Hungarian University of Agriculture and Life Sciences (MATE)

SOIL SEED BANK EXAMINATIONS IN GRASSLAND TYPES WITH DIFFERENT WATER REGIME

Theses of doctoral (PhD) dissertation

DOI: 10.54598/001270

SCHELLENBERGER JUDIT

Gödöllő
2021

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Discipline: Environmental Sciences

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1. Background and objectives

By definition, the seed bank is the stock of the naturally occurring seeds which have a metabolism independent of the mother plant and at the same time viable. Most of the terrestrial plants accumulate the largest mass of their seed bank in the soil and on the soil surface, which is the so-called soil seed bank (hereinafter the short “seed bank” term also refers to the seed bank of the soil even without prefix).

The greatest importance of the seed bank resides in its recovery potential, thus its role is increasingly valued in our changing environment. Although, the seed bank of each community and habitat markedly differ from each other, therefore the recovery values they represent are not the same.

The cognition of seed banks – as a potential resource for conservation and restoration – of the European grassland- and wetland habitat types threatened by landscape alteration and climate change-related drastic habitat- and diversity loss is one of the fundamental tasks of nature conservation and restoration ecology. Among these, there is a particular urgency to explore the seed bank of wetlands more accurately – including their types with grassland physiognomy –, which has been barely explored so far both domestically and in Europe. Many authors are calling for the documentation of these as soon as possible. This is especially relevant in the continental region, including Hungary, where the water supply is a crucial ecological constraint, and where the impact of climate change on wetlands may become serious in the near future.

In addition to the abovementioned, broadening the relatively small information on the web of soil—vegetation—seed bank interactions is also essential. With regard to the impact of climate change on soil parameters (e.g. drying, warming, pathogens), it is a key issue to know, how the very different seed bank of each habitat reacts to its direct environmental changes, and how this affects its potential for recovery. The tolerance of the seeds to soil parameters, as well as the rearrangement of species composition and seed adaptation for new germination conditions of the above-ground recent vegetation (hereinafter shortened as “vegetation”) should be taken into consideration in this.

Thus, in our changing environment, the prediction of the recovery potential (and planning the necessary treatments) can be correct only with the combined knowledge on the self-dependent state of the seed bank predestinated by the plant and the (direct/indirect) modifying effect of the soil.

Motivated by these 2 “hot spots”, I aimed to expand the knowledge on the soil seed bank of grassland types with different water regime and on their web of environmental interactions by the collective evaluation of 1.) the soil seed bank, 2.) the recent above-ground vegetation and 3.) the soil moisture interpreted in the context of major soil parameters, which are examined along the soil moisture gradient (hereinafter shortened as “moisture gradient”) of slopes.

In a narrower sense, through the example of grassland types with different water regime, I aimed to explore:

- what relationship exists between the seed bank quantity (density, diversity) and the soil moisture requirement (hereinafter shortened as “moisture requirement”) of the vegetation,
- whether there is a relationship between the seed bank quality (species/abundance texture, naturalness, seed bank type) and the moisture requirement of the vegetation,
- whether a relationship can be expected between the moisture requirement of the vegetation and its ability to recover from its seed bank.

In relation to these, I set up the following hypotheses on the soil seed bank of grassland types with different water regime:

1.) The 1.a.) density and the 1.b.) diversity of the seed bank change with the soil moisture content (but not necessarily direct causal) along the slope, such that they decrease from the relatively wet grassland type through the ecotone one to the relatively dry one.

2.) The $\frac{L}{U}$ ratio (where “L” refers to the seed bank of the lower, i.e. 5—10 cm, soil depth interval, and “U” of the upper, i.e. 0—5 cm, depth interval) is higher in the relatively wet grassland type than in the relatively dry one and lower than in the ecotone one in terms of both the 2.a.) density and the 2.b.) diversity.

3.) The floristic similarity between the seed bank and the vegetation is higher in the relatively wet grassland type than in the relatively dry one and lower than in the ecotone one, which latter has a species-accumulative role.

