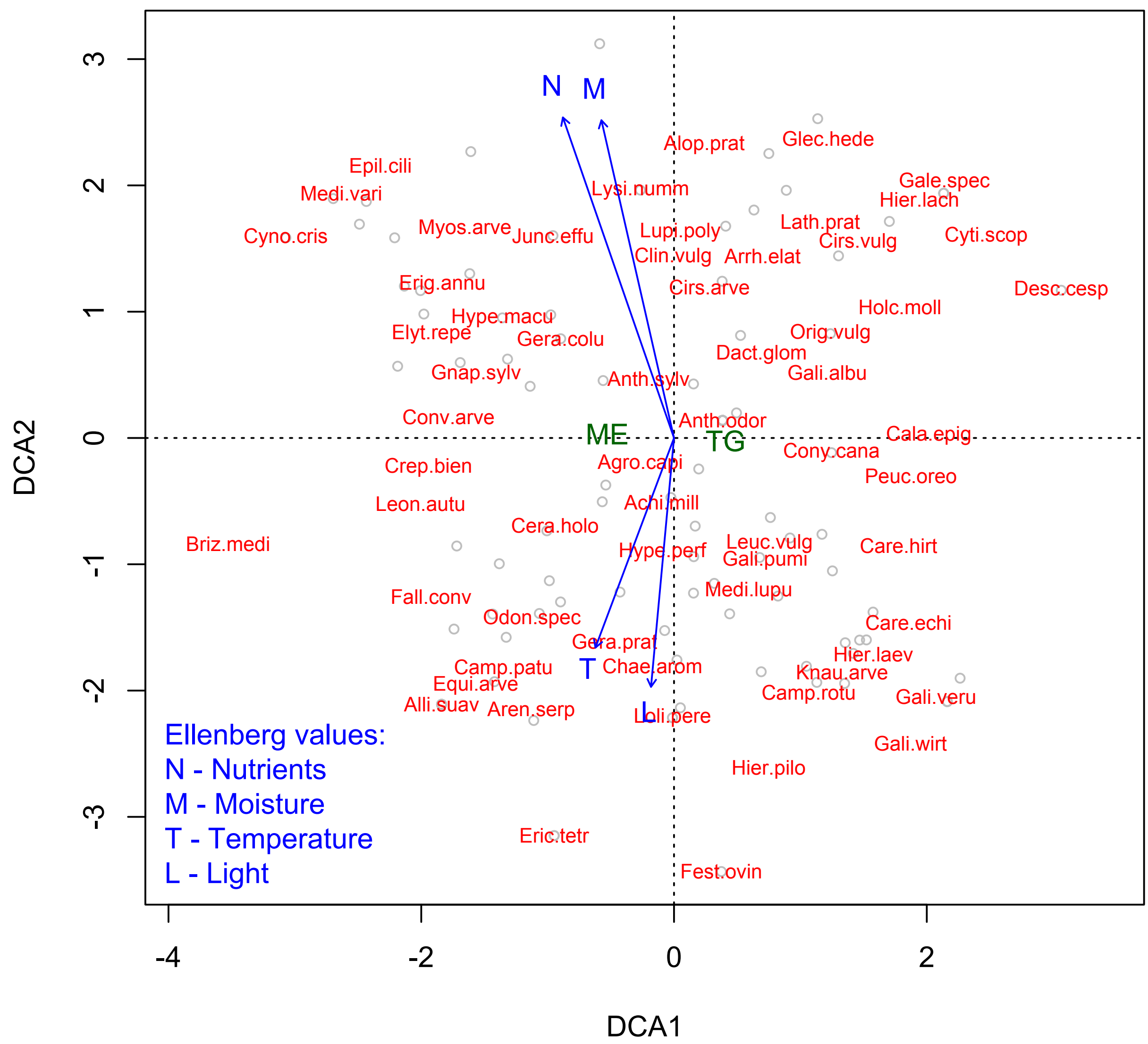

Fig. 12. DCA ordination of vegetation data with projected Ellenberg Indicator Values, showing potential gradients present in data. More frequent species are red, less frequent species are grey circles, sites are not displayed. Management types are also projected in green, TG – training grounds, ME – undisturbed meadows.

The last ordination performed (Fig. 12.) was a DCA of the square root transformed vegetation data to uncover plain structures in the data in unconstrained form. Projected Ellenberg Indicator Values (EIV) were used to identify some factors behind the gradients present. None of the EIV correlates with first axis, so the main gradient has to be explained in another way, possibly by the military management factor (also projected in the plot).

6.4. Spatial scale

The variability of plant diversity influenced by military land-use can be very different when observed on a different scale, some grains appropriate to observe the differences were uncovered. Landscape macro clusters based on mutual proximity of points show significant differences (Fig. 13.). Some of them underwent different treatments in the past such as aircraft ammunition testing (parts of clusters 3 and 4) or aircraft landing (cluster 1). Clusters explained 20 % of the variability in the dataset (Multiple R-squared). The analysis of Beta diversities in the same clusters showed no significant difference between clusters, tested with Kruskal-Wallis test (Fig. 14.).

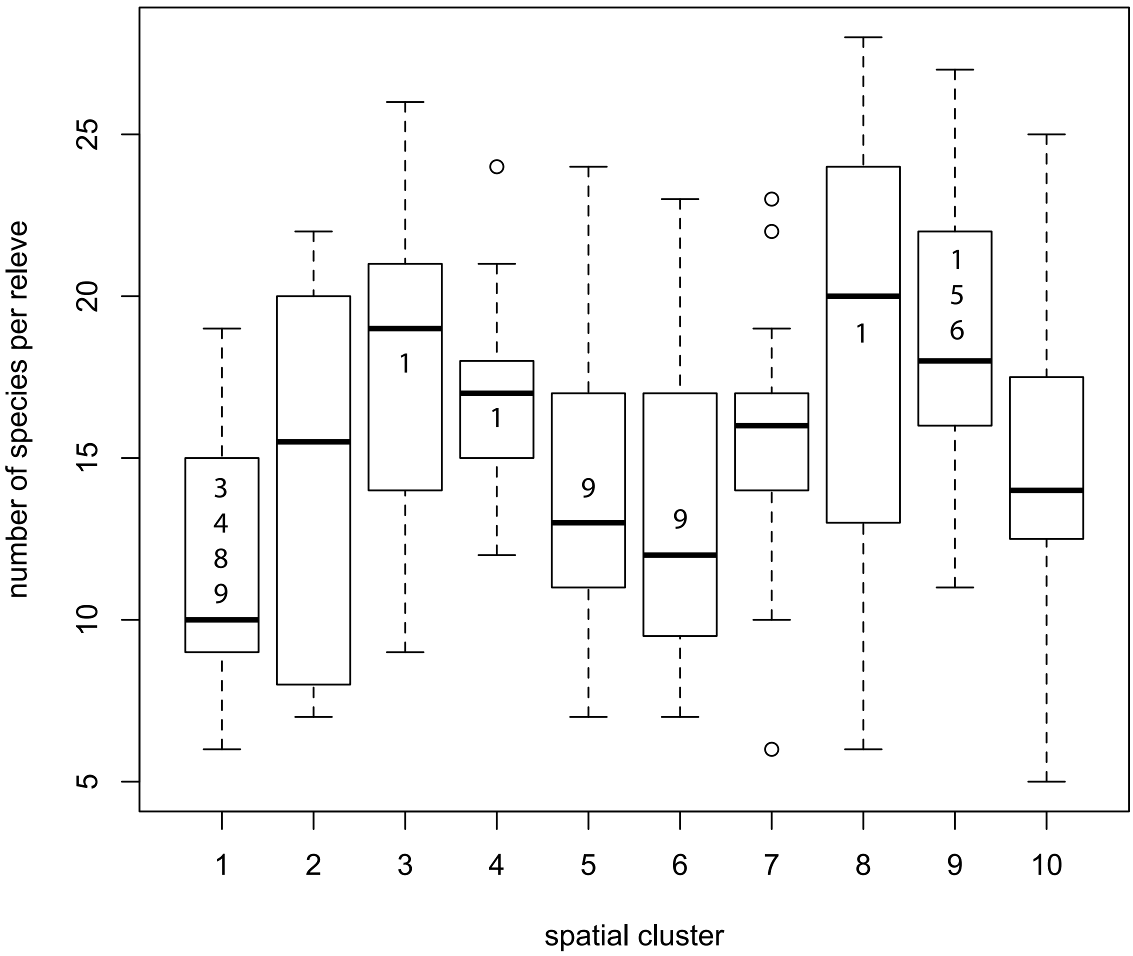

Fig. 13. Species richness of samples in spatially defined clusters. Numbers in boxplots correspond to numbers of clusters that are significantly different.

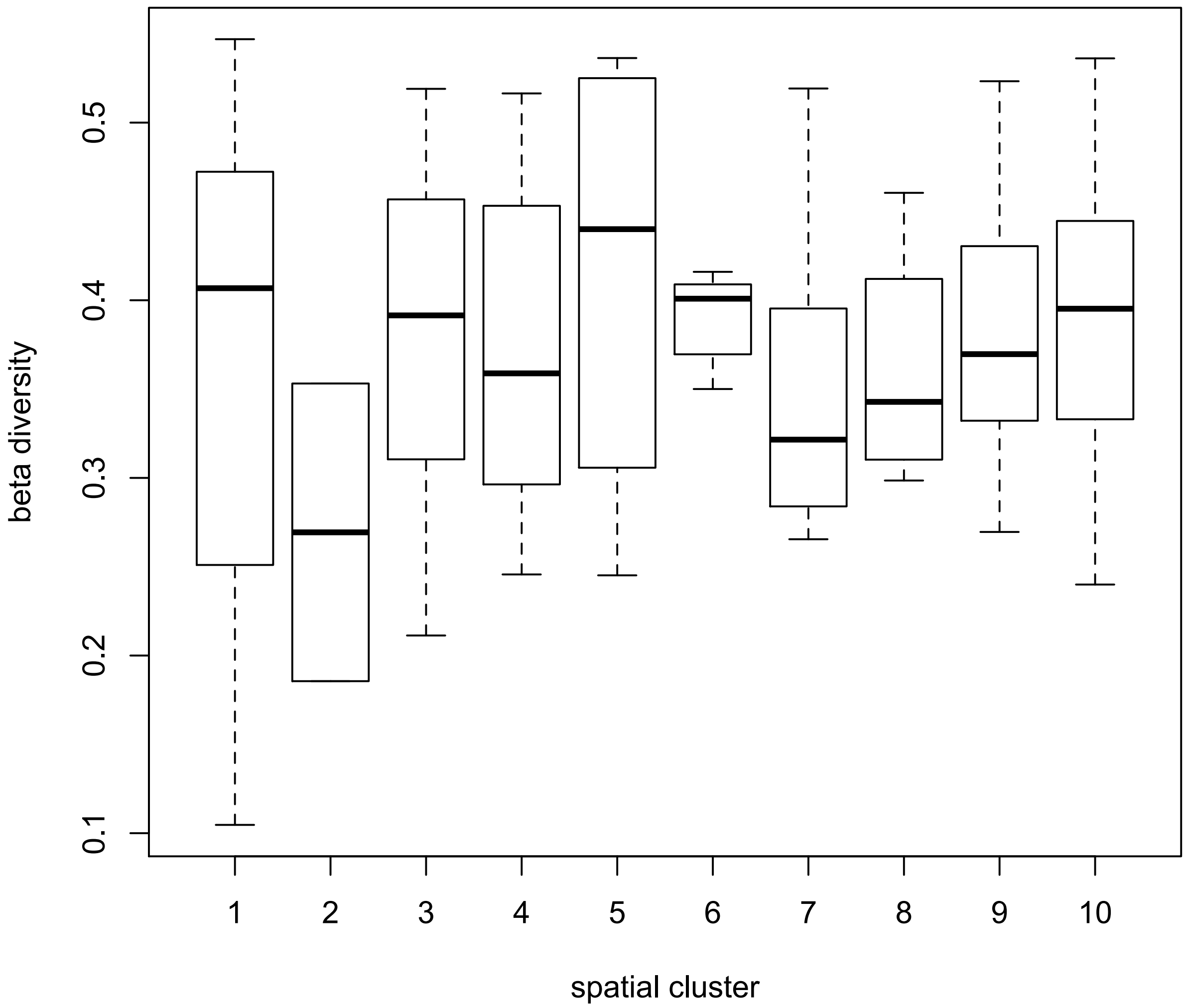

Fig 14. Beta diversity for samples in the ten spatial clusters. No cluster is significantly different than the others.

