Response of phylogenetic structure of vegetation to changing soil properties in Latvian grasslands

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Abstract

Grasslands as important parts of agricultural landscape in Latvia and potential response of phylogenetic structure of grassland's vegetation to chemical properties in the area were studied in this thesis. The research is based on vegetation data obtained from phytosociological survey of different types of grasslands across Latvia which produced 87 phytosociological relevés. Soil samples from each plot were taken to determine soil chemical properties. Subsequent statistical analysis produced interpreted results.

The key result of this research is detection of response of phylogenetic structure to soil chemical properties. Taxa significantly respond to concentration of nitrogen, potassium and sodium. The strongest correlation with chemical properties was proven in family Poaceae and order Poales. These taxa positively correlated with high concentration of nitrogen and in case of Poaceae with potassium. Moreover, nitrogen-rich soils were more often covered with graminoids. Family Rosaceae and order Rosales responded positively to higher concentration of sodium in soils. Negative correlation between nitrogen-rich soils and legumes (Fabaceae and Fabales) was found as another important result of this research. Statistical tests did not prove any significant relationships of phylogenetic structure and soil properties in higher than order taxa level.

Introduction

Grasslands of west boreal zone are mostly considered as a remainder of traditional extensive agricultural practises (management – harvesting and grazing) which has been applied in Baltic area for centuries in the past (Gustiņa 2016). However appearance of these vegetation formations in current landscape has changed and area of semi-natural grasslands has strongly decreased recently. Furthermore the quality and degree of naturalness also strongly dropped down. (National report 2014). Degradation of semi-natural grasslands in Baltic area is a result of inappropriate management applications or land abandonment mostly (Rūsiņa 2017). Intensive agriculture usage of grasslands sites poorly influenced the soil chemistry besides the vegetation of grasslands itself. Change of chemical composition of soil properties may reflect as decline of vegetation composition, respectively its diversity and productivity (Mládková et al. 2015).

Diversity of plant community is a key factor determining its vitality, respectively quality of whole ecosystem.Exploring biodiversity in higher taxonomical levels (etc. phylogenetic structure) may help us to study important ecological questions and processes that can be implemented in nature conservation's practice (Cheng et al. 2018, Bitomský 2020).

This thesis is trying to studyrelationship between phylogenetic structure of vegetation and specific soil properties on selected grassland sites in Latvia. Results of the study may extend current knowledge of ecological processes in grassland communities moreover they can be applied in grassland's conservation management.

Methods & Material

The thesis is based on a biological research on selected grassland sites across Latvia. Biological research included collection of vegetation data soil samples during vegetation season in 2018 and 2019. Selection of studied sites was non-random. Biological research was realized on grassland sites which are involved in GrassLIFE project (LIFE16 NAT/LV/000262). Common feature for all studied sites is their location in protected areas. Localisation of studied sites is displayed in a figure below.

Vegetation data collection

Vegetation community of all grasslands was sampled by plots of a standard size of 1m^2 which adjacent to the soil pit where soil samples had been collected. Size of sampling plot had to be large enough to reflect the true species composition of specific grassland (Auestad et al. 2008, Dong et al.2019) but also small enough to maintain soil chemistry homogeneity. Composition of soil chemical properties may change with the growing distance from the sampling soil pit according to Price et al. 2014 and Xue et al. 2019. Coverage of every species was recorded in each sampling plot in percentage scale. Species with coverage lower than 1 % were labelled as a species with rare presence with coverage 0.5 %. Collected vegetation data was digitalized using turboveg software and 87 relevés form 87 sampling plots were created.

Each detected species was classified according to the APG IV system (2016) to higher taxa, such as family, order etc. The APG IV system was used also to unify nomenclature of all higher taxa. Ferns were classified according to Christenhusz et al. 2014, 2019. Coverage of higher taxa in each relevé was counted as a sum of coverage of all detected species in taxon. Detected species was divided into families, orders and one higher taxon consist of related orders according to their evolutionary proximity.

Soil data collection

Information about soil chemistry was gotten from a vast soil research. This research was based on collection of soil samples from each study grassland site. Soil samples were collected from soil profiles in depth 0 to 10 cm which were uncovered by digging soil pits. Collected samples from fields were air-dried afterwards. Dry out samples were crushed, sieved by 2 mm sieve and used in following laboratory analysis.

Performed laboratory analysis followed standardized methods of International Organization for Standardization (Cools & De Vos 2010). For this thesis purposes these soil chemical properties were measured: percentage of total nitrogen and carbon in soil, pH, amount of exchangeable cations and amount of present phosphorus. Phosphorus detection was based on Mehlich 3 method (Mehlich 1984).

Statistical analysis

The statistical analysis of the obtained data was performed using the RStudio software. Redundancy analysis (RDA) was used to determine the relationship between individual taxonomic units and elements contained in the soil profile. Using RDA, all possible combinations of all eight chemical characteristics were analysed by entering the values of at least three of them together with data on the coverage of each taxonomic unit within a taxonomic group (family, order, etc.). Subsequently, each RDA performed was tested by analysis of variance (ANOVA) with a parameter significance level of p-value = 0.05. Combinations of chemical characteristics whose analyses showed significant p-values were recorded.

