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EFFECTS OF VARIOUS MANAGEMENT FACTORS ON THE COMPOSITION OF XERO-MESIC SANDY GRASSLANDS TO SUPPORT CONSERVATION PLANNING

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1. INTRODUCTION

Species-rich, semi-natural grasslands are one of the most fundamental parts of most European landscapes with great conservation and economic value. The traditional, usually extensively used grasslands usually have a great species pool and contain a high proportion of endemic, while have permanent composition in time and space.

Most of the species-rich, semi-natural grasslands are situated in potentially forested landscapes and constantly applied extensive management techniques are the basis to maintain them and ensure their optimal conservation state.

In the past, traditional management systems were able to maintain and support semi-natural grasslands with their mostly more adaptive management techniques in the various, specific landscapes. There were several management types, like mowing and grazing, usage of animal manure, sometimes even fire, and so on. An adaptive grassland management system is also based on the optimal intensity and spatio-temporal application forms of these management types and/or different intensity levels of management. Most of the previous investigations in the topic focused on the effects of only one or two management techniques and observed their intensity levels, however, the spatio-temporal applications should be observed as well. Spatio-temporal application methods of different management types and their intensity levels is one of the potentially most important basis for adaptive conservation grassland management. Spatio-temporal complexity of management is related to the land-use heterogeneity hypothesis, what has great importance in conservation practice. Based on this, my hypothesis was that relatively high spatial and temporal complexity of management correlate with higher grassland diversity, more balanced plant functional type dominance relations and a more heterogeneous vegetation physiognomy, as well as higher conservation efficiency.

I also suppose that extensive application of different management types, like mowing and grazing in relation to their spatial and temporal complexity of application within years and between years have great, positive effects on plant diversity, composition of plant functional types and plant physiognomy and their interactions in grasslands.

To prevent the nowadays widely common schematic ” grassland conservation management techniques it is important to search the locally most effective, often traditionally applied management techniques and compare their specific effects for more adequate, local applications. In the Felső-Kiskunság area

(Turján region), I investigated conservation practice effects on species-rich, xero-mesic sand steppe grasslands and asked the following questions:

- How does the types of management, intensity and spatio-temporal complexity of management affect plant diversity and dominance relations of plant functional types and plant physiognomy?
- Are the effects of grassland management changing between years?
- Based on the above-mentioned questions and new results, how can this complex picture be adapted in grassland conservation management practices?

2. MATERIALS AND METHODS

2.1. Physical geography of the sampled grasslands and their surroundings

The sampled grasslands are situated on the Hungarian Great Plain, in the Upper Kiskunság, within the Turján region near Kunpeszér, Kunadacs and Tatárszentgyörgy villages (coordinates: 47.04023°N 19.15289°E). The regional climate is continental with sub-mediterranean effects. The annual temperature is 10,2–10,5 ^{o}C, the annual rainfall is 520-550 mm. Soils are mostly sandy soils with fen and marsh soil mosaics. Potential vegetation type is the sandy forest steppe with some fen and marsh meadows and forest mosaics. Recently, semi-natural grasslands with great size are typical grazed mostly by cattle and sometimes sheep and horse. A relatively fast drying-out tendency dominates the landscape, related to the canals that were created during the first part of the XXth century.
The sampled grassland type is widespread in this landscape, and is a typical ecotone grassland, namely the xero-mesic sandy grassland, a transitional zone between *Molinia* fens and pannonian sandy steppes. Most of these grasslands are under nature conservation law and have been managed by the Kiskunság National Park Directorate since 1975.

