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Assessment of grassland restoration potential using vegetation and soil indicators: how to treat outliers?

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INTRODUCTION

GrassLIFE project aims at active protection of five grassland habitats of EU importance on 1320 ha in Latvia. The aim of the project is to recreate semi-natural grasslands in the place of old fallow-lands and previously improved grasslands. The main methods applied are soil fertility reduction by intensive mowing and grazing, seed addition by green hay, and sowing of *Rhinanthus* spp.

Restoration success depends primarily on suitable environmental conditions and the recolonization capacity of target species. The later can be successfully overcome by seed addition using seed-containing green hay or other seed transfer methods (Kiehl et al. 2010). The precondition for successful seed transfer is appropriate soil conditions. A negative relationship of soil fertility and semi-natural grassland plant species richness has been demonstrated (e.g. Janssens et al., 1998). One of the most frequently discussed soil factors is plant available phosphorus (P). It is argued that only sites with P content less than 10-16 mg kg^{-1} (Olsen) are appropriate for semi-natural grassland restoration (Gilbert et al. 2009). The common guidelines to choose the right restoration/recreation method is to perform pre-restoration assessment of soil fertility and vegetation composition. If the soil available P (Olsen) is > 25mg kg^{-1}, and vegetation is dominated by aggressive species like *Dactylis glomerata, Phleum pratense, Anthriscus sylvestris, Ranunculus repens*, than the potential of enhancement of species richness is low (Blakesley, Buckley, 2016).

Our aim was to clarify the relationship between plant available P and vegetation composition prior to restoration in GrassLIFE farms. We asked if we can rely on vegetation indicators to select restoration/recreation method without measuring plant available P?

STUDY AREA

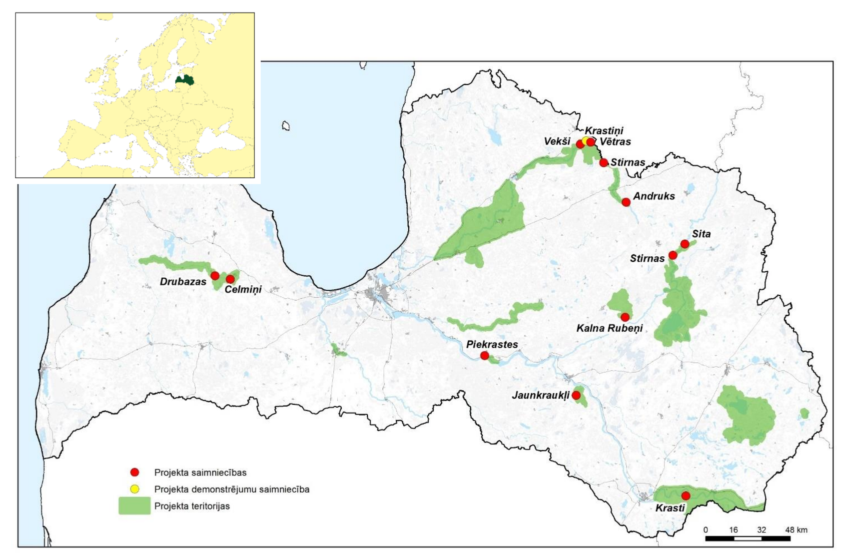

Fig. 1. Project areas. Natura 2000 areas in green, red dots – project partners (farms)

Latvia is a lowland country (highest point is 312 m) located at the eastern coast of the Baltic Sea. Forests cover about 50 % of the country, mires 6 %, and agricultural land 38 %, while semi-natural grasslands occupy only about 0.7 % of the territory. The mean annual temperature is 6.2 °C (February –4.6 °C, August +17.1 °C), and precipitation is 650 mm. The vegetation period lasts for 180–200 days.

Habitat restoration activities are implemented in 12 project farms (project partners) and on semi-natural grasslands managed by Latvian Fund for Nature. All project partners are small to medium-sized entrepreneurs who manage 40 to 400 ha large semi-natural and perennial grassland areas located in eight Natura 2000 sites. Most of them are beef calves growing farms who diversify their economic activities by tourism, bee-keeping, poultry farming, grain or vegetable growing. Two of the partners are entrepreneurs whose core business is not connected with agricultural sector. They keep cattle exclusively for managing their semi-natural grassland areas.