Results

Statistical analysis of the data was carried out within individual taxonomic groups at the level of families, orders, and another higher taxonomic unit, known as the fourth clade, which included the taxonomic units Commelinids, Fabids, Malvids, Campanulids, Lamiids, Equisetidae, Ophioglossidae, Ranunculales, Saxifragales, Caryophyllales, Ericales, and Asparagales. Higher taxonomic groups did not show significant results during testing mainly due to the high variability of data within taxonomic units and are therefore not commented on in the following text.

The analyses involved 87 phytocenological images taken during the field survey. To each of them were assigned values of soil characteristics from the associated soil sample analysis. During the fieldwork, 209 plant species were found and classified into 33 families, 21 orders and twelve taxa at the level of the fourth clade.

Response of families to soil chemical properties

By successively testing the RDA analyses, which examined the relationship between the individual components of soil chemistry and vegetation composition from the perspective of the families, using analysis of variance, the combination of the elements nitrogen, sodium and potassium (NKNa) achieved the lowest p-values - p-value = 0.032. The combination of nitrogen, potassium, carbon, sodium (NKCNa) was also statistically significant – this combination of chemical properties was selected and statistically analyzed.

The RDA analysis showed that the families Poaceae, Rosaceae and Ranunculaceae respond positively to the selected chemical elements. The occurrence of the family Poaceae is linked to increasing levels of potassium in the soil. Species of the Ranunculaceae family occur together with higher values of carbon and nitrogen. The Rosaceae family shows a tendency towards increasing soil sodium content. A negative relationship to sodium is evident in the Fabaceae. Potassium is negatively correlated with the Urticaceae and nitrogen substrates are not suitable for the Caryophyllaceae according to the RDA, in the latter two cases the strength of the correlation is low.

The RDA also showed an almost zero correlation between sodium and potassium. The values of carbon and nitrogen show the highest degree of positive correlation of all the chemical traits assessed by RDA.

Response of orders to soil chemical properties

The ANOVA test generated significant p-values only for the combination of chemical characteristics: nitrogen, potassium, sodium. Other combinations of soil nutrients in combination with soil pH did not show statistically significant test values. The combination of NCKNa nutrients that determined the occurrence of some families in the phytocenological images reached p-values weakly exceeding the 0.05 significance level (specifically 0.055). Therefore, a statistically significant combination of elements - NKNa, i.e. nitrogen, potassium, sodium - was selected to assess the effect of soil chemistry on the taxonomic group of orders.

Soil chemistry properties are positively correlated with the orders Rosales, Poales, Apiales and partly also with Ranunculales. Taxa Ranunculales and Poales are positively correlated with increasing soil nitrogen values. The correlation for the order Poales is stronger than for the order Ranunculales, where it is low. Similar to the family Rosaceae, the higher taxon Rosales is positively correlated with soil sodium. Apiales is weakly positively correlated with elevated levels of soil sodium and potassium. There is a relatively strong negative correlation between soil potassium levels and the orders Fabales, Lamiales and Caryophyllales.

Response of fourth clade taxa to soil chemical properties

Statistical tests of redundancy analyses for all combinations of soil chemical properties and their association with taxa of the fourth clade taxonomic group did not show significant results in any case. Even so, some combinations of chemical properties were at least close to the specified significance level of 0.05. The response of higher taxa from fourth clade taxonomic group to soil chemical composition is questionable due to statistically non-significant analyses, and potential correlations between taxa cannot be confidently established to determine the eventual response of taxa to soil chemical composition.

Discussion

On the basis of the modelling and statistical testing performed, it is possible to predict the association of some phylogenetic groups to elevated levels of certain nutrients in the soil. The phylogenetic structure was influenced by the concentrations of nitrogen, sodium and potassium in the soil. At the family level, carbon also determined the occurrence of some taxonomic units.

The strongest correlations with soil chemistry were exhibited by taxa from the grasses-Poaceae and Poales, with this relationship occurring mainly at sites that had been fertilized, mulched, or seeded with a grass mixture in the past. According to Zhao et al. (2019), who study the response of phylogenetic community structure in temperate grasslands, higher soil nitrogen levels help to increase the cover of grasses in the vegetation. Moreover, nitrogen reduces the abundance and cover of non-grass plant species (Ren et al. 2017). This was confirmed at the level of orders, where grasses (Poales) tended to higher nitrogen values. However, the family Poaceae showed higher potassium affinity. A possible explanation is provided by Divito & Sadras (2013) who linked potassium to increased nodulation and subsequent improved nitrogen fixation by nitrifying bacteria, thereby increasing the nitrogen values that plants are able to fix. In addition, the work of Merunková & Chytrý (2012) report a negative relationship between high soil potassium and species richness of grass communities due to the dominance of more competitive grasses, which they explain by increased grass cover in relation to higher soil potassium values. The higher abundance of grasses in relevés produced lower phylogenetic diversity, which can be inferred from the negative correlation of the taxa Poaceae and Poales with several other taxa within the phylogenetic level, especially at the level of orders. Poales shows negative relationships with the orders Boraginales, Geraniales, Saxifragales, Myrtales, Rosales and Caryophyllales. According to Güsewell (2004), grasses are associated with soils with low phosphorus concentrations. The main reason is their adaptation to phosphorus limitation in the form of recycling senescent leaves. Correlations between Poaceae and Poales with soil phosphorus values, however, have not been confirmed. Phosphorus values did not show significant correlations with any of the taxa.

Other taxonomic groups that responded to soil chemistry were Rosales and the members of the family Rosaceae. Taxa from this group were more frequent in soils rich in sodium, i.e. in more saline soils. This relationship may be the result of the adaptation of Rosaceae representatives to elevated salinity levels reported by Zhang et al. (2019) in a study on the response of selected species of this family to salinity stress. In terms of the species representation of the taxon Rosales, hence Rosaceae, these taxa included rather euryvalent plant species that are sometimes considered as ruderal species such as *Fragaria vesca*, *Filipendula ulmaria*, *Potentilla reptans*, *Potentilla argentea*, *Rubus idaeus*, *Geum urbanum*, etc. The affinity between Rosales taxa and high sodium soils can be also explained by the high resistance to adverse conditions caused by soil salinity. The families Onagraceae and Geraniaceae were positively correlated with Rosacea. Representatives of these taxa were more frequent in the presence of representatives of the Rosaceae family. The correlation with representatives of Onagraceae is relatively strong, suggesting that representatives of this family seek sodium-rich soils. However, this statement cannot be confirmed. The correlation is most likely the result of the similarity in the ecological requirements of the species in these two groups, as there were mostly ruderal and euryvalent plant species within the Onagraceae (*Oenothera biennis* and *Epilobium montanum*).

Fabaceae and Fabales taxa both responded negatively to high soil nitrogen levels, a trend also addressed in studies by Divito & Sadras (2013), Zhao et al. (2019) and Ren et al. (2017). These studies agreed on the exclusive effect of nitrogen in relation to representatives of the taxonomic units Fabaceae and Fabales. Fabaceae and Fabales are being displaced by expanding grass species, according to Zhao et al. (2019). However, this relationship was not confirmed in the thesis.

Correlations at the family level (Fabaceae and Poaceae) and at the order level (Fabales and Poales) did not show significant values in statistical tests. The work of Divito & Sadras (2013) shows a positive correlation between representatives of the taxon Fabales with higher levels of potassium and phosphorus. According to these authors, potassium helps the fixation of atmospheric nitrogen through symbiosis between plants and nitrifying bacteria. This type of symbiosis is characteristic of the Fabales taxon (Kneip et al. 2007), but the correlation between potassium and phosphorus was not confirmed in the research discussed. Within families and orders, a negative correlation was found between the Fabaceae/Fabales and Rosaceae/Rosales groups. Representatives of the negatively correlated taxa do not occur together in the vegetation. According to APG IV (2016) and Ravi et al. (2007) these groups can be considered as evolutionarily very close (sister) and because of this evolutionary proximity they may share their ecological niches, thus amplifying the effect of interspecies competition (Dong et al. 2019).

The affinities of other phylogenetic units to selected soil characteristics were investigated. However, the correlation values were low and thus the response of phylogenetic groups to soil substrate is questionable. Specifically, there was a positive relationship of the family Ranunculaceae with soil carbon and nitrogen values and the higher taxonomic unit Ranunculales with higher soil nitrogen.

The family Caryophyllaceae showed strong negative correlation with soil nitrogen concentration. Its parent taxonomic unit Caryophyllales reacted negatively with high levels of soil potassium. Inspection of the dataset shows that these taxonomic units include typical meadow plant species that, according to Rūsiņa (2017), serve as indicators of semi-naturalness of sites with higher species diversity in Latvia or are species that seek undivided vegetation (e.g. *Dianthus deltoides*, *Lychnis viscaria*, *Arenaria serpyllifolia*, *Cerastium semidecandrum*, *Herniaria glabra*, etc.). Thus, their negative relationship can be explained by the above commented negative relationship between nitrogen- and potassium-rich soils and species diversity (Merunková & Chytrý 2012, Ren et al. 2017), hence the above mentioned increased expansion capacity of grasses on the potassium-nitrogen gradient. Moreover, representatives of the taxa Caryophyllaceae and Caryophyllales are significantly negatively correlated with grass species.

In modelling the responses of the phylogenetic structure of grassland communities to soil chemistry properties, the higher taxonomic level reported in APG IV (2016) was also tested. This level consisted of the taxa Commelinids, Fabids, Malvids, Campanulids, Lamiids and orders that could not be assigned to any of these taxa according to the system. The resulting response to soil chemical properties was not statistically confirmed at this taxonomic level. A possible reason for this is the high variability of the data in the input dataset, where groups that include multiple orders may have had higher cover values compared to sister taxa that include only one order. None of the publications discussed discuss the relationship between these groups and soil chemistry, so a more thorough investigation of this issue would be advisable.