2.2. Sampling protocol and the investigated management factors

Every sampled grassland site was at least 5 ha to exclude the source of extra variance of edge effect. Samplings were performed during the second half of June and first part of July in 2015 (17 grassland sites were sampled), 2016 (9 sites), 2017, 2018 and 2019 (12 sites in each year). The 2015 samplings were made in 10, 1x1 meter quadrats in each grassland and these quadrats were placed on a transsect line at least 4 meters from each other. In 2015 summer, three types of grassland management and three levels of management intensity and spatio-temporal complexity were investigated (Table 1). In 2016, species-area relationship sampling was performed by 3, 10 x 10 meters quadrats, where 5 cm x 5 cm was the smallest scale and bigger quadrat sizes were 10 cm x 10 cm, 25 cm x 25 cm, 50 cm x 50 cm, 1 m x 1 m, 2 m x 2 m, 4 m x 4 m and 10 m x10 m. Results of this species-area sampling showed that 2x2 m scale is the most informative scale and based on it field samplings were continued by this quadrat size in 2017, 2018 and 2019. In these years, a standardized field sampling was performed with 12 sites and an average of 9 quadrates placed on a transsect line per site were applied. In the 2017-18-19 years, three types of management, two management intensity levels (where low level: ≤0.5 SLU/hectare; and high level: ≥0.5 SLU/ha) and two spatio-temporal management complexity levels (where low level was a unified category of low and medium level of spatio-temporal complexity levels in Table 1 and high level was the same what is the high level of spatio-temporal complexity in Table 1) were observed in order to investigate the realistic and firmly existing and observable managment situations at a landscape scale and because of field sampling optimalisation in time and space. Species coverages in every plots was registered in percentage.

Table 1. Details of the three observed management factors and their levels in the summer monitorings of 2015, 2017, 2018 and 2019. In 2017, 2018 and 2019 only low and high level of managment intensity and spatio-temporal managment complexity were observed. Herbage removal intensity of management was expressed by Standard Livestock Unit (SLU), which is a non-lactating bovine weighing 500 kg (=1 SLU) and by mowing frequency per year.

Management factors	Meanings and scales of management factors
Type of grassland management (*T*)	**Mowing** (*M*), **Grazing** (*G*), **Combined** (mowing and grazing combined within a year or between years, *C*)
Herbage removal intensity (*I*)	**Low**: 0.5 standard livestock unit (SLU) per hectare grazing, or mowed once a year **Medium**: 0.5-0.8 SLU/ha grazing, or mowed once a year with subsequent grazing in the same year **High**: >0.8 SLU/ha grazing livestock
Spatio-temporal complexity of management (*C*)	**Low**: permanent grazing in a single grazing unit (no variance in grazing pressure within and between years) **Medium**: grazing with standard within-year sequence of two grazing units, or one mowing with 10% left uncut, or mowing once a year combined with subsequent grazing **High**: mowing and grazing combined between years, or grazing with a varying sequence of four grazing units between years

2.3. Investigated dependent variables

During analyses, three alpha diversity factors (species richness, Shannon and Simpson diversity) were used as dependent variables. I measured the effects of the three management factors on dominances (based on estimated cover and species numbers) of 11 plant functional types, namely 1.) forbs, 2.) Poaceae, 3.) Poales, 4.) Phanerophytes, 5.) degradation tolerants, 6.) generalists, 7.)

natural competitors, 8.) ruderal competitors, 9.) specialists, 10.) Therophytes, and 11.) protected species (according to the Hungarian law).

Four other vegetation physiognomy factors were measured and estimated in every quadrat in summer samplings of 2017, 2018 and 2019, namely 1.) average plant height, 2.) total plant cover, 3.) proportion of gaps with only plant litter and 4.) pure soil surface proportion.

2.4. Data analyses

Based on the species and cover data of the sampled quadrats, diversity (species richness, Shannon and Simpson diversity) and plant functional type groups were calculated. In analyses, the abovementioned diversity indices, plant functional types and plant physiognomy factors were built into models as dependent variables and grassland management factors (***T***, ***I***, ***C***) were used as explanatory variables.

To analyse distribution types of data before any other analyses, Shapiro-Wilk normality test and gamma test were applied. LMER and GLMER tests and post hoc tests were applied to determine the relationships and differences between factors and factor levels. In models, management factors as categorical factor combinations were also used (***T***+***I***, ***T***+***C***, ***I***+***C***, ***T***+***I***+***C***) to determine their combined effects. In models, management factors were fixed and the site was a random factor. For quantitative explanatory variables, the squared terms were also included in the model. To compare the power of positive and negative relationships and parsimony, unadjusted R^2-values and the AICc method were used.

To compare overall species-area relationships in grasslands with different management types, unlogarithmized species-area relationship curves were used in analyses of 2016 summer data.