On smaller scales the differences were rather small and not as significant. Triplets with bigger distance amongst samples had slightly higher diversity as expected, but were not significantly different on training grounds and undisturbed meadows (Fig. 15. A). Also the interaction plot does not show any important differences in the increase of species number with increasing distance amongst samples (Fig. 15. B). In the model used for analyzing the spatial distribution of diversity there was a 24.3 % variability of species richness on the triplet level and 75.3 % variability between triplets.

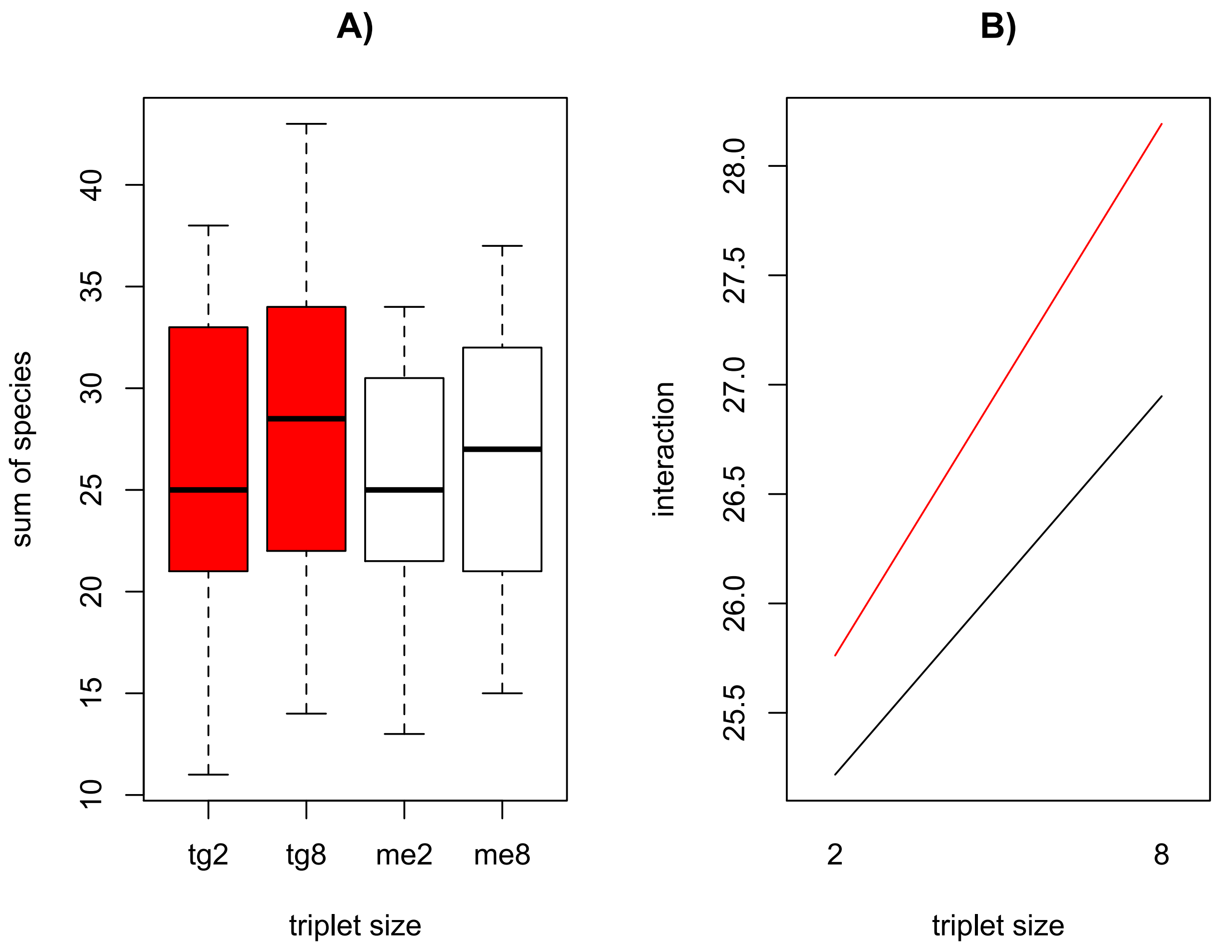

Fig. 15. Gamma diversities of triplets of different inter-sample distance. A) Sums of species from triplets of different management types. B) Interaction between triplets of size two and eight meters from training grounds (red line) and meadows (black line). The differences are not significant (ANOVA).

In comparing the vegetation distance matrix with the geographic distance matrix, the results of the Mantel test show no significant correlation between the two. The plot of the vegetation and geographic distances (Fig. 16.) only shows bigger variance in vegetation distance when data points are closer to each other, but there is no real correlation of the two distances.

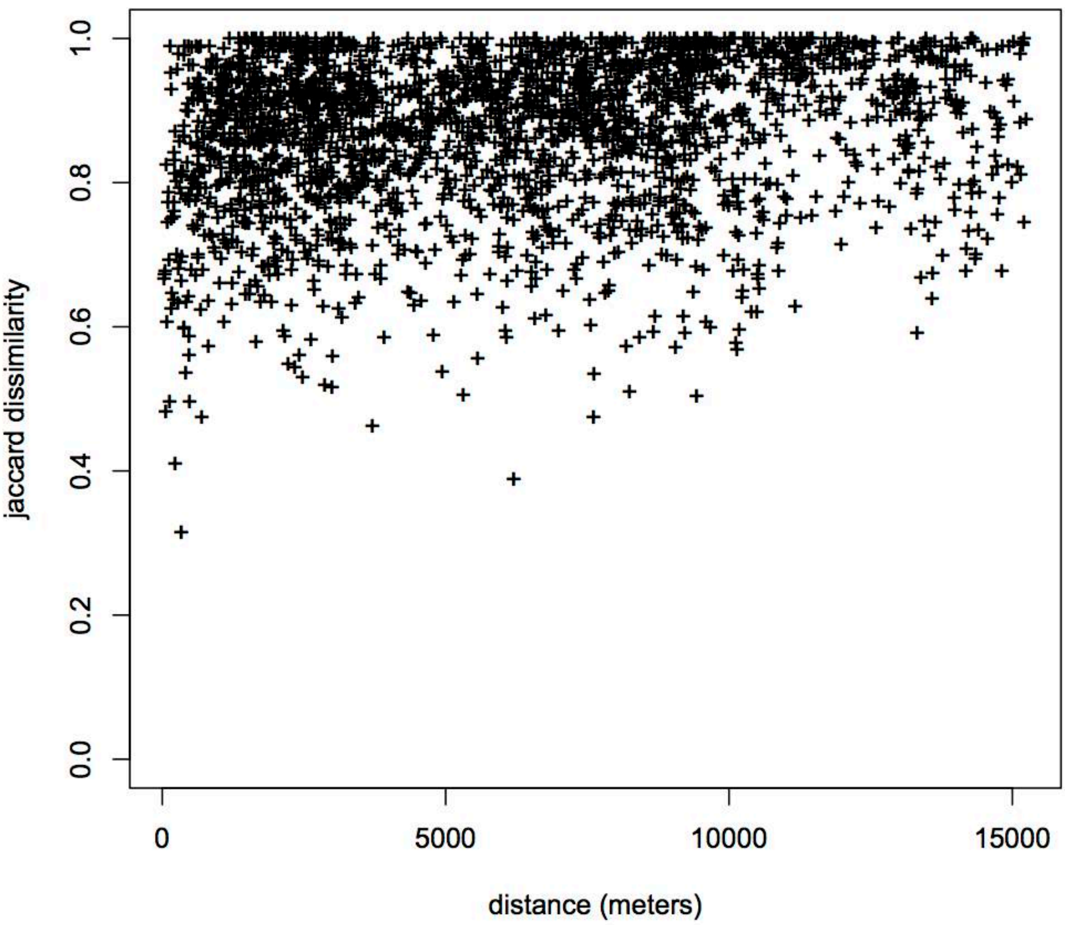

Fig. 16. Comparison of geographic distances amongst sampled points and their vegetation distances (based on Jaccard index). No significant correlation was found.

6.5. Soil properties

Measurements of soil samples in triplets were used to assess the amount of variability located to the small scale and to large scales. The variability was divided between the triplet (variability inside triplet) and among-triplet variability (see Table 1.).

Table 1. Percentages of variability in measured soil chemical properties on the level of triplet and amongst triplets.

	inside triplet	outside triplet
C total	11.83 %	88.17 %
N total	15.83 %	84.17 %
P exchangeable	6.85	93.15 %
C/N ratio	21.63 %	78.37 %

In general, the training grounds yielded more variability in chemical properties in almost all analyses (except exchange phosphorus). Soil reaction was significantly higher (less acidic) on the training grounds $p = 0.0213$ (Fig. 17.), and the variance of soil reaction on training grounds was also significantly different ($p < 0.001$, variance test) than in the meadows. Another analysis showed positive correlation between soil reaction and number of species (Fig. 18.). However, pH was the only soil variable with this kind of significant correlation with species number. Other variables of relations to species richness were tested with Kruskal-Wallis test with non-significant results. More results of chemical analyses for soil nitrogen, carbon and phosphorus in relation to past management are shown at Fig. 19. The first two (A and B) are significantly different. Results of the Multiple-way ANOVA model of soil environmental variables are in Table 2.

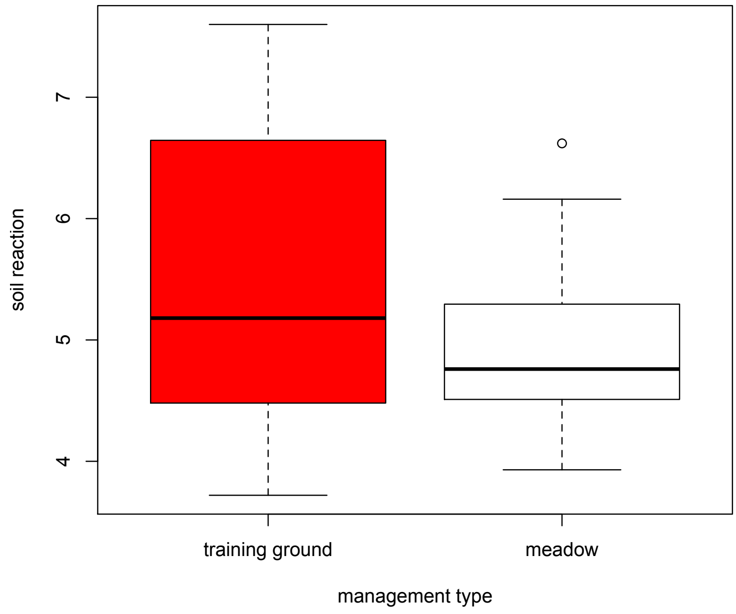

Fig. 17. Soil reaction differences on different management types. The two management types are significantly different and have different variance.

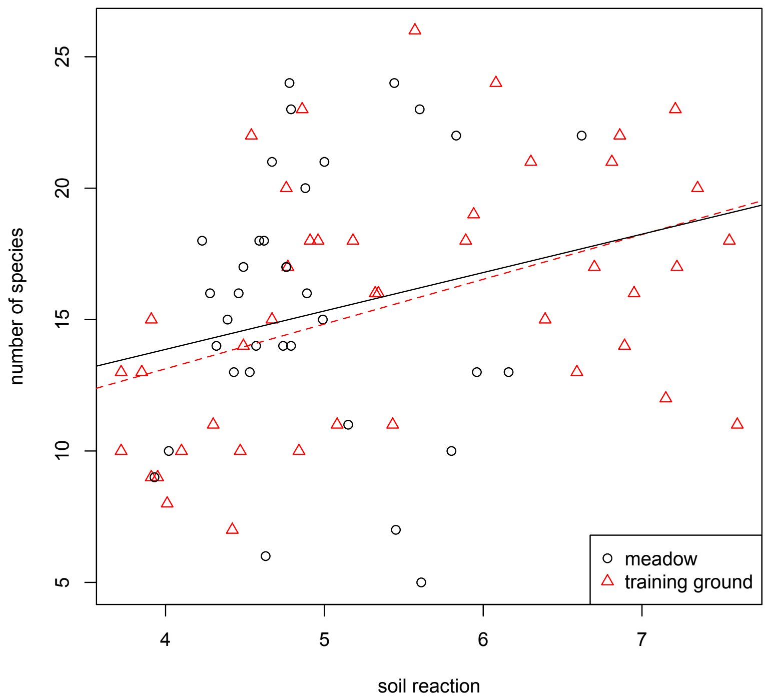

Fig. 18. Plot of soil reaction and species richness with data points of management types plotted in different colors (red triangles – training grounds, black circles – undisturbed meadows). Solid black line shows a linear regression line for all data points and the dashed red line only for training ground points. For meadow points (only) the correlation is not significant.

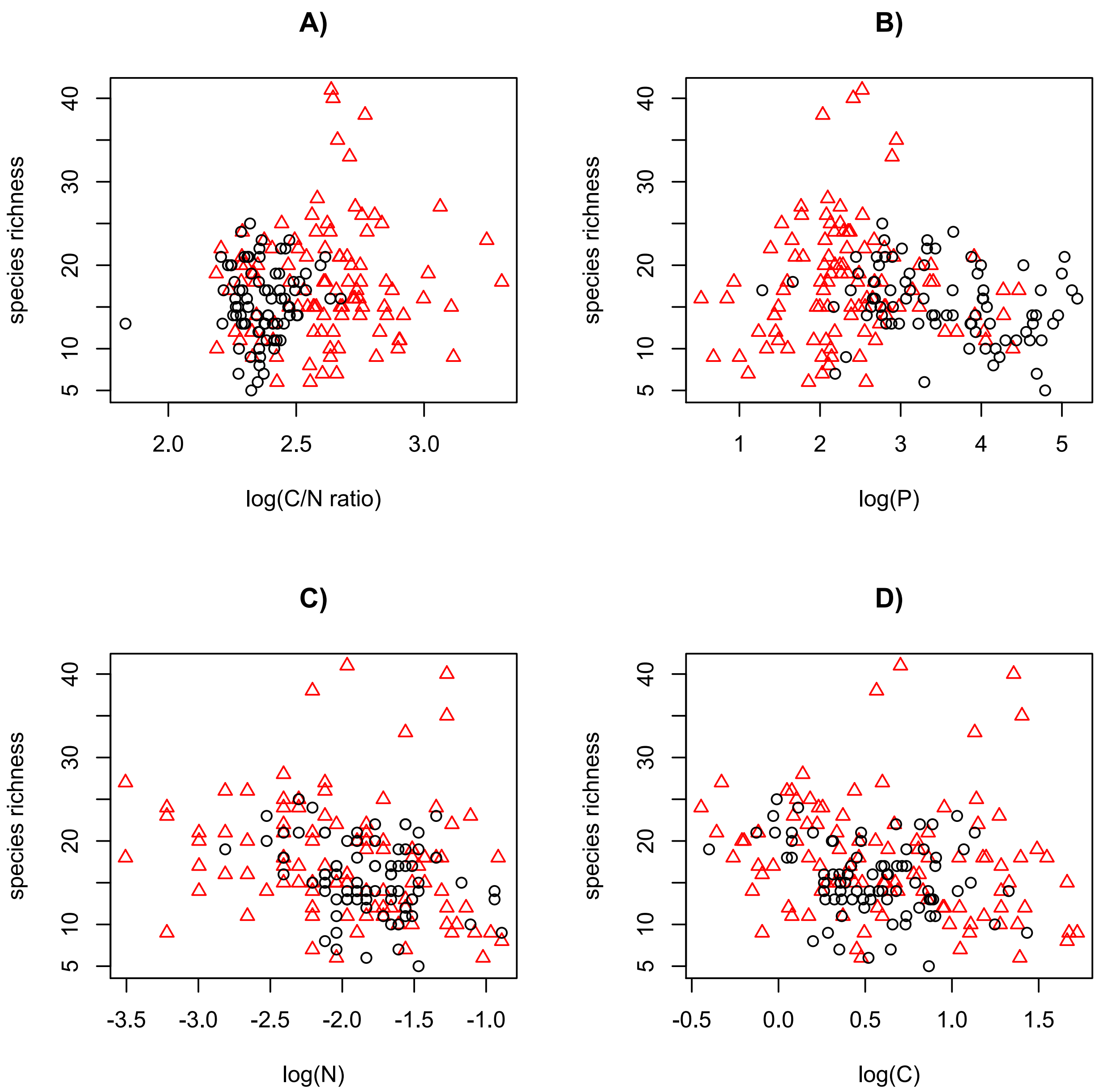

Fig. 19. Plot of soil reaction and species richness with data points of management types plotted in different colors (red triangles – training grounds, black circles – undisturbed meadows).

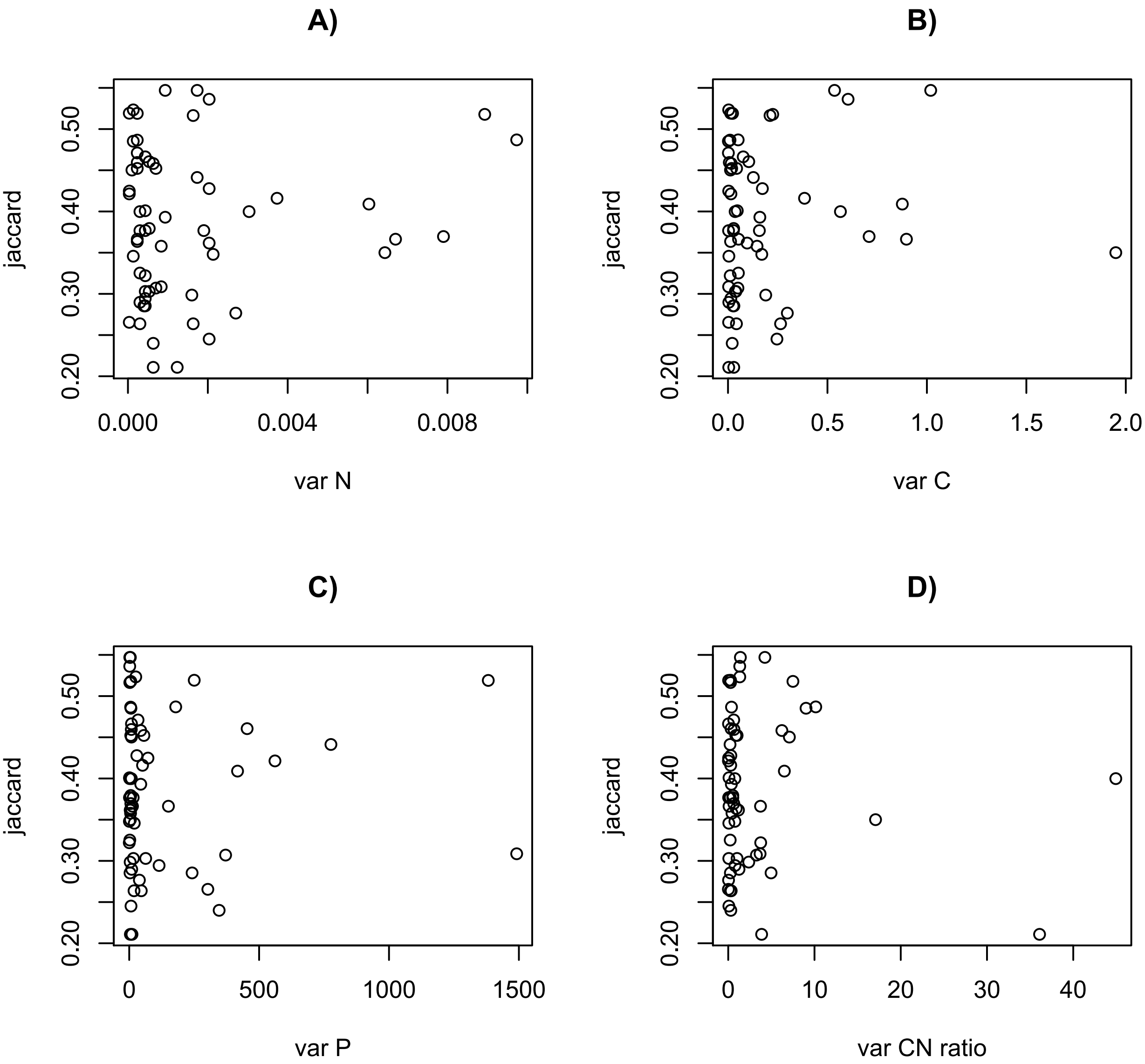

Fig. 20. Variance coefficients of soil properties in a triplet, and Beta diversity (Jaccard index) of a triplet. None yielded significant correlation (Kruskal-Wallis test).