METHODS

Vegetation description

In total, 55 grasslands were chosen for analysis to encompass all variation in management history and present-day vegetation. To evaluate grassland semi-naturalness we used a list of expansive species and semi-natural grassland indicator species developed for Latvian semi-natural grasslands (Rūsiņa (ed.) 2017) (Table 1). We classified grassland as semi-natural if at least five indicator species were commonly present in vegetation. Areas without any indicator species and with percentage cover of expansive species >25% were classified as improved grasslands, and areas intermediate between two previous categories as semi-improved grasslands. 87 vegetation plots of $25 m^2$ were described (18 plots in semi-natural grasslands, 25 plots in semi-improved, and 42 plots in improved grasslands). Percentage cover of all vascular plant species and total cover of each vegetation layer and litter layer were recorded. Nomenclature for vascular plants followed Gavrilova & Šulcs (1999).

Soil analysis

Soil samples were taken from the upper layer of 0 to 10 cm from the soil pit dug next to the vegetation plot. Soil sample preparation for chemical analysis included air-dried soil sample sieving through a 2-mm sieve. Exchangeable elements (Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, Fe^{3+}, Mn^{2+}) (mg kg^{-1}), were determined in $BaCl_2$ solution by using an atomic absorption spectrometer Perkin Elmer Analyst 200. Soil pH_{BaCl2} was measured with a glass electrode in 1 M $BaCl_2$ (1:2.5 mass-to-volume ratio), using a pH-meter WTW inoLab. Total nitrogen and total carbon content (%) were determined by dry combustion (elementary analysis) by using an element analyzer "EuroVector". Plant available soil phosphorus was determined according to Mehlich 3 method (Mehlich, 1984). To compare data with critical phosphorus levels from literature according to Olsen method, results of Mehlich 3 were recalculated based on assumption that Olsen method extracts only 40% of the amount of phosphorus extracted by Mehlich 3 (Zbíral, Němec, 2002).

Data analysis

Vegetation compositional patterns were analysed using non-metric multidimensional scaling (NMS) ordination with Sorensen distance measure (McCune, Mefford, 1997). Monte Carlo test was used to evaluate the extracted axes. Outlier analysis was performed prior to ordination, and plots with standard deviation greater than 2.00 were omitted (in total, 7 plots were excluded from NMS analysis).

Table 1. Semi-natural grassland plant indicator species and expansive species

Indicator species		Expansive species	
Acinos arvensis	Linum catharticum	Aegopodium podagraria	Medicago sativa
Agrimonia eupatoria	Nardus stricta	Alopecurus pratensis	Phalacroloma annuum
Astragalus danicus	Ophioglossum vulgatum	Anthriscus sylvestris	Phleum pratense
Briza media	Pimpinella saxifraga	Arctium tomentosum	Phragmites australis
Cardamine pratensis	Plantago media	Artemisia vulgaris	Plantago major
Carex caryophyllea	Platanthera bifolia	Bromopsis inermis	Ranunculus repens
Carex flacca	Polygala comosa	Calamagrostis epigeios	Rubus caesius
Carex ornithopoda	Polygala vulgaris	Chaerophyllum aromaticum	Rumex confertus
Carex panicea	Primula veris	Chelidonium majus	Saponaria officinalis
Cirsium acaule	Ranunculus auricomus	Cirsium arvense	Solidago canadensis
Dianthus deltoides	Scorzonera humilis	Dactylis glomerata	Taraxacum officinale
Filipendula vulgaris	Sedum acre	Elytrigia repens	Trifolium repens
Fragaria viridis	Sieglingia decumbens	Erigeron canadensis	Urtica dioica
Galium boreale	Succisa pratensis	Filipendula ulmaria	
Galium verum	Thymus ovatus	Galega orientalis	
Geranium palustre	Thymus serpyllum	Heracleum sibiricum	
Gymnadenia conopsea	Trifolium montanum	Lolium perenne	
Helichrysum arenarium	Trollius europaeus		
Helictotrichon pratense	Viscaria vulgaris		
Leontodon hispidus			

CONCLUSIONS

Soil P content did not correlate significantly with abundance of expansive species or semi-natural grassland indicator species, thus general guidelines for choosing of restoration method in relation to levels of soil P could only partly be used in study area.

Vegetation seemed to be better indicator of restoration potential than soil P levels. Still, other soil factors could be important, for instance K and N.