To compare different management factor level effects on grassland species dissimilarity in the 2017, 2018 and 2019 years, NMDS multivariation analyses with the Jaccard-dissimiliarity index were applied.

Analyses were conducted in the R 3.5.1 software environment using the ’MuMIn’, ’goft’, ’r2glmm’, ’lme4’, ’multcomp’, ’visreg’, ’vegan’, ’ggplot2’, ’dplyr’ packages.

3. RESULTS

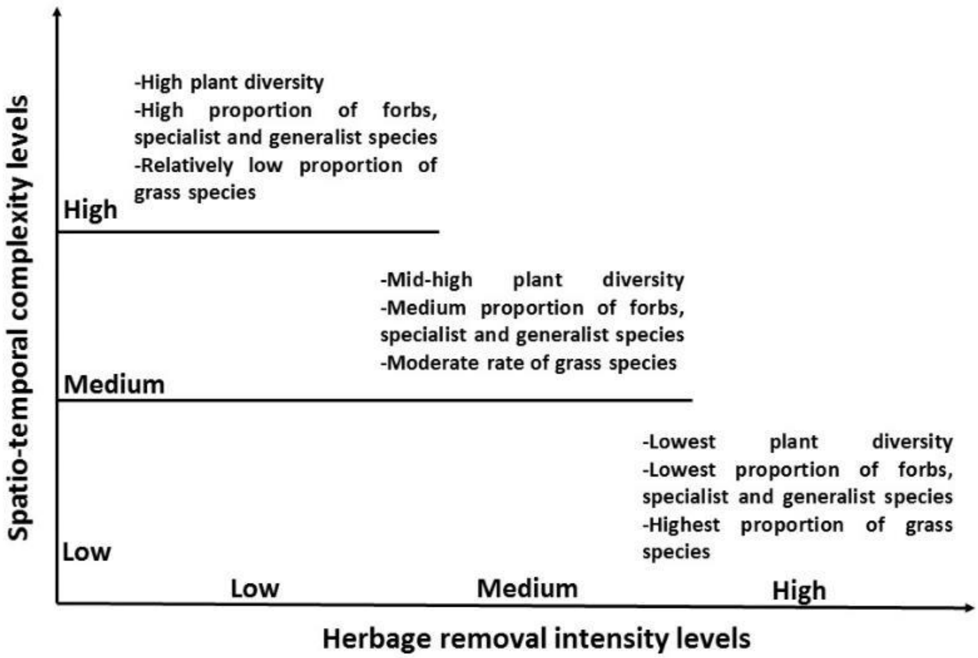
3.1. Effects of conservation management factors on grasslands in different years

3.1.1. Effects of management types, herbage removal intensity and spatio-temporal complexity of management on grassland vegetation in 2015

Management type, as fixed factor, did not affect significantly the plant diversity and plant functional type (PFT) covers and species numbers. On the other hand, management intensity and spatio-temporal management complexity levels had stronger effects on plant diversity and PFTs. Higher spatio-temporal complexity as like lower management intensity has positive effects on plant diversity, forbs group and specialists and negative effect on Poaceae group. Low spatio-temporal complexity of management as like a high level of management intensity have negative effects on plant diversity, forbs, and positive effects on the Poaceae group.

In general, spatio-temporal complexity of management showed the greatest effects in simplex models, management intensity showed less, but also strong effects on several dependent variables (Figure 1.). In some cases, a combination of management factors could be important to take into consideration, mainly the most complex, three management factor model (***T***+***I***+***C***).

Figure 1. Overall and strongest effects of herbage removal intensity and spatio-temporal complexity of management on plant diversity and plant functional types.



3.1.2. Species-area relationships in the three, differently managed types of grasslands in 2016

From the average species numbers of different quadrat scales, we can see that the differently managed sites have similar species numbers, and the species-area profiles of three, different management types are relatively similar.

Mowing, grazing and combined management types resulted in similar species-area relationship, but mostly on lesser scales, there were differences in species numbers. In the greatest, 10x10 m scale, the grazed and mown sites have greater, while the combined grasslands had considerably smaller species number values. In 4x4 m scale, mown sites had the greatest species numbers, while in 50x50 cm, 1x1 m and 2x2 m scales the greatest species numbers were found in combined managed grasslands. In the less scales, namely in 5x5 cm, 10x10 cm and 25x25 cm, there weren't any great difference between differently managed grasslands.

Based on the species-area profiles of the three, differently managed grasslands, the 2x2 m quadrat scale seemed to be one of the most informative one in species registration, because the inflection points of species-area curves were not far upper than this scale. On the other hand, this is one of the most transparent scale in field samplings („human scale"), mostly easier to use for a more exact cover estimations than 4 m x 4 m and 10 m x10 m scales.

3.1.3. Fundamental relations between management factors and grassland diversity, plant functional types and physiognomy of grassland vegetation in 2017, 2018 and 2019

Spatio-temporal complexity of management seemed to be the most powerful management factor in forming grassland diversity and forbs and clonal Poales groups. Higher spatio-temporal complexity of management resulted in higher grassland diversity and lower resulted in low in general.
Choice of management type was important, because diversity was significantly higher in grazed and combined managed grasslands. Phanerophyte coverage was significantly higher in grazed grasslands than in mown sites, combined grasslands had intermediate values in 2018. Proportion of only plant litter covered surface was significantly higher in combined grasslands than in grazed ones in 2018. In 2019, on grazed grasslands the total cover of plants was significantly higher than in combined ones and the mown grasslands had intermediate values.
Low and high herbage removal intensity levels of management did not make any difference between different grasslands in 2017-2018-2019.
Most complex, three management factor models affected mostly the different response variables, mostly important in formation of litter cover proportion, total cover of plants and plant height.
From viewpoint of plant interaction based vegetation evaluation, Poales coverage was optimal between 40-50%, forbs coverage was optimal approximately 50%, because diversity values were highest on this cover in general in the 2017, 2018 and 2019 years. For maximalising plant diversity optimal coverage of Phanerophytes was 10-15%, optimal litter-covered surfaces proportion was approximately 25%, optimal pure surface proportion was 5-7% and optimal total plant cover was 70%. In 2017, 2018 and 2019 the greatest diversity values were experienced between 15-20 cm plant height.

3.2. Dissimilarities in vegetation in relation to grassland management factors in 2017, 2018 and 2019

The Jaccard-based dissimilarity did not show great differences between different management types (grazed, mown, and combined) and higher and lower level of management intensity and spatio-temporal complexity of management. In 2018 and 2019, there were relatively few dissimilarities between mown and grazed grassland sites. In general, the investigated grasslands have relatively similar species pools and it is not in strong relationship with their recent management.

3.3. Effects of grassland management factors on the presence and dominance of protected or specialist species

Some of the 14 registered protected and specialist species were relatively strongly different in their coverages between differently managed grasslands and there were strong fluctuations in their relative presence between 2017, 2018 and 2019 years.

Among the 14 protected plant species that I registered during the field observations, *Allium sphaerocephalon*, *Astragalus asper*, *Blackstonia acuminata*, *Dianthus superbus* and *Iris sibirica* had very low presence, that is why it is impossible to evaluate their exact preferences in relation to management and any other factors. On the other hand, *Centaurea sadleriana* is one of the most common species in these grasslands with no exact preference, rather a generally present species in the sampled grasslands. *Silene multiflora* preferred the mown and combined managed grasslands and the lower spatio-temporal complexity of managment. *Orchis coriophora* was common in most of the grasslands with no difference in its presence between the differently managed grasslands. In contrast, *Iris spuria* mostly preferred low intensity and high spatio-temporal complexity of management in the sampled grasslands. *Gymnodenia conopsea*, *Koeleria javorkae* and *Ophrys scolpax* were mostly presented in mown and combined grasslands. *Schoenus nigricans* preferred those grasslands which were managed by a high level of spatio-temporal complexity, in some cases on pastures. *Scorzonera humilis* relatively evenly occured in differently managed grasslands, but a bit preferred those patches that were managed by low intensity and low spatio-temporal complexity and also occured on mown or combined grasslands.

3.4. Realized connection between grassland vegetation factors and different conservation management factors

Based on hypothetic relations there were 31 potentially existing relations between grassland management factors and different plant functional types, plant physiognomical factors, and diversity indices. 6 relationship was relatively robust and strong, 4 is positive, 2 is negative because it was experienced more or less strongly mimimally 2 times from the 4 sampling years (2015, 2017, 2018, 2019). 7 relationship was experienced as less strongly positive and another 3 was less strongly negative. By this, 16 from the total 31 hipothetic relationships are existing and another 15 relationship were not proven.

Spatio-temporal complexity has got a strong effect on grassland diversity and forbs and Poales species cover or species number. ~50% of forbs and ~15% of Phanerophytes cover as like 2-5% of pure soil surface has positive effect on grassland diversity, but higher Poales proportion (>60%) and higher average plant height (>25 cm) can negatively affect grassland diversity

4. NEW SCIENTIFIC RESULTS

1. High level of sppatio-temporal complexity of management had most positive effects on plant diversity and forbs' cover, greater than herbage removal intensity or different types of managements, like grazing or mowing.

2. Mostly extensive grazing management in connection with higher spatio-temporal management complexity were the most positive combination in grassland conservation. Highest diversity and best conservation effectivity were experienced.

3. Strong differences were experienced within and between years in explanatory power of management factor combinations.

4. However, extensive grazing with higher spatio-temporal complexity of management may have most positive effects in general in the sampled species rich grasslands, but mowing may have more positive effects on some specialist and protected plant species. By this, mowing is more optimal in some special conservation cases.

5. Based on the results of the thesis, it would be important to pay more attention to the spatial and temporal viewpoints of management in grassland conservation practice and studies.

5. DISCUSSION AND RECOMMENDATIONS

Based on the above-presented results, by a high level of spatio-temporal complexity in line with extensive grazing management, we can reach the highest plant diversity. In some cases, mowing was also important to conserve populations of different protected or specialist plant species, mostly mesophile and/or hydrophile ones, such as *Gymnadenia conopsea*, *Silene multiflora* or *Koeleria javorkae*. On the other hand, mowing had potentially negative effects on heterogeneous plant physiognomy and on the long term may have negative effects on vegetation diversity. Uncut lines in mown grasslands with changing position in different years can enhance spatio-temporal complexity of vegetation physiognomy that may have positive effects on vegetation diversity through more diverse microclimate and relatively more diverse reproduction opportunities of plant populations in time and space. Extensive grazing helped keep the optimal proportion of shrubs and in parallel, form vegetation physiognomy and structure to become more heterogeneous and through this, enhancing microhabitats and refugees for native plant populations. A higher level of herbage removal intensity with a lower level of spatio-temporal complexity of management may result in a higher proportion of mostly clonal and perennial Poales and lower proportion of forb species and by this, in lower plant diversity. In contrast, higher level of spatio-temporal complexity with lower level of herbage removal intensity can result in lower proportion of Poales and higher proportion of forbs, which can positively affect plant diversity. By mostly extensive grazing and higher level of spatio-temporal management complexity, we are able to form Phaneropyte coverage positively and by this, higher amount of microhabitats can develop, leading to a more heterogeneous vegetation, less Poales cover, that can result in higher diversity. The highest plant diversity can be reached through keeping Poales at 50-60% cover, forbs at 40-50% cover and Phanerophytes at 10-25% cover. In addition, by keeping 10-30% litter covered gaps by management, plant diversity of grasslands can also be affected strongly positively.

Based on these results, we can state that spatio-temporal management complexity in combination with mostly extensive grazing can help us to reach higher level of plant diversity through more complex vegetation structure in time and space and higher presence of some protected, specialist species, like *Iris spuria*. It is also important to leave uncut lines on mown grasslands with changing in time and space to enhance more complex plant physiognomy and apply the combination of mowing and grazing both among and within years.

For a more accurate investigation and more descriptive results, it is important to sample high nature value grasslands in different years because of the great fluctuations in dominance relations of species among years based on annual and local climate and environmental conditions.

Based on these results and the logical structure of this thesis, we can reach a more effective conservation management in a long term. Moreover, by a detailed and careful approach, based on local environmental circumstances and local grassland management traditions of different regions, it is possible to adapt some of the elements of this thesis in grassland conservation planning of other areas.

6. ARTICLES IN RELATION WITH THE THESIS

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