4.) More of the abundant species of the relatively wet grassland type’s vegetation reserve a dense and/or persistent seed bank than those of the relatively dry one, but less than those of the ecotone one.

5.) The seed bank of the relatively wet grassland type has better naturalness comparing to that of the dry one and especially to that of the ecotone one.

6.) Resulting from hypotheses 1—5.), the chance of spontaneous recovery of the relatively wet grassland type from the seed bank is better than that of the relatively dry one.

7.) A species occasionally may have different seed bank types under different environmental conditions.

2. Materials and methods

2.1. The study areas and the sampling design

Two areas with the size of 60×10 m served as study areas for my examinations. One of them was on a South-Southwest-facing toe slope near Sajókápolna, the other was on an East-facing slope near Tihany. Both areas are maintained by mowing. In Sajókápolna, there is an intermittent pond connecting to the bottom of the study area and in Tihany, there is Lake Belső.

I set 3 parallel, 60 meters long, non-adjacent, longitudinal transects on each study area. Ten permanent, non-adjacent, 2×2 m sampling plots were assigned in each transect in Sajókápolna and 9 in Tihany.

2.2. Data collection on the soil, above-ground vegetation and soil seed bank – overview of the available data

The samplings and surveys were carried out by plots in case of the soil (2012., 2013., one or more times depending on the soil parameters), the vegetation (2013. spring, autumn) and the seed bank (2013. spring).

In the frame of the soil examinations, the following soil parameters have been defined from the samples representative for the 0—10 cm depth interval of the soil using laboratory testing methods corresponding to Hungarian standards: soil moisture content (w) [m/m%], consistency according to Arany (K_A), humus content (H) [m/m%], carbonate content ($CaCO_3$) [m/m%], water-soluble salt content [m/m%], pH determined in KCl (pH_{KCl}).

In the frame of vegetation surveys, the species were registered and the Braun-Blanquet method-based % cover was estimated. With the derived data, I had the following vegetation data for each plot: list of species, species-specific and total cover (D) [%], total litter [%], total uncovered surface [%], number of species (S) [pcs], Shannon index (HS).

In the frame of seed bank examinations from the samples representative for the 0—5—10 cm soil depth interval, I proceeded 8 month long greenhouse seedling emergence method after conducting ter Heerdt volume reducing procedure and 4 types of dormancy breaking treatments, whereby the species and numbers of individuals were registered. With the derived data, I had the following seed bank data on both the U and L depth intervals of each plot: list of species, species-specific and total seed density (d) [pcs/m^2], number of species (S) [pcs], Shannon index (HS).

Furthermore, for the lists of species, I had the Raunkiaer's life form (LF), Borhidi's social behaviour type and the belonging naturalness (SBT and P), and relative soil moisture requirement (WB) attributes available.

2.3. Data processing and analysis

At the first stage, I used descriptive approach, and at the second stage, I used inductive approach for analyses. Within those 1.) habitat- and 2.) finer scale analyses were included.

2.3.1. Descriptive approach for analyses

Fine scale changes in quantities along the slope were revealed by simple statistical measures ($\overline{X}$±SD).

For habitat-scale analyses, the 3 grassland types with assumedly different water regime were demarcated by fuzzy c-means clustering (FCM) along the slope. This clustering was based on the cover-weighted WB of the vegetation-forming species. The demarcation was adjusted in the light of field inspection, and then I checked it with linear discriminant analysis (LDA) performed on the set of soil parameters and vegetation properties.

For the habitat classification of the 3 grassland types, I used the 2011 version of the General National Habitat Classification System.

For revealing the quantitative differences of the 3 grassland types, I calculated simple statistical measures ($\overline{X}$±SD) and total species number.

Simple statistical measures (min., Q_1, $\overline{X}$, M_e, Q_3, max.), also calculated from the quantities, were used for comparing the grassland types by their most abundant 5 species.