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RESULTS

Vegetation composition

NMS ordination showed vegetation composition to vary with amount of total N and Ellenberg moisture and nitrogen. The NMS ordination was best wit by three-axis solution. The first two axis accounted for 64% of the variability in the data. Semi-natural and semi-improved grassland plots were separated from improved grassland plots along the Axis 2. The highest values (above >25 mg kg^{-1}) of soil phosphorus were associated both with improved and with semi-improved grasslands at the driest end of the moisture gradient.

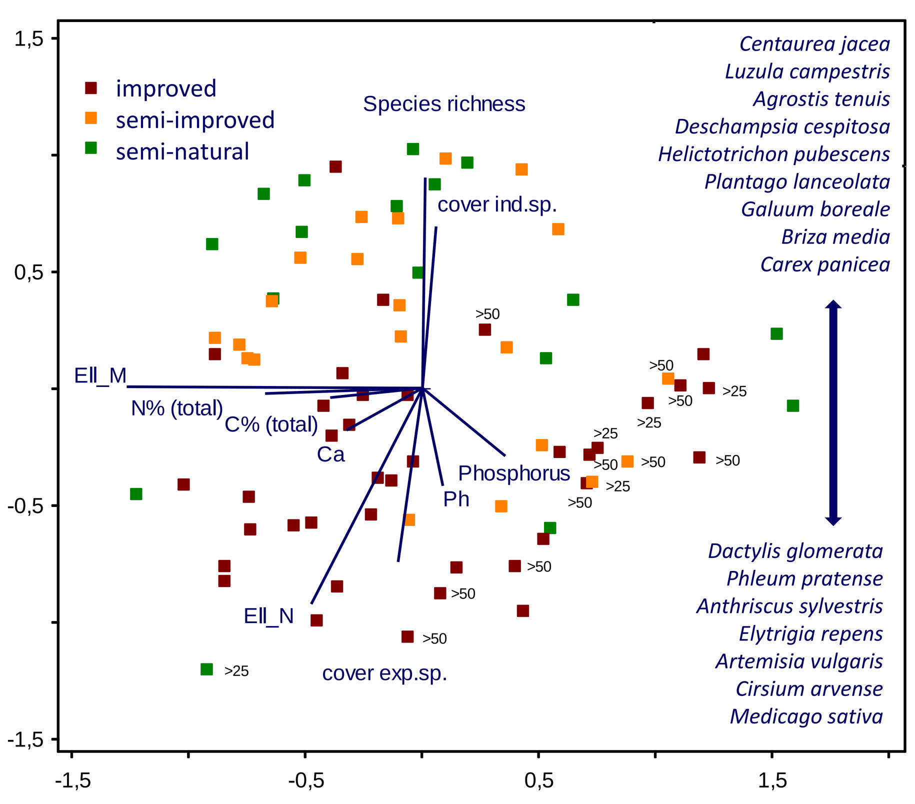


Fig. 2. NMS ordination of vegetation plots overlaid by soil factors (chemical analysis), Ellenberg indicator values for moisture (Ell_M) and nitrogen (Ell_N), and vegetation cover of expansive species and semi-natural grassland indicator species. Final stress 15.95, final instability 0.00, number of iterations – 84. Coefficient of determination for the correlations between ordination distances and distances in the original space was 0.36 for Axis 1, 0.28 for Axis 2, and 0.14 for Axis 3. >25 and >50 indicate plots with phosphorus content higher than 25 and 50 mg kg^{-1}, respectively.

Relationship between semi-natural grassland indicator species, expansive species and soil P

Both semi-natural grassland indicator species and expansive species did not show significant correlations (Kendall) with soil P. Although indicator species occurred more frequently in soils with low soil P, considerable share of occurrences were also in soils with soil P > 25 mg kg^{-1} (Table 2).

Table 2. Percentage frequency of semi-natural grassland indicator species in soils with different levels of soil P (only species with at least 10 occurrences are shown)

	Soil P (mg kg^{-1})			
	<10	10-25	25-50	>50
Carex panicea	100	0	0	0
Filipendula vulgaris	86	0	0	14
Ranunculus auricomus	84	13	3	0
Trifolium montanum	83	17	0	0
Galium boreale	83	13	0	4
Briza media	78	6	11	6
Geranium palustre	77	23	0	0
Leontodon hispidus	67	22	11	0
Linum catharticum	67	17	17	0
Primula veris	67	0	17	17
Helictotrichon pratense	64	21	14	0
Dianthus deltoides	60	10	10	20
Fragaria viridis	50	13	19	19
Plantago media	45	18	27	9
Galium verum	38	38	25	0
Agrimonia eupatoria	29	19	19	33
Pimpinella saxifraga	22	28	22	28
Viscaria vulgaris	14	14	57	14
Sedum acre	0	17	67	17

OUTLIERS

Low soil P with abundant expansive species

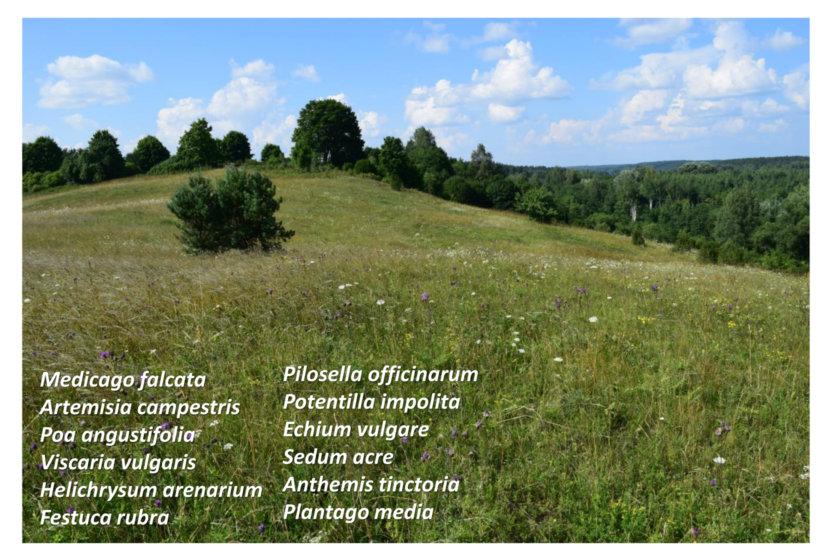
45 out 87 plots were located on soils with very low soil P (<10 mg kg^{-1}). Vegetation composition of more than a half of these plots showed low restoration potential with cover of expansive species like *Alopecurus pratensis, Phleum pratense, Dactylis glomerata* higher than 25%. Only two of sites showed high K level (>120 mg kg^{-1}), and total N was lower than 0.6%. The negative effects of nitrogen enrichment on biodiversity are primarily connected with soil acidification (Ceulemans et al. 2014). Soil pH was in a range from 4.5 to 6.6, and it was not significantly different from plots with lower cover of expansive species.

Soil texture: fine sand
Deposits: alluvial
pH: 4.71
CEC: 28.64
C: 8.87%
N: 0.54%
K: 58.68 mg kg^{-1}
P (Mehlich 3): 7.4 mg kg^{-1}
P (Olsen, recalc.): 2.96 mg kg^{-1}
Species richness: 26 ($25 m^2$)

Soil texture: loamy sand
Deposits: alluvial
pH: 5.74
CEC: 12.96
C: 2.37%
N: 0.21%
K: 175.59 mg kg^{-1}
P (Mehlich 3): 14.50 mg kg^{-1}
P (Olsen, recalc.): 5.80 mg kg^{-1}
Species richness: 21 ($25 m^2$)

High soil P without expansive species

21 out of 87 plots were characterised by high content of soil P (>25 mg kg^{-1}). Vegetation composition showed high potential of restoration in more than half of them (12 plots), and no other soil factors were indicating elevated soil fertility. All of them were located in drought-prone sites either on steep slopes or on sandy bedrock over deep-lying groundwater. According to previous research (Blakesley, Buckley, 2016), drought-prone sites can be easily restored even with high P levels, as dryness hampers P up-take by plants.



Soil texture: fine sand
Deposits: glaciofluvial
pH: 5.34
CEC: 3.27
C: 1.81%
N: 0.09%
K: 49.71 mg kg^{-1}
P (Mehlich 3): 97.9 mg kg^{-1}
P (Olsen, recalc.): 39.16 mg kg^{-1}
Species richness: 36 ($25 m^2$)

Soil texture: loamy sand
Deposits: glacial
pH: 7.11
CEC: 18.4
C: 2.57%
N: 0.18%
K: 63.87 mg kg^{-1}
P (Mehlich 3): 174.20 mg kg^{-1}
P (Olsen, recalc.): 69.68 mg kg^{-1}
Species richness: 33 ($25 m^2$)