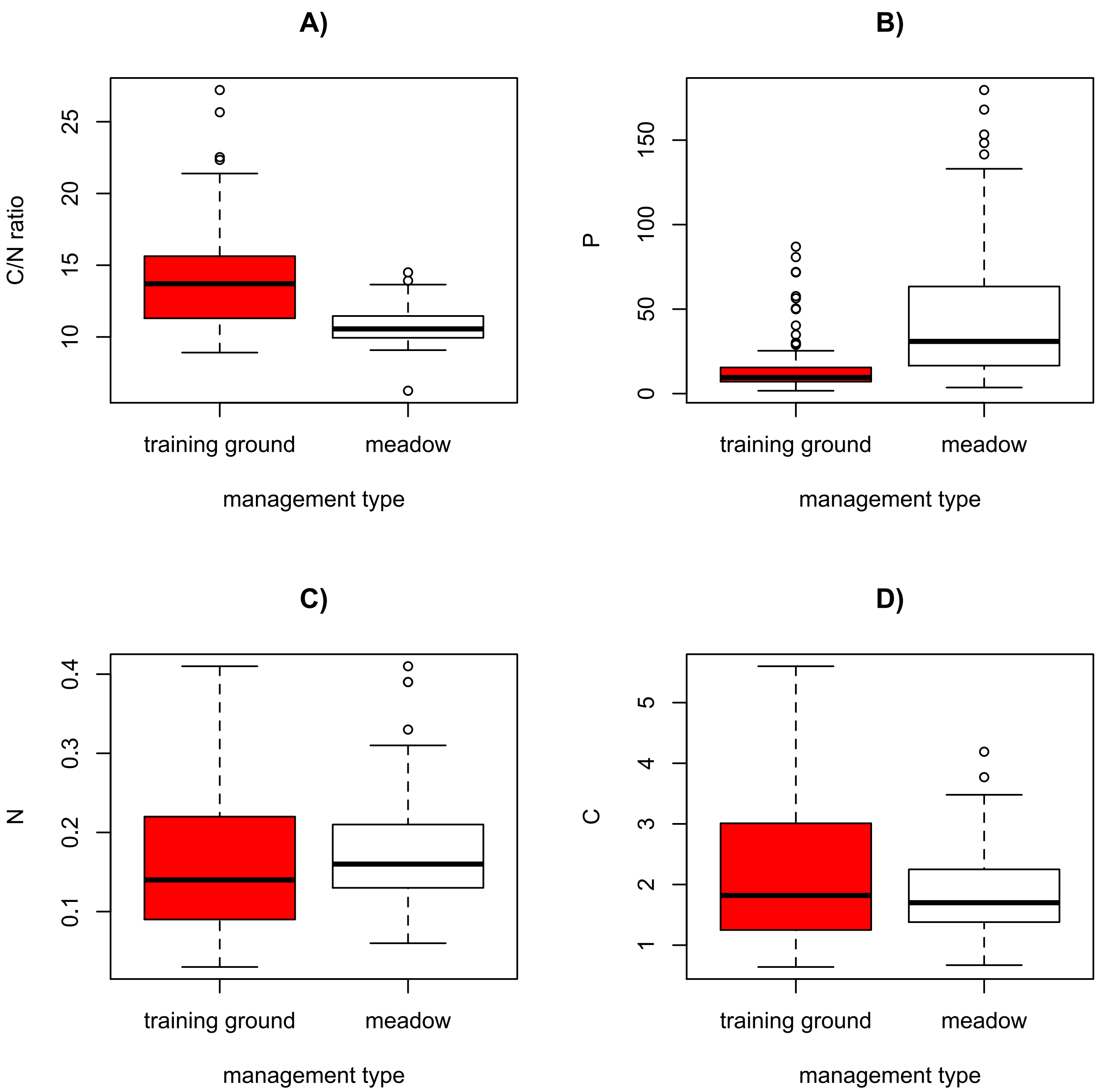

Fig. 21. Boxplots for soil chemical properties on different management types. C/N ratio and exchangeable phosphorus yield significant differences. For total nitrogen and total carbon the differences are not significant.

*Table 2. Model coefficients and p-values of the soil environmental variables in the multiple-way ANOVA model. Significant variables are marked with asterisks (0 '***' 0.001 '**' 0.01 '*' 0.05).*

Variable	Coefficient	Std. error	p-value	
C total	0.0720	0.0644	0.2632	
N total	-1.8125	0.8674	0.0366	*
P exchangeable	-0.0017	0.0005	0.0033	**
C/N ratio	-0.0040	0.0100	0.6827	

6.6. Invasive plants

The test for the effect of military management on invasive or alien species yielded positive results. The data included four of 29 invasive and expansive plant species listed in the Ministry of Agriculture's regulation (MZE ČR 2005): *Calamagrostis epigejos, Cytisus scoparius, Lupinus polyphyllus* and *Tanacetum vulgare*. The mentioned species can be found in moderate to high densities and are more frequent in former military training grounds ($p < 0.001$, see Fig. 22.).

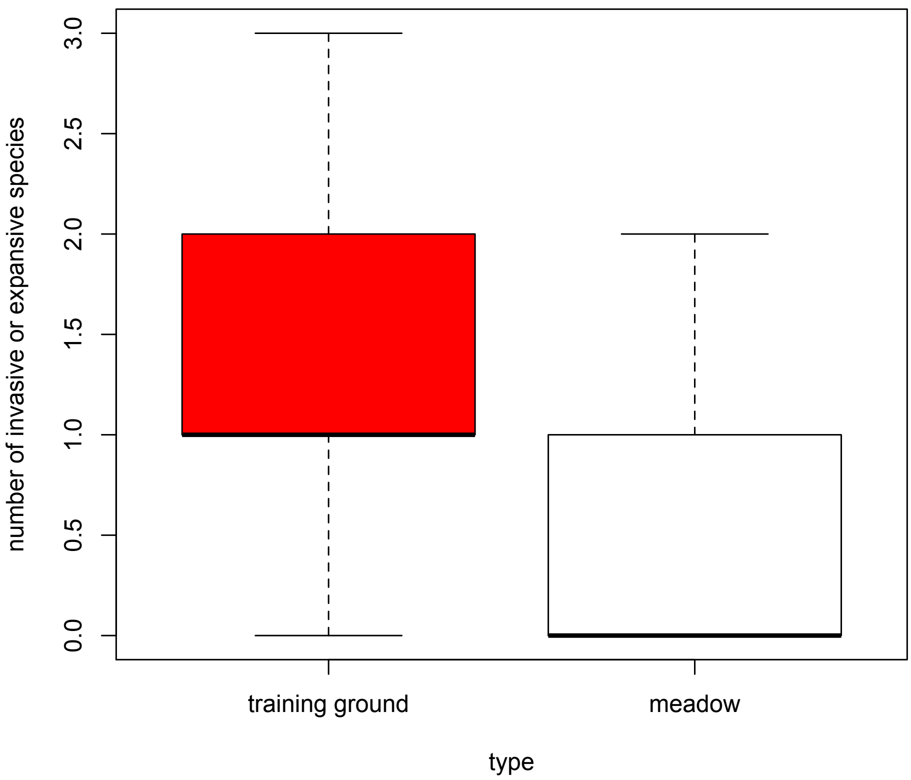

Fig. 22. Boxplot of the occurrence of the four invasive species on training grounds and undisturbed meadows. The difference is significant at the level of $p < 0.001$.

When comparing the four invasive species cover values with the disturbance levels of their habitats no correlation was found, and Kruskal-Wallis test results were insignificant (Fig. 23.). However, it is interesting to notice a slightly different pattern in *Calamagrostis epigejos* than in other species. It seems to be more disturbance-tolerant than the rest. This fact is in agreement with the field experience of author.

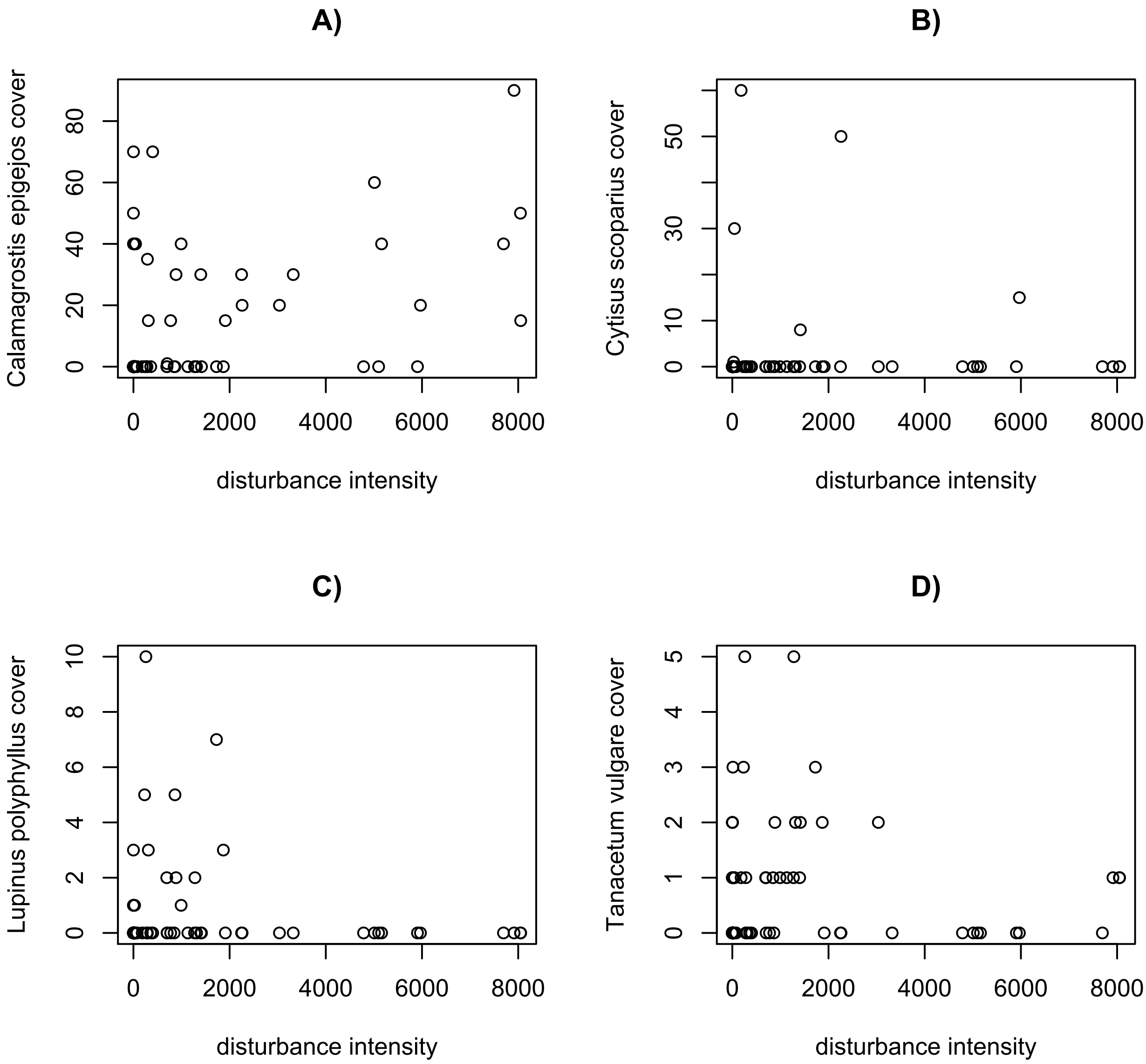

Fig. 23. Plots of disturbance intensity and cover values of the four invasive / expansive species. On the vertical axis cover percentages of species in samples are plotted. No significant correlations were found.

6.7. Calamagrostis epigejos

This highly expansive competitive grass was observed on both types of grasslands, but the data shows a significantly higher occurrence on the training grounds ($p < 0.001$). Also the relationship between *C. epigejos* cover and species richness in the sample was subject of interest. The test did not yield a significant correlation, but the plot shows a larger variability in species richness in low *C. epigejos* cover values and low species richness in high densities of *C. epigejos*. This could be the result of dense circular swards (sometimes up to ten meters wide) of *C. epigejos*, which usually allows very few other species to grow in it. Just a quick look at the data reveals that in more than 20 % of training ground samples C. epigejos covers more than 40 % of the area, whereas on undisturbed meadows it is only 7.9 % of all samples. The results of the Chi^2 test are significant ($p < 0.001$).

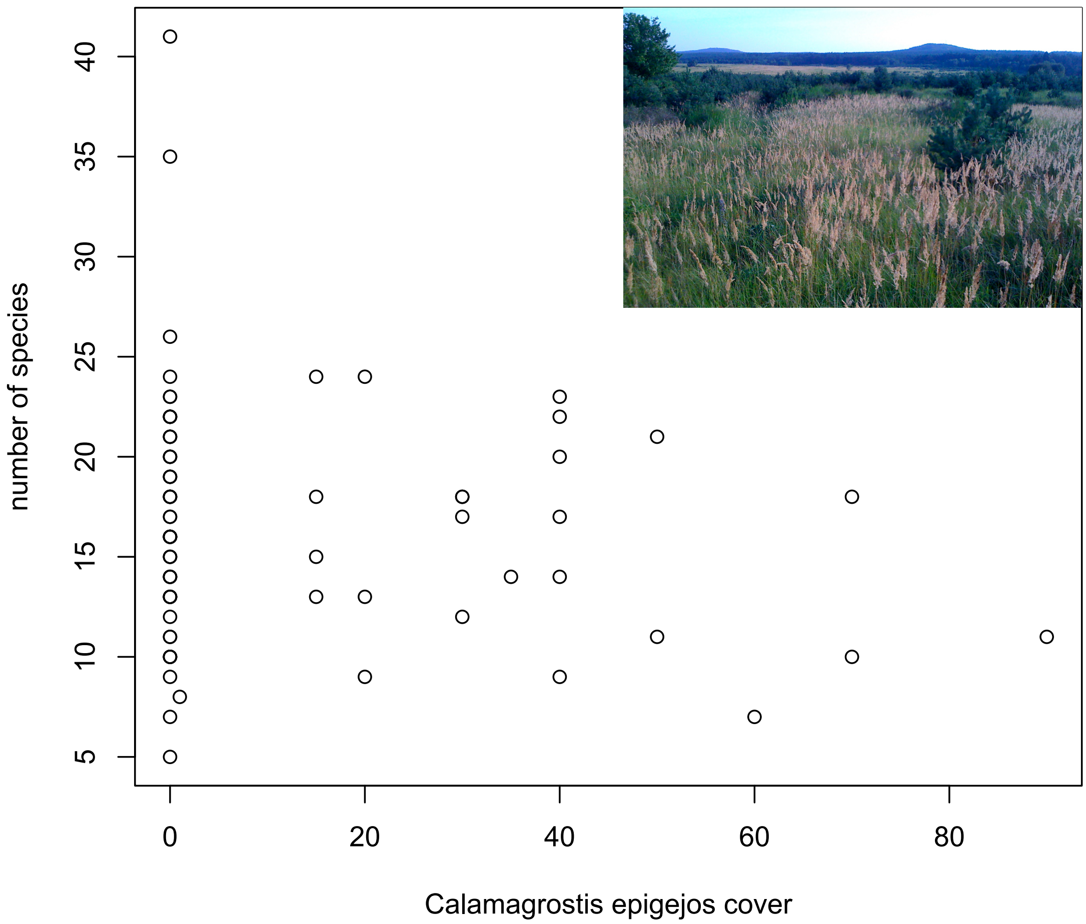

Fig. 24. Plot of species richness in samples with various cover of C. epigejos.

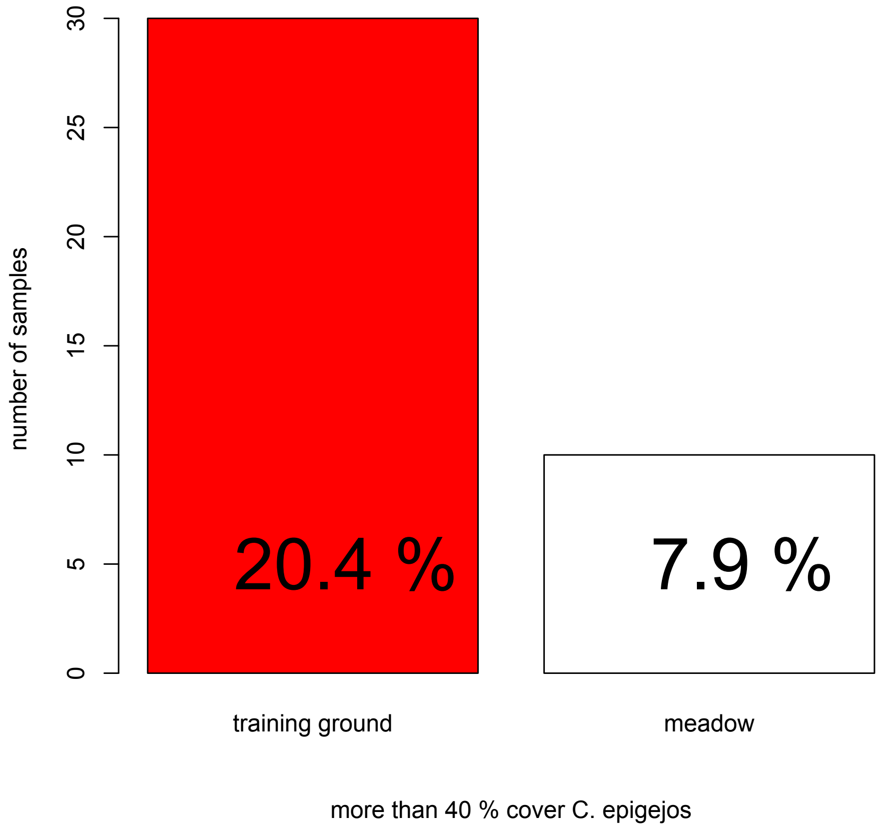

Fig. 25. Samples with dominating C. epigejos (more than 40 % of cover) in both management types. Numbers in boxes show percentage of al samples of the management type (Chi² $p < 0.001$).

The overall percentage of graminoids (grass-like plants) in the communities was investigated, but the results did not show any significant difference in species number between training grounds and military undisturbed meadows. Most likely different grass species prevail on different habitat types, but the graminoid cover values do not differ significantly.

6.8. Overview of tested variables

To sum up all the results achieved in various linear analyses, a correlation coefficient table of all used environmental variables was created (Table 3.). These kinds of results should bring more understanding to the overall functioning of the whole system in the Doksy region. Worth mentioning is the significant correlation between the Disturbance intensity index (*Disturbance*) and management type (*Type*), confirming the correctness of the variable used in most analyses (*Type*). Also interesting are the correlations of soil variance coefficients within the triplet (*Variance N, Variance C, Variance P and Variance CN*) with management type, confirming larger variability of military training area on a micro scale.

Table 3. Correlation matrix of all environmental variables used in the analyses. Significant correlations are marked with stars ($p < 0.05$, ** $p < 0.001$)*

	Type	Cluster	Disturbance	Wettness index	Species number	Grass percentage	Shannon index	Light (EIV)	Temperature (EIV)	Continentality (EIV)	Moisture (EIV)	pH (EIV)	Nutrients (EIV)	N	C	C/N ratio	P exchangeable	pH	variance N	variance C	variance P	variance CN	Gamma diversity	Beta diversity	Jaccard index	Bray-Curtis index
Type	1	0.01	0.667**	0.051	0.193	0.102	0.287*	0.177	-0.011	0.002	-0.247	0.042	-0.212	-0.177	0.033	0.702**	-0.587**	0.26	0.274*	0.377**	-0.318*	0.466**	0.209	0.102	0.247	0.235
Cluster	0.01	1	0.227	0.015	0.079	-0.06	-0.036	0.229	0.300*	0.115	-0.038	0.09	-0.087	-0.01	0.049	0.108	0.112	0.237	-0.042	-0.055	0.048	0.035	0.239	-0.15	0.094	0.099
Disturbance	0.667**	0.227	1	0.114	0.18	-0.092	0.215	0.295*	0.048	0.095	-0.325*	0.024	-0.273*	-0.410**	-0.155	0.750**	-0.430**	0.181	0.091	0.207	-0.277*	0.531**	0.285*	0.029	0.238	0.237
Wettness index	0.051	0.015	0.114	1	-0.005	0.135	0.121	0.397**	0.087	0.005	-0.128	-0.365**	-0.293*	0.112	0.167	0.231	-0.103	-0.136	0.18	0.219	-0.273*	0.034	-0.063	0.059	0.032	0.036
Species number	0.193	0.079	0.18	-0.005	1	-0.417**	0.882**	0.112	0.203	0.011	-0.183	0.237	0.015	-0.301*	-0.277*	0.128	-0.257	0.446**	-0.102	0.046	-0.229	0.098	0.802**	0.420**	0.167	0.152
Grass percentage	0.102	-0.06	-0.092	0.135	-0.417**	1	-0.177	-0.23	-0.402**	0.002	0.478**	-0.025	0.133	0.057	0.008	-0.046	-0.144	-0.253	0.188	0.148	-0.075	-0.004	-0.548**	0.043	-0.382**	-0.370**
Shannon index	0.287*	-0.036	0.215	0.121	0.882**	-0.177	1	0.15	0.143	0.067	-0.111	0.181	0.081	-0.285*	-0.238	0.235	-0.287*	0.411**	-0.023	0.118	-0.262	0.157	0.646**	0.433**	0.223	0.206
Light (EIV)	0.177	0.229	0.295*	0.397**	0.112	-0.23	0.15	1	0.172	-0.096	-0.553**	-0.209	-0.417**	-0.016	0.113	0.379**	0.019	0.197	-0.2	-0.143	-0.058	0.143	0.138	0.032	0.024	0.001
Temperature (EIV)	-0.011	0.300*	0.048	0.087	0.203	-0.402**	0.143	0.172	1	0.288*	-0.314*	0.1	-0.051	0.103	0.162	0.118	0.191	0.431**	-0.119	-0.166	0.271*	0.162	0.229	-0.002	0.277*	0.267
Continentality (EIV)	0.002	0.115	0.095	0.005	0.011	0.002	0.067	-0.096	0.288*	1	0.185	0.399**	0.408**	0.043	0.015	-0.032	0.266	0.177	0.014	0.058	0.266	-0.017	0.086	-0.062	-0.035	-0.037
Moisture (EIV)	-0.247	-0.038	-0.325*	-0.128	-0.183	0.478**	-0.111	-0.553**	-0.314*	0.185	1	0.302*	0.627**	-0.02	-0.159	-0.372**	0.057	-0.195	0.097	0.109	-0.023	-0.313*	-0.271*	0.056	-0.217	-0.203
pH (EIV)	0.042	0.09	0.024	-0.365**	0.237	-0.025	0.181	-0.209	0.1	0.399**	0.302*	1	0.653**	-0.121	-0.146	-0.066	0.017	0.323*	-0.074	0.094	0.149	-0.173	0.198	0.049	0.054	0.038
Nutrients (EIV)	-0.212	-0.087	-0.273*	-0.293*	0.015	0.133	0.081	-0.417**	-0.051	0.408**	0.627**	0.653**	1	-0.116	-0.248	-0.395**	0.247	0.078	-0.146	-0.074	0.251	-0.276*	0.03	-0.011	-0.04	-0.037
N	-0.177	-0.01	-0.410**	0.112	-0.301*	0.057	-0.285*	-0.016	0.103	0.043	-0.02	-0.121	-0.116	1	0.921**	-0.306*	0.394**	-0.107	0.275*	0.156	0.256	-0.253	-0.268*	-0.156	0.103	0.103
C	0.033	0.049	-0.155	0.167	-0.277*	0.008	-0.238	0.113	0.162	0.015	-0.159	-0.146	-0.248	0.921**	1	0.018	0.279*	-0.025	0.402**	0.331*	0.186	-0.116	-0.22	-0.16	0.183	0.18
C/N ratio	0.702**	0.108	0.750**	0.231	0.128	-0.046	0.235	0.379**	0.118	-0.032	-0.372**	-0.066	-0.395**	-0.306*	0.018	1	-0.469**	0.245	0.237	0.360**	-0.326*	0.492**	0.169	0.015	0.299*	0.294*
P exchangeable	-0.587**	0.112	-0.430**	-0.103	-0.257	-0.144	-0.287*	0.019	0.191	0.266	0.057	0.017	0.247	0.394**	0.279*	-0.469**	1	0.036	-0.101	-0.211	0.716**	-0.276*	-0.168	-0.232	-0.138	-0.143
pH	0.26	0.237	0.181	-0.136	0.446**	-0.253	0.411**	0.197	0.431**	0.177	-0.195	0.323*	0.078	-0.107	-0.025	0.245	0.036	1	0.017	0.006	0.049	0.376**	0.544**	-0.133	0.279*	0.263
variance N	0.274*	-0.042	0.091	0.18	-0.102	0.188	-0.023	-0.2	-0.119	0.014	0.097	-0.074	-0.146	0.275*	0.402**	0.237	-0.101	0.017	1	0.835**	-0.109	0.236	-0.116	-0.032	0.002	0.001
variance C	0.377**	-0.055	0.207	0.219	0.046	0.148	0.118	-0.143	-0.166	0.058	0.109	0.094	-0.074	0.156	0.331*	0.360**	-0.211	0.006	0.835**	1	-0.173	0.016	-0.039	0.104	0.094	0.095
variance P	-0.318*	0.048	-0.277*	-0.273*	-0.229	-0.075	-0.262	-0.058	0.271*	0.266	-0.023	0.149	0.251	0.256	0.186	-0.326*	0.716**	0.049	-0.109	-0.173	1	-0.196	-0.147	-0.2	-0.084	-0.084
variance CN	0.466**	0.035	0.531**	0.034	0.098	-0.004	0.157	0.143	0.162	-0.017	-0.313*	-0.173	-0.276*	-0.253	-0.116	0.492**	-0.276*	0.376**	0.236	0.016	-0.196	1	0.188	-0.05	0.169	0.152
Gamma diversity	0.209	0.239	0.285*	-0.063	0.802**	-0.548**	0.646**	0.138	0.229	0.086	-0.271*	0.198	0.03	-0.268*	-0.22	0.169	-0.168	0.544**	-0.116	-0.039	-0.147	0.188	1	-0.117	0.355**	0.352**
Beta diversity	0.102	-0.15	0.029	0.059	0.420**	0.043	0.433**	0.032	-0.002	-0.062	0.056	0.049	-0.011	-0.156	-0.16	0.015	-0.232	-0.133	-0.032	0.104	-0.2	-0.05	-0.117	1	-0.2	-0.225
Jaccard index	0.247	0.094	0.238	0.032	0.167	-0.382**	0.223	0.024	0.277*	-0.035	-0.217	0.054	-0.04	0.103	0.183	0.299*	-0.138	0.279*	0.002	0.094	-0.084	0.169	0.355**	-0.2	1	0.996**
Bray-Curtis index	0.235	0.099	0.237	0.036	0.152	-0.370**	0.206	0.001	0.267	-0.037	-0.203	0.038	-0.037	0.103	0.18	0.294*	-0.143	0.263	0.001	0.095	-0.084	0.152	0.352**	-0.225	0.996**	1

7.Discussion

7.1. Military management and diversity

The impact of approximately fifty years of military land-use in the former military area Ralsko was studied. It has been more than twenty years since the Soviet army abandoned it. The grasslands were unmanaged and left to natural succession. From the data collected it is clear that the two types of grasslands are different in vegetation composition and other indicators. However, it is necessary to realize that besides the active disturbance effects of military land-use, it also creates a kind of isolation from what occurs typically in central-European landscape. It is inevitable in the Czech cultural landscape that grasslands will be sustained by human activities such as pasturing or mowing. Therefore, the fact that grasslands in the military training area Ralsko was used for training also means that it was not mowed or grazed, which might have affected them. Many studies focusing on grazing (Matthijs 1996; Dupre & Diekmann 2001) or mowing (Házi *et al.* 2011) showed that they can significantly affect plant species diversity and vegetation composition.

The study tries to describe the complex phenomenon in the landscape encompassing the history of the whole area. The military operations and trainings were only one of the factors. Nevertheless, it is known that military land-use usually has some impact on vegetation composition and sometimes even on species richness. In the case of this study, species richness is not very different on training grounds and undisturbed meadows. There are several possible explanations for this:

1) The area used to be richer in species in the period of disturbance and especially in the time immediately after abandonment. However, recently it has lost most of its species richness because of natural succession. It changed from the stable disturbance regime, maintaining different successional stages on small patches, therefore sustaining a variable mosaic to an abandoned, undisturbed grassland. Today, highly competitive species of later successional stages takeover most of the grasslands and create temporally blocked stage (Lepš 1990). This hypothesis could be supported by measurements from the close proximity of some recent disturbances. Samples situated in such places showed rapidly increased species richness. This is also in agreement with other studies and experiments conducted with heavy military vehicles and artificially created disturbance (Leis *et al.* 2005). Most studies of this kind describe species richness increase after such actions. These studies are focusing on the community regeneration, which might also mean getting to the stable species composition and number. The restoration studies come up with different results depending on the soil quality and natural conditions. For example, dry acidic grassland took about

10 years to recover (Jentsch *et al.* 2009), but mesotrophic grassland took between 30 and 40 years, and calcareous grassland even up to 50 years (Hirst *et al.* 2005).

2) The other possible explanation for why the diversity increase was smaller than expected is through the nutrient poor sandy soils. Several studies mention different reactions to disturbance of different communities based on various kinds of soils (Althoff *et al.* 2007; 2009). In general, more acidic, nutrient poor soils showed lower diversity growth and faster regeneration after disturbance. In some studies, authors were concerned mainly with canopy recovery and did not care about species diversity (Kade & Warren 2002; Guretzky *et al.* 2006). However, vegetation cover renewal can depend on soil quality and environmental characteristics such as moisture and nutrients concentration (Kade & Warren 2002).

When discussing the possibilities of disturbance impact on a grassland community, the reciprocal relationship between disturbance and biodiversity should be considered (Hughes *et al.* 2007). It is not only the disturbance intensity that affects the biodiversity, but also the biodiversity and species composition affect the severity of the disturbance effect (Tilman & Downing 1994; Dickson *et al.* 2008). It has been observed that repeated severe disturbance can lead to the exclusion of some rare species because they are less likely to recover quickly enough (Tilman & Haddi 1992). This kind of recruitment limitation was described as example of disturbance decreasing species richness. However, it is necessary to be aware of the reason of species scarcity on the site. In the case of the Ralsko military area there are rare species that are outcompeted by dominant grasses and, therefore, tend to be rare. There are also several species found only in recently disturbed areas. The difference in drought disturbance, described by Tilman (1992), affects the whole area. Small local disturbances occurring on military training grounds should also be considered, for the effects can be very different.

7.2. Invasive species

An important thing to be aware of is that the actual nature of species richness increases because some species are simply undesirable. Even though there is an in the the actual species number, in the long-term perspective they will cause the community to loose diversity (Hughes *et al.* 2007). Special groups of plants with this kind of impact are called invasive plants. In the long term they can change environmental conditions for other species and rapidly decrease species diversity transforming the whole ecosystem (Dennehy *et al.* 2011). In the case of the abandoned military area Ralsko and other abandoned military areas, invasive plants play a relatively important role.

According to results of present study, all four invasive species showed high fidelity values for training grounds. An American monitoring study has found invasive species spreading on actively disturbed military grasslands (Althoff *et al.* 2006). There is a question about the main means of invasive species promotion by military management. It can either be only the possibility of transport on wheels or tracks of military vehicles allowing them to spread rapidly throughout the area. Or the factor of a suitable environment in disturbed patches and uncovered soil might also play a role. The expansive grass *Calamagrostis epigejos* is a very strong competitor and using a combination of *phalanx* and *guerilla* strategy, it can spread rapidly by vegetative growth and create whole patches where it dominates. These structures are even visible from aerial photos. Even though *C. epigejos* is not an invasive plant in Czech Republic, it bears some characteristics of dangerous invasive species, changing its environment by large amounts of litter. This shades smaller competitors, prevents them from germination (Rebele & Lehmann 2001). Probably some of these characteristics are the reasons why this species is on the list of invasive and expansive plants of the Ministry of Agriculture (MZE ČR 2005). Taking the practical side of the issue, most people would ask, what can be done to stop the spreading of such species or at least slow them down? Studies on *C. epigejos* show that it responds to management actions like plowing or milling rather poorly, and after burning, it even resprouts rapidly (Rebele & Lehmann 2001). Unfortunately, no precise records of fires occurring in the military area Ralsko are available, except for one record from 1990 close to the military airport Hradčany (Adámek, unpublished data). The samples in this area show very high covers of *C. epigejos* (50 % and more) and relatively low species richness. More wildfires during the time of active military use can be expected throughout the whole area, especially in regions with ammunition testing. Therefore the presence of this expansive species could be strongly promoted by military management, but more exact data on wildfires from the whole area would be needed to make this clear. Successful management of *C. epigejos* and other strongly competitive plant species often requires regular mowing (Lehmann & Rebele 2002; Házi *et al.* 2011) or grazing (De Bonte *et al.* 1999). For management of all particular invasive species, expert knowledge is required. According to studies on the management of grasslands invaded by *C. scoparius* (Bossard & Rejmanek 1994; Srinivasan 2011), fire might seem a useful management tool, but considered the above mentioned effect on *C. epigejos* its application might cause a disaster to the whole ecosystem. *C. scoparius* is also one of the species promoted by disturbance (Bossard 1991). It is probably still taking advantage of past colonization possibilities with its long persisting seed bank (Bossard & Rejmanek 1994). Concerning studies on *L. polyphyllus* invasion and management, Valtonen et al. (2006) emphasizes the need for more thorough studies. They however suggest regular management like mowing to prevent seeds from germination and to eradicate the species. Unfortunately, no information about fire affecting Lupine invasion are known. There is also very little information known about *T. vulgare* spreading in connection with disturbance. It has been monitored while spreading along forest roads, which includes disturbance as well (Birdsall, McCaughey, & Runyon 2011), but further understanding of its behavior in grasslands and reactions to different treatments is needed to avoid any management mistakes. To sum up, it can be expected that the four invasive species present in the dataset (*C. epigejos, C. scoparius, L. polyphyllus* and *T. vulgare*) are rather promoted than inhibited by military management, but lack of any management action for twenty years might have also played a role in their spreading.

7.3. Environmental gradients

The study area is a relatively heterogenic part of the landscape consisting of patches with different soil characteristics, different moisture and also different management. Several authors concerned in soil and vegetation disturbance by military vehicles suggest that such use can change physical and chemical properties of soil (Prosser *et al.* 2000; Anderson *et al.* 2005). Main means of such change are soil compression, that can affect soil's permeability for water (Kade & Warren 2002), and destruction of vegetation cover, taking the nutrients away from the site (Leis *et al.* 2005) but also increasing Nitrogen mobility in soil for some time (Jentsch *et al.* 2009). In the present case the landscape before the founding of military area can be expected to be more or less homogenous (on a large scale), so there is no reason to expect bigger environmental differences to occur before. The landscape was normally inhabited with small agriculture etc., but all of it ceased when the army took control of the land. Nowadays, the environmental conditions are different for former training grounds and for the land left in normal agricultural landscape.

The difference in soil pH and in C/N ratio is rather the case of bigger variance on the training grounds that could be explained by bigger variability of natural conditions (on multiple scales) than on meadows unused by army. The patchiness and mosaic composition of different habitats could have been induced by military management with its irregular placement of vehicle tracks and craters. The pressure of past military management probably ranged in size and intensity (Warren *et al.* 2007). To compare, the other meadows were managed mainly by mowing or pasturing. This could account for the observed heterogeneity in resulting environmental conditions. However, the difference in exchangeable P is probably a different case. It exhibits lower values of P in the training ground soils than in undisturbed meadows. Two possible explanations could be suggested:

1) due to the overall poor and low quality soils, the agriculture has always been hard there and people might have used fertilizers (natural, such as manure, or artificial) to add needed nutrients to the system. Therefore, the meadows, which were probably agriculturally managed (some of them might even have been used as fields for a while), are exhibiting higher concentrations of exchangeable phosphorus. The increase in total nitrogen caused by agricultural use and fertilization is not expected, because it suffers more from losses in soluble organic forms and does not persist as long as phosphorus (McLauchlan 2007). 2) The missing phosphorus could be lost from the training grounds ecosystem by the burning of vegetation (probably occurred during training) and washing the freed nutrients away with outflowing water (White *et al.* 2008) or down to deeper layers of the soil. Soils, here in this area, are sandy and with very deep horizons (Sádlo, personal conversation) and washing out of released nutrients could occur easily.

There is a question of how soil properties affect species richness and vegetation composition. In this study only soil reaction showed significant effect on species richness. None of the other measured environmental properties had significant effect on species richness. However, they did have effect on vegetation composition and seem to be one of the important gradients present.

In the vegetation composition graphs, the influence of the management factor is visible as a strong predictor of vegetation composition. This is an important achievement of this study. It brings clear proof of vegetation composition difference with military management. Before, only a few authors were concerned in comparing vegetation composition of military disturbed and undisturbed grasslands (Jentsch *et al.* 2009). The fact that the factor of past military management is still traceable is in agreement with the findings of (Hirst *et al.* 2005), claiming that mesotrophic grasslands take 30 – 40 years to recover and calcareous grassland even up to 50 years. Many other human activities in the landscape are known to have effects persisting for a long time. Therefore the land-use history of a focus area is necessary to be taken into account, whether it was a field (Karlik & Poschlod 2009) or even a thousand years old Roman estate (Dambrine *et al.* 2007). The CCA ordination shows that some environmental variables are partially correlated with the level of disturbance. Total carbon and C/N ratio were used in the study of Leis *et al.* (2005) to quantify past disturbance, considering it to be a measure of plant biomass removed from system and, therefore, Carbon missing. Almost all measured environmental variables grow with disturbance (except exchange P). This could be connected more with the different management types rather than disturbance itself (highly correlated, Table 3.). Due to mowing and hay removal or grazing, the surrounding grasslands have lost some nutrients in the past decades, whereas training grounds have never had biomass removed from the site, so the nutrients should have stayed where they were. A special case occurs when phosphorus is washed out after fires (see above). The interesting thing is also the comparison with CCA ordination of data from the training grounds only. When compared to the full dataset analysis, the ordination diagram is not that different, showing that the main variability lies in the training grounds. There are, however, several noteworthy differences. Compared to the full data diagram, in the training ground data all nutrient arrows point more or less in the same direction (including phosphorus). This confirms the idea of phosphorus runoff connected with fires. Here all samples are from the same management type and, therefore, theoretically, they had the same probability of fire, but the disturbance intensity is different. In other ways the ordination diagram shows very similar patterns as the main one. The role of wetness index on training grounds should be mentioned as one of the main predictors of species composition.

Some species displayed in the ordination space give interesting information by their position. For example, the position of *Pinus sylvestris* on the right side of spectrum could be assigned to the colonization of unmanaged military grasslands by this tree species. It is common in surrounding forests and may therefore be interpreted a sign of future afforestation of disturbed sites if no management steps are coming.

7.4. Spatial scales

As mentioned before, larger heterogeneity in some environmental conditions on the military training grounds than on undisturbed meadows was discovered. Based on this knowledge, different scale processes could be expected, responsible for changes or variability of different grain. Due to the expected larger variability on training grounds, triplets of different distance amongst the three samples were used, hypothesizing that the sum of species in smaller triplets should be smaller than in bigger triplets. On military managed grasslands the difference is expected bigger than on undisturbed meadows. The results exhibit a slight increase of species richness with bigger inter sample distance, but with no significant difference of species richness growth on training grounds and meadows. Unfortunately the only thing that can be concluded is that at this spatial scale there is no difference. With approximately one quarter of explained variability lying in the triplets, it is not that small of a part to be ignored. For further studying different pattern of samples should be used. Bigger inter sample distances for the “distant” triplets or maybe a pair design with two triplets on the same spot would help to improve the results. This could eliminate part of the unwanted variability between the triplets, however in the present study due to multiple study objectives, pair design of triplets was not possible.

Some variability in species richness was explained by spatial cluster, showing that variability of particular regions of the area is rather large. Some of the clusters had, been exposed to different treatments. One cluster is placed around the military airport Hradčany (cluster 1) and two others lie close to the target area for testing of explosive ammunition (clusters 3 and 4). The airport one was significantly different in species richness from four other clusters. Most likely due to dry conditions at the airport and perhaps the regular trampling effect of vehicles and people using the airport for walks and other recreational purposes, grassland diversity has decreased. Unfortunately, a study has never been done to compare the different kinds of possible military impacts. It is therefore hard to decide the time or origin of the main vegetation change. The need for further study on this topic should be emphasized.

7.5. Discussion of used methods

Reliable methods were used, based on cited references of other works or on as reliable records and data as possible, however it is good to discuss potential problems. One potential source of errors could be the definition of training ground. Originally training grounds were defined solely by visual approximation based on aerial photographs from the year 2001 (10 years after abandonment). That was not very reliable, so the aerial photographs from the years 1953, 1971 and 1989 were used to verify the division of points. For each point all three time-layers were checked again and reclassified if necessary. One problem of possible importance is the clarity of decision, because disturbances are usually of a point or linear character (craters, tracks etc.) and these are not covering the whole area. In the classification of the land the grasslands that were found disturbed were expected to be disturbed more or less evenly during the time. For the purposes of analyses, training grounds were considered homogenous areas. Another solution dealing with the problem of discrete spatial extent of disturbances is the disturbance index calculated on the basis of classified raster image (Hirst *et al.* 2000) where the amount of disturbance is actually calculated from a circular area of 40 meters in diameter around the point. The time layer chosen for this calculation is the year 1989, which is two years before abandonment. Full activity of the army can be expected at this time period (unlike the last year – 1991, when most soldiers were leaving).

The soil samples collected should be viewed with the knowledge of their origin. They were collected from approximately 10 – 15cm depth from the center of each square for vegetation sampling. Only one soil sample from each square was collected, so they can be influenced by a random variation present in soil. For an overall picture of soil characteristics, it should be sufficient.

Another typical problem of a student thesis is that the student's knowledge level and the determination ability changes over time. Beneficial and error-free is the fact that all 273 reléves were sampled by the author himself. Since this is a student thesis and sampling was conducted during studies, the ability of author to determine species was gradually improving, and, therefore, it could be a possible source of error. With expectation of such a situation, both training grounds and meadows were sampled evenly during all three years of the study so the effect of determination error should be evenly distributed. Moreover during the sampling process, all unidentified specimens were collected and taken to the Department of Botany laboratories and determined using expert knowledge of experienced botanists.

For quantification of diversities various methods are used in present ecologic literature. A simple species number per sample for Alpha diversity was used in this study in most analyses for its simplicity and easy interpretation. Various indices of quantifying Alpha diversity are used in many studies (Milchunas *et al.* 2000; Reif *et al.* 2011) for they include the abundance of species in the calculation of diversity. Shannon's index, one of the most commonly used in the present days was also used in this study. A little bit more complicated, is the Beta diversity assessment method where tens of indices are used and most of them are mathematically convertible to the others (see (Tuomisto 2010a; b)). They differ in a few areas: whether they describe turnover along some gradient or variation, their use of presence / absence data and consideration of joined absences (Anderson 2011). It is also practical to use those frequently used in literature. The Jaccard dissimilarity and Bray-Curtis dissimilarity were used here because they are calculated based on differences in pairs of samples. They are reliable in small number of samples (Beta diversity was calculated for three samples at a time). Also the most classical Beta diversity quantification method by Whittaker was added, because it is still one of the most frequently used in literature, and it is simple and elegant. The use of multiple measures of Beta diversity should be a kind of defense against bias by wrong choice of index. According to the test of beta diversity, in different management types the results were similar in the sense that they did not show a difference. The slight variation observed might be explained by different ways of calculation. Perhaps the performance of the multiplicative diversity relationship is not the best in three-sample datasets. The possibility of choosing from a number of indices might be very beneficial in some cases, when one is interested in the specific characteristics of the community or is focused on some special environment. In the case of generally quantifying overall variance, as it was in this case, it is highly recommendable to use multiple indices and compare their results if they differ. It is also interesting to note the difference in the performance of the pair-indices (Jaccard and Bray-Curtis) that were averaged, and the classic community based Beta diversity index. It is necessary to be aware of the origin of the results obtained and interpret them according to this.

7.6. Beta diversity

One of the main focuses of this study was to the Beta diversity, because of an important phenomenon of the general homogenization on grater scales. It has been discussed (Loreau 2000) that increase in local diversity does not always mean increase in regional diversity and hence may cause homogenization of the landscape. This often occurs with widespread anthropogenic means of seed dispersal of various species. It is often generalist species well adapted to anthropogenic transport that colonize freshly created disturbances in military training areas (Hirst *et al.* 2000) so the few well adapted species will be widespread all over the area and cause Beta diversity decrease (Steiner & Köhler 2003). The hypothesis in this study was that rather homogenous kind of disturbance by military vehicles with included mean of seed dispersal will yield different values of beta diversity at military training grounds. Based on present results, the Beta diversity of training grounds was not different from that on meadows. Important thing to consider is whether it means that proposed effect of generalists spreading in disturbed tank tracks is not present, or that Beta diversity can be also lowered in meadows by other processes. Possible factor causing homogenization of cultural meadows might be their similar management. As discussed before, they were not left unmanaged and the agricultural management including mowing, hay-making and occasional grazing tend to promote the same species in all the meadows, causing homogeneity and decrease in Beta diversity (Cousins & Eriksson 2002). It is therefore important not to only pay attention to numerical differences of diversity indices, but also try to understand the processes standing behind them.

8. Conclusions

The study of species diversity in the abandoned military area Ralsko on multiple spatial scales yielded some interesting results. The data confirmed a significant effect of past military management on vegetation composition. There was also an interesting variability in abiotic conditions observed on the military training areas, probably connected with the effect of the management. Processes operating on several spatial scales were uncovered through changes in vegetation and species richness; on the largest scale, military use in general, than on smaller scale, different military activities – aircraft landing, explosions, tracked vehicles driving. On an even smaller scale little point disturbances, such as single craters or tank tracks, were found to play a role. The difference in Alpha, Beta or Gamma diversity was not confirmed, but this might also be caused by too long a time since the military management ceased. Finally, four important invasive plant species growing in the area were pointed out. They were probably promoted by military management and left totally uncontrolled today. This poses a serious threat to the ecosystem and some management steps should be taken.

9. Bibliography

Abella, S.R. (2010) Disturbance and Plant Succession in the Mojave and Sonoran Deserts of the American Southwest. *International Journal of Environmental Research and Public Health*, **7**, 1248–1284.

Althoff, D.P., Althoff, P.S., Lambrecht, N.D., Gipson, P.S., Pontius, J.S. & Woodford, P.B. (2007) Soil properties and perceived disturbance of grasslands subjected to mechanized military training: Evaluation of an index. *Land Degradation & Development*, **18**, 269–288.

Althoff, D.P., Gipson, P.S., Pontius, J.S. & Woodford, P.B. (2006) Plant community and bare ground trends on Fort Riley, Kansas: implications for monitoring of a highly disturbed landscape. *Transactions of the Kansas Academy of Science*, **109**, 101–119.

Althoff, P.S., Kirkham, M.B., Todd, T.C., Thien, S.J. & Gipson, P.S. (2009) Influence of Abrams M1A1 main battle tank disturbance on tallgrass prairie plant community structure. *Rangeland ecology & management*, **62**, 480–490.

Anderson, A., Palazzo, A., Ayers, P., Fehmi, J., Shoop, S. & Sullivan, P. (2005) Assessing the impacts of military vehicle traffic on natural areas. Introduction to the special issue and review of the relevant military vehicle impact literature. *Journal Of Terramechanics*, **42**, 143–158.

Anderson, M.J. (2011) Navigating the multiple meanings of beta diversity: a roadmap for the practicing ecologist (vol 14, pg 19, 2011). *Ecology Letters*, **14**, 210–210.

Birdsall, J.L., McCaughey, W. & Runyon, J.B. (2011) Roads Impact the Distribution of Noxious Weeds More Than Restoration Treatments in a Lodgepole Pine Forest in Montana, U.S.A. *Restoration Ecology*, **20**, 517–523.

Bossard, C.C. (1991) The role of habitat disturbance, seed predation and ant dispersal on establishment of the exotic shrub Cytisus scoparius in California. *American Midland Naturalist*, 1–13.

Bossard, C.C. & Rejmanek, M. (1994) Herbivory, growth, seed production, and resprouting of an exotic invasive shrub Cytisus scoparius. *Biological Conservation*, **67**, 193–200.

Connell, J.H. (1978) Diversity in tropical rain forests and coral reefs. *Science*, **199**, 1302–1310.

Cousins, S.A. & Eriksson, O. (2002) The influence of management history and habitat on plant species richness in a rural hemiboreal landscape, Sweden. *Landscape Ecology*, **17**, 517–529.

Dambrine, E., Dupouey, J., Laut, L., Humbert, L., Thinon, M., Beaufils, T. & Richard, H. (2007) Present forest biodiversity patterns in France related to former Roman agriculture. *Ecology*, **88**, 1430–1439.

De Bonte, A.J., Boosten, A., Van der Hagen, H. & Sýkora, K.V. (1999) Vegetation development influenced by grazing in the coastal dunes near The Hague, The Netherlands. *Journal of Coastal Conservation*, **5**, 59–68.

Demarais, S., Tazik, D.J., Guertin, P.J. & Jorgensen, E.E. (1999) Disturbance associated with military exercises. *Ecosystems of Disturbed Ground* (ed L.R. Walker pp. 385–396. Elsevier, Amsterdam.

Dennehy, C., Alverson, E.R., Anderson, H.E., Clements, D.R., Gilbert, R. & Kaye, T.N. (2011) Management Strategies for Invasive Plants in Pacific Northwest Prairies, Savannas, and Oak Woodlands. *Northwest Science*, **85**, 329–351.

Dickson, T.L., Wilsey, B.J., Busby, R.R. & Gebhart, D.L. (2008) Grassland plant composition alters vehicular disturbance effects in Kansas, USA. *Environmental management*, **41**, 676–684.

Dupre, C. & Diekmann, M. (2001) Differences in species richness and life-history traits between grazed and abandoned grasslands in southern Sweden. *Ecography*, **24**, 275–286.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

GRASS Development Team, 2008. Geographic Resources Analysis Support System (GRASS) Software, Version 6.3.0. http://grass.osgeo.org

Guretzky, J., Anderson, A. & Fehmi, J. (2006) Grazing and military vehicle effects on grassland soils and vegetation. *Great Plains Research: A Journal of Natural and Social Sciences*, 803.

Házi, J., Bartha, S., Szentes, S., Wichmann, B. & Penksza, K. (2011) Seminatural grassland management by mowing of Calamagrostis epigejos in Hungary. *Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology*, **145**, 699–707.

Hirst, R.A., Pywell, R.F., Marrs, R.H. & Putwain, P.D. (2005) The resilience of calcareous and mesotrophic grasslands following disturbance. *Journal of Applied Ecology*, **42**, 498–506.

Hirst, R., Pywell, R. & Putwain, P. (2000) Assessing habitat disturbance using an historical perspective: The case of Salisbury Plain military training area. *Journal Of Environmental Management*, **60**, 181–193.

Hughes, A.R., Byrnes, J.E., Kimbro, D.L. & Stachowicz, J.J. (2007) Reciprocal relationships and potential feedbacks between biodiversity and disturbance. *Ecology Letters*, **10**, 849–864.

Jentsch, A., Friedrich, S., Steinlein, T., Beyschlag, W. & Nezadal, W. (2009) Assessing Conservation Action for Substitution of Missing Dynamics on Former Military Training Areas in Central Europe. *Restoration Ecology*, **17**, 107–116.

Kade, A. & Warren, S.D. (2002) Soil and Plant Recovery After Historic Military Disturbances in the Sonoran Desert,USA. *Arid Land Research and Management*, **16**, 231–243.

Karlik, P. & Poschlod, P. (2009) History or abiotic filter: which is more important in determining the species composition of calcareous grasslands? *Preslia*, **81**, 321–340.

Kubát, K., Hrouda, L., Chrtek, J.J., Kaplan, Z., Kirschner, J. & Štěpánek, J. (2002) *Klíč Ke Květeně České Republiky*. Academia, Praha.

Kubát, M. (2010) *Vliv Lokální Pokryvnosti Dřevinného Patra Na Bylinnou Vegetaci Na Malé Prostorové Škále* (ed J Vojta). Univerzita Karlova v Praze, Prague.

Lehmann, C. & Rebele, F. (2002) Successful management of Calamagrostis epigejos (L.) ROTH on a sandy landfill site. *Journal of Applied Botany-Angewandte Botanik*, **76**, 77–81.

Leis, S., Engle, D., Leslie, D. & Fehmi, J. (2005) Effects of short- and long-term disturbance resulting from military maneuvers on vegetation and soils in a mixed prairie area. *Environmental management*, **36**, 849–861.

Lepš, J. (1990) Stability. *Succession in abbandoned fields: Studies in Central Bohemia, Czechoslovakia* (ed J. Osbornová Kluwer Academic Publishers, Dordrecht.

Loreau, M. (2000) Are communities saturated? On the relationship between alpha, beta and gamma diversity. *Ecology Letters*, **3**, 73–76.

Lu, H.-P., Wagner, H.H. & Chen, X.-Y. (2007) A contribution diversity approach to evaluate species diversity. *Basic And Applied Ecology*, **8**, 1–12.

Malmivaara, M., Lofstrom, I. & Vanha-Majamaa, I. (2002) Anthropogenic Effects on Understorey Vegetation in Myrtillus Type Urban Forests in Southern Finland. *Silva Fennica*, 1–15.

Matthijs, J.H. (1996) Impact of grazing and atmospheric nitrogen deposition on the vegetation of dry coastal dune grasslands. *Journal Of Vegetation Science*.

McLauchlan, K. (2007) The Nature and Longevity of Agricultural Impacts on Soil Carbon and Nutrients: A Review. *Ecosystems*, **9**, 1364–1382.

Milchunas, D.G., Schulz, K.A. & Shaw, R.B. (2000) Plant Community Structure in Relation to Long-Term Disturbance by Mechanized Military Maneuvers in a Semiarid Region. *Environmental management*, **25**, 525–539.

Ministerstvo zemědělství ČR, Seznam invazních a expanzivních druhů vyšších rostlin, které narušují funkci ekosystémů a mohou způsobovat hospodářské škody. Vyhláška č. 482/2005 Sb.

Novak, J., Sádlo, J. & Svobodova-Svitavska, H. (2012) Unusual vegetation stability in a lowland pine forest area (Doksy region, Czech Republic). *The Holocene*, **22**, 947–955.

Oksanen, J., Blanchet, G.F., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H. & Wagner, H. (2013) vegan: Community Ecology Package.

Olff, H., Vera, F.W.M., Bokdam, J., Bakker, E.S., Gleichman, J.M., de Maeyer, K. & Smit, R. (1999) Shifting Mosaics in Grazed Woodlands Driven by the Alternation of Plant Facilitation and Competition. *Plant Biology*, **1**, 127–137.

Olsen, R.S. (1982) Phosphorus. *Methods in Soil Analysis, Part 2*, 9th ed (ed A.L. Page pp. 403–430. ASA, Madison, Wisconsin.

Pottier, J. & Evette, A. (2010) On the Relationship Between Clonal Traits and Small-Scale Spatial Patterns of Three Dominant Grasses and its Consequences on Community Diversity. *Folia Geobotanica*, **45**, 59–75.

Prosser, C.W., Sedivec, K.K. & Barker, W.T. (2000) Tracked vehicle effects on vegetation and soil characteristics. *Journal of Range Management*, 666–670.

Rebele, F. & Lehmann, C. (2001) Biological flora of Central Europe: Calamagrostis epigejos (L.) Roth. *Flora*, **196**, 325–344.

Reif, J., Marhoul, P., Čížek, O. & Konvička, M. (2011) Abandoned military training sites are an overlooked refuge for at-risk open habitat bird species. *Biodiversity And Conservation*, **20**, 3645–3662.

Rejmanek, M., Rejmankova, E. & Holzner, W. (2004) Species diversity of plant communities on calcareous screes: the role of intermediate disturbance. *Preslia*, **76**, 207–222.

Rosenthal, G. (2010) Secondary succession in a fallow central European wet grassland. *Flora*, **205**, 153–160.

Sádlo, J., Cílek, V., Dreslerová, D., Hájek, P. & Pokorný, P. (2005) *Krajina a Revoluce*. Malá Skála.

Srinivasan, M.P. (2011) Exotic shrub invasion in a montane grassland: the role of fire as a potential restoration tool. *Biological invasions*, **14**, 1009–1028.

Steiner, N.C. & Köhler, W. (2003) Effects of landscape patterns on species richness—a modelling approach. *Agriculture, Ecosystems & Environment*, **98**, 353–361.

Tilman, D. & Downing, J.A. (1994) Biodiversity and stability in grasslands. *Nature*, **367**, 363–365.

Tilman, D. & Haddi, El, A. (1992) Drought and biodiversity in grasslands. *Oecologia*, **89**, 257–264.

Tuomisto, H. (2010a) A diversity of beta diversities: straightening up a concept gone awry. Part 2. Quantifying beta diversity and related phenomena. *Ecography*, **33**, 23–45.

Tuomisto, H. (2010b) A diversity of beta diversities: straightening up a concept gone awry. Part 1. Defining beta diversity as a function of alpha and gamma diversity. *Ecography*, **33**, 2–22.

Valtonen, A., Jantunen, J. & Saarinen, K. (2006) Flora and lepidoptera fauna adversely affected by invasive Lupinus polyphyllus along road verges. *Biological Conservation*, **133**, 389–396.

Warren, S.D., Holbrook, S.W., Dale, D.A., Whelan, N.L., Elyn, M., Grimm, W. & Jentsch, A. (2007) Biodiversity and the heterogeneous disturbance regime on military training lands. *Restoration Ecology*, **15**, 606–612.

White, J.R., Gardner, L.M., Sees, M. & Corstanje, R. (2008) The Short-Term Effects of Prescribed Burning on Biomass Removal and the Release of Nitrogen and Phosphorus in a Treatment Wetland. *Journal of Environment Quality*, **37**, 2386.

Whittaker, R.H. (1960) Vegetation of the Siskiyou Mountains, Oregon and California. *ECOLOGICAL MONOGRAPHS*, **{30}**, {280–338}.

zanikleralsko.cz - The website focused on history of abandoned villages in the Ralsko military area