For comparing the LF, SBT and WB spectrum of the 3 grassland types, I calculated species number-based and abundance-weighted group contribution. The comparison for the naturalness of the grassland types was served by the quasi mean of the Ps belonging to the SBT.

For the classification of the seed bank of a species, I used Thompson's 3-category (transient: viable for ≤1 year, short-term persistent: viable between 1—5 years, long-term persistent: viable for ≥5 years) seed bank classification system. To evaluate my data on a species' seed bank type (novelty, quality), I used 2 domestic and 2 European reference databases. Classification was performed by the total study areas and also by grassland types.

To express floristic similarities, I calculated Sørensen- (QS) and Jaccard index (J).

2.3.2. Inductive approach for analyses

Depending on the fulfilment or violation of applicability criteria, I performed either one-way analysis of variance (ANOVA), or Welch's ANOVA, or Kruskal–Wallis test, and as post hoc test, Tukey–Kramer pairwise test after the former 2 and Mann–Whitney pairwise test after the latter during the habitat-scale comparisons. To compare the quantities between the U and L depth intervals, I used two-sample paired t-test or Wilcoxon signed rank test.

The fine-scaled relationship analyses were aimed at exploring whether there is a relationship between the soil moisture content – not ignoring the effects of other soil parameters – and the vegetation or the seed bank. At the first stage, I performed dimension reducing principal component analysis (PCA) on the soil parameters, I extracted the principal components (PC), and I examined the relationship of the PCs by a linear regression model based on the generalized least squares (GLS) method first with the vegetation and then with the seed bank. At the second stage of the analysis, instead of PCs, I involved soil parameters in the model. To further search for relationships between 2 variables – due to a violation of the criterion for Pearson's correlation – I calculated Spearman's rank correlation.

The statistical programs used were Past 3.01. and R 3.4.3.

3. Results

3.1. Main features of the soil

The analysis of the change in soil moisture content along the slope proved a strong moisture gradient. The presence of this gradient made the study areas suitable for examining the objectives.

Among the other soil parameters, $CaCO_3$ content (mid-slope peak) and K_A (decreased with increasing altitude) in Sajókápolna, $CaCO_3$ (increased with increasing altitude) and water-soluble salt content (decreased with increasing altitude) in Tihany showed such contrasting change along the slope that their effect (if any) should be detectable in the seed bank.

3.2. Main features of the above-ground vegetation

Regarding its change along the slope, the cover increased with the altitude in Sajókápolna, while in Tihany it slightly decreased. The diversity (species number, Shannon index) fluctuated along the slope.

Through FCM cluster analysis, field inspection and LDA analysis, I verified the zonation of the 3 grassland types with different water regime along the slope. From then on, I refer to them as wet, ecotone and dry grassland types, referring to the relative moisture requirement of the vegetation. According to the demarcation, the plots with the lowest slope position in the transects and the ones immediately following them (6 in total) were representative for the wet grassland type, the plots with the highest slope position in the transects and the ones immediately preceding them (6 in total) were representative for the dry grassland type, and the plots located between these (a total of 18 (Sajókápolna) and 15 (Tihany)) were representative for the ecotone grassland type. I performed habitat-scale analyses accordingly.

Based on the habitat classification, the wet grassland type corresponds to the so-called non-tussock tall-sedge beds (code: B5); the dry grassland type in Sajókápolna corresponds to the so-called semi-dry grasslands (code: H4), and in Tihany to the so-called slope steppes on stony soils (code: H3a). The latter 2 are Natura 2000 habitat types as well (H4=6210, H3a=6240*). The unit called ecotone grassland type is the transition between the wet and the dry one.

The 3 grassland types differed significantly in terms of mean cover (although it is important that it did not fall below 100% anywhere in Tihany), while they were more uniform in terms of diversity (species number, Shannon index).

In Tihany, the distribution of cover among the 5 most abundant species was relatively balanced in each grassland type. In Sajókápolna, this was not true in the wet grassland type, as *Carex acutiformis* was monodominant there.

The LF spectrum showed the dominance of perennials in each grassland type. The SBT spectrum of the 3 grassland types in Sajókápolna differed, the wet grassland type mainly reflected competition but also stress and disturbance, the dry one showed mainly signs of stress but also disturbance and competition, the ecotone one mainly reflected disturbance. The SBT spectrum of the 3 grassland types in Tihany were similar as disturbance tolerant species were dominant in each; in addition, the wet grassland type and the ecotone one showed signs of competition, and besides these, the dry one showed signs of stress as well. Naturalness of the wet grassland type was similar (Tihany) or better (Sajókápolna) than that of the dry one and far better than that of the ecotone one. The WB spectrum of the 3 grassland types differed in the expected way.

3.3. Main features of the soil seed bank

The seed density and the diversity (species number, Shannon index) fluctuated along the slope, the former between a wide range.

Based on the 2 study areas, I made an attempt to determine the seed bank types of 157 species in total. The highest percentage of these were transient and the lowest percentage were long-term persistent, which may have been associated with the large number of grassland species. Compared to reference databases, 62 of these turned out to be first publication in regional level, 19 of which turned out to be novel in Europe as well. Comparing the seed bank type composition of the 3 WB category groups formed by appropriate merges, it was confirmed that the representation of species with persistent seed bank as compared to species with transient seed bank decreased from the WB10—7 (high moisture requirement) group through the WB6—4 (medium moisture requirement) group to the WB3—1 (low moisture requirement) group. Most of the species from the WB10—7 group were short-term persistent within the persistent main category. The relatively high contribution to persistency by the species within the WB10–7 group reflects adaptation to recurrent disturbances.

The 3 grassland types differed significantly in terms of mean seed density, in particular: wet grassland type > ecotone grassland type > dry grassland type. There was no (Sajókápolna) or only a small (Tihany) difference in the mean diversity (species number, Shannon index) among the 3 grassland types. It was confirmed in all 3 grassland types, that the seed bank of the U significantly exceeds that of the L in terms of both density and species number. In terms of density, the $\frac{L}{U}$ ratio was similar (Sajókápolna) or lower (Tihany) in the wet grassland type than in the dry one and lower than in the ecotone one. In terms of diversity, the $\frac{L}{U}$ ratio was higher (Sajókápolna) or lower (Tihany) in the wet grassland type than in the dry one and lower than in the ecotone one. The $\frac{L}{U}$ ratio thus only partially corresponded to the pre-assumptions. However, rather than in relative terms, it was proved in absolute terms that both the density and diversity of the L are higher in the wet grassland type than in the dry one, thus the former had a larger persistent stock.

Among the 5 most abundant species in Sajókápolna the hygrophytes outnumbered the weeds, while in Tihany the opposite was the case. In Tihany, the distribution of seed density among the 5 most abundant species was relatively balanced in each grassland type. This was not the case in Sajókápolna in the wet grassland type, where *Lythrum salicaria* was monodominant, and in the ecotone one, where *Erigeron annuus* had a remarkably high mean. These exemplified the tendency of wetland species to build a large seed bank, similarly to species with weedy character. Furthermore, it was true for each grassland type that the largest mass of the seed bank originated from a few species (especially in Sajókápolna), and aggregation was already present in the case of the abundant species.

In terms of the LF spectrum, the 3 grassland types were similar in Tihany: they were characterized by the dominance of perennials; and they differed in Sajókápolna: besides the large representation of perennials, the presence of annuals were also considerable (the latter mainly in the ecotone grassland type and in the dry one). The SBT spectrum of the 3 grassland types differed in Sajókápolna. The stress tolerants dominated in the wet grassland type, the ruderals dominated in the ecotone one, while the stress tolerants and ruderals were both pronounced in the dry one. The SBT spectrum of the 3 grassland types in Tihany were quite similar due to the dominance of the disturbance tolerants, but besides this, the wet grassland type showed signs of competition and the dry one showed signs of stress as well. Naturalness was basically low, but comparing the 3 grassland types, it was also found that it was similar (Tihany) or moderately better (Sajókápolna) in the wet grassland type than in the dry one, and far better than in the ecotone one. The WB spectrum of the 3 grassland types was more uniform in Sajókápolna: the ones with higher moisture requirement dominated in each of them. In Tihany, a more pronounced WB zonation evolved, but even then it did not completely follow the zonation of the vegetation.

3.4. Main results on the relationship between the soil moisture and the above-ground vegetation in terms of their changes along the slope

The PCA analysis confirmed the crucial role of soil moisture content among soil parameters. The PCs of the analysis provided the raw data for exploring relationships on a coarser level.

Multiple-stage analysis with linear regression models based on the GLS method showed that in the web of soil interactions, jointly with the effect of other soil parameters, the soil moisture was most strongly related to the species number (Sajókápolna, Tihany) and the cover (Sajókápolna) of the vegetation, in such way that it was a significant negative relationship within the given moisture range in the transition of the given habitat types.

3.5. Main results on the relationship between the soil moisture and the soil seed bank in terms of their changes along the slope

The model described for the vegetation showed that in the web of soil interactions, soil moisture was most closely related to the seed density (Sajókápolna, Tihany), in such way that it was a significant positive relationship within the given moisture range in the transition of the given habitat types. A similar relationship to the species number of the seed bank was detected in Sajókápolna.

Overall, the positive relationship between seed density and soil moisture on the plant component side is essentially due to species culminating in the wet end of the moisture gradient with higher moisture requirement, which species typically have a dense, persistent, slowly depleting seed bank, and at the same time due to species culminating in the dry end of the moisture gradient with lower moisture requirement, which species typically have sporadic and/or a transient, rapidly depleting seed bank. Besides these, in Tihany, coincidences such as the more ruderal nature of the wet end and middle part of the moisture gradient, which also predestinates a dense persistent seed bank, may also play a role in the development of the trend, and at the same time, the fact that species related to the strongly calcareous soil of the drier end of the moisture gradient typically have a low tendency to build a seed bank. This trend may also have received more/less amplification from the soil component side depending on the ratio of soil moisture, O_2 content, and pathogenic fungi.

3.6. Main results on the relationship between the above-ground vegetation and the soil seed bank in terms of their changes along the slope

In the example of Sajókápolna, I found a non-significant but weak negative relationship between the cover and the seed density. Although, it may reflect the relationship between the seed density and the soil moisture (cf. the relationships described above), this may also suggest that high cover has a negative effect on seed density (promoting fungal infection by changing the microclimate).

3.7. Main similarities between the above-ground vegetation and the soil seed bank in each grassland type

In terms of abundances, the extremes in the vegetation were lower than in the seed bank. In terms of diversity, the diversity of the vegetation was higher than that of the seed bank, but the difference between them was lower in the wet grassland type than in the other 2.

The floristic similarity between the seed bank and the vegetation was basically low but comparing the 3 grassland types, it has been concluded that it was higher in the wet grassland type than in the dry one, but lower than in the species-accumulative ecotone one. The shared species between the vegetation and the seed bank were mostly hygrophytes in the wet grassland type, especially dry grassland species in the dry one, and mainly species with weedy character in the ecotone one in Sajókápolna. The shared species were largely hygrophytes and/or species with weedy character in the wet grassland type, mostly ruderal dry grassland species in the dry one, and mainly weed species in the ecotone one in Tihany.

Most of the abundant species of the vegetation were not detectable in the seed bank. However, more of the abundant species of the wet grassland type's vegetation reserved a dense and/or (at least short-term) persistent seed bank than those of the other 2 types. Among them, *Carex acutiformis* in Sajókápolna was particularly noteworthy with its dense seed bank which – under favourable soil conditions – can be short-term persistent; and *Poa trivialis* in Tihany, with its especially dense, short-term persistent seed bank. Most of the abundant species of the seed bank were persistent; in the vegetation, a small part of them was absent or abundant, a large part of them had a small cover (more valuable: *Pseudolysimachion longifolium, Lychnis flos-cuculi*).

It follows from the above: The chance of spontaneous recovery of the wet grassland type from the seed bank in the Sajókápolna study area is not complete, and can be taken into account only in short-term, but even then, it is better than that of the dry grassland type. The formation of a vegetation, which is different from the original, but has higher moisture requirement, may be supported more substantially for a limited period by the seed bank in the Tihany study area as well. In the dry grassland type and in the ecotone one, a large weed seed bank may threaten the recovery of the natural vegetation.

The seed bank classification of abundant species by grassland types provided an opportunity to observe the possible modifying effect of the soil on the self-dependent state of the seed bank type predestinated by the plant. The cases of *Carex acutiformis* (short-term persistent seed bank in the ecotone grassland type and transient seed bank in the wet grassland type) in Sajókápolna, and *Verbena officinalis* (short-term persistent seed bank in the ecotone grassland type and long-term persistent seed bank in the dry grassland type) as well as *Achillea collina* (short-term persistent seed bank in the ecotone grassland type and transient seed bank in the dry grassland type) in Tihany indicated most clearly the role of environmental influences. The case of the former 2 was primarily due to the tolerance of the seeds to soil moisture (and indirectly to anoxia in saturated soils or to fungal infection in unsaturated but moist soils). The latter case was primarily due to the adaptation (seed size) of the plant to the germination conditions.

3.8. Overview of new scientific results

1.) I have prepared detailed documentation on the 1.1.) soil seed bank, 1.2.) recent above-ground vegetation and 1.3.) major soil parameters with particular interest on the moisture content, which developed along the soil moisture gradient of a slope, first in Sajókápolna and then in Tihany, as 2 separate study areas.

2.) Based on the example of the tall-sedge bed – as a relatively wet grassland type –, semi-dry grassland (Sajókápolna), or slope steppe (Tihany) – as a relatively dry grassland type –, described along the slope, as well as their ecotones, I have proved the following theses:

- 2.1.a.) The density of the seed bank along the slope changed in a significantly positive way with the soil moisture content – within the given moisture range – such that it decreased to a quarter from the relatively wet grassland type through the ecotone one to the relatively dry one. This was primarily due to the ability of taxa with higher moisture requirement to build a larger seed bank as compared to the ones with lower moisture requirement, i.e. the indirect effect of soil moisture through the vegetation response.
- 2.1.b.) No (Tihany) or only marginally significant positive relationship (Sajókápolna) was detected along the slope between the diversity of the seed bank and the soil moisture content.
- 2.2.a.) In terms of density, the $\frac{L}{U}$ ratio was similar (Sajókápolna) or lower (Tihany) in the relatively wet grassland type than in the relatively dry one and lower than in the ecotone one.
- 2.2.b.) In terms of diversity, the $\frac{L}{U}$ ratio was higher (Sajókápolna) or lower (Tihany) in the relatively wet grassland type than in the relatively dry one and lower than in the ecotone one. At the same time, in absolute terms, both the density and diversity of the L were higher in the wet grassland type than in the dry one, thus the former had a larger persistent stock.
- 2.3.) The floristic similarity between the seed bank and the vegetation was higher in the relatively wet grassland type than in the relatively dry one, but lower than in the ecotone one, which latter has a species-accumulative role. In the Sajókápolna study area, in the case of the wet and ecotone grassland types, the degree of similarity found can be explained by the disturbance associated with more unpredictable hydrological conditions, while in the case of the dry grassland type, it was because of the stability. In the Tihany study area, the recognized degree of similarity was due to the only moderately prevailing anthropogenic disturbance in the case of the dry grassland type, while

it was due to the more intensively prevailing anthropogenic disturbance in the case of the wet and ecotone grassland types.

2.4.) More of the abundant species of the relatively wet grassland type's vegetation reserved a dense and/or (at least short-term) persistent seed bank than those of the relatively dry one and those of the ecotone one. In this respect, the seed bank of *Carex acutiformis* in the study area of Sajókápolna, and the seed bank of *Poa trivialis* in the study area of Tihany was of great importance.

2.5.) Naturalness of the seed bank of the relatively wet grassland type was similar (Tihany) or moderately better (Sajókápolna) than that of the relatively dry one, and was far better than that of the ecotone one.

2.6.) Resulting from theses 2.1—2.5.): In the Sajókápolna study area, the chance of spontaneous recovery of the relatively wet grassland type from the seed bank is not complete, but better than that of the relatively dry one. In the Tihany study area, the recovery of a vegetation, which is not the original but also has higher moisture requirement, may be supported more substantially by the seed bank. However, beyond 5 years from degradation, the prospects for regeneration also deteriorate considerably for these wet grassland types. In both study areas, the large seed bank of weeds may be a threat in the case of the dry and ecotone ones.

2.7.) The cases of *Carex acutiformis* (Sajókápolna), *Verbena officinalis* and *Achillea collina* (Tihany) suggested that a species may have different seed bank types under different environmental conditions. On the one hand, this could be explained by the tolerance of the seeds to soil moisture and on the other hand by the adaptation (seed size) of the plants to germination conditions.

3.) In regional terms, I made the first report on the seed bank types of 62 species, 19 of which are novel in Europe as well.

4. Conclusions and proposals

4.1. The main conclusions to be drawn from the results, their extrapolability and applicability

My results on the seed bank of grasslands with different water regime and on their web of environmental interactions are useful for local nature conservation in their tighter interpretation, but they are even more valuable in their broader extrapolation since they are useful in restoration ecology. As my results come from investigation of Natura 2000 habitat types, they have particular importance in a European respect.

From my results on the individual seed bank of a species in the study, it can be concluded that for the species whose seed survival depends not only on genetics but can be influenced by the environment, the seed bank type should not be interpreted at species level but rather in environmental context. My result on the seed bank type of a given species therefore can be extrapolated to populations of the species living under similar environmental conditions to my study areas.

My results on the seed bank of the examined grassland types as habitat types can be extrapolated in a trend-like manner to representatives of tall-sedge bed-like habitats with only moderately predictable hydrology, as well as to more stable representatives of semi-dry grassland-like and slope steppe-like habitats, which are formed in the temperate zone. From the former, we are more likely to expect that many of their typical species will be able to survive the shorter (≤5 years) drought in seed stage and then recover from it. Spontaneous recovery cannot be expected from the seed banks of more stable semi-dry grasslands and slope steppes after degradation. It can be drawn as a coherent conclusion that the drying out of a wetland with a moderately predictable hydrology beyond more than 5 years, in the case of the neglect of its water management, may give way to weedy- or at best xero-tolerant vegetation, which upon further degradation leads to weed expansion and may eventually become completely impoverished in species as it cannot recover from the seed bank.

4.2. Main proposals on the topic

Since a group of species can produce different seed bank types under different environmental and soil conditions, I consider it expedient to publish the data on the seed bank type of the species with the specific soil conditions, primarily including properties reflecting the soil moisture content in the examined locality. The soil conditions could be provided by the specifically measured soil parameters, and/or the habitat type that well describes the complex of the soil conditions and/or ecological indicator values calculated for the vegetation. Reporting the data of seed bank types of species extended with "soil-habitat type-moisture indication" and the introduction of such metadata into the databases would provide an opportunity for meta-analyses to explore the relationship of the soil parameters and the seed bank. Having such information, the future direction in which the climate change may shift the seed bank type of a species through the changes of the soil parameters and thus the survival and recovery potential of the species could be estimated. Knowing this, species conservation could be more successful, and the necessary restorative ecological interventions could be planned more precisely as well.

5. Publications related to the topic of the dissertation

Grouping of the publications corresponds to the template of the Doctoral School.

1. Peer-reviewed research articles

1.1. With impact factor (according to WEB OF SCIENCE), in English

1.1.1. Hungarian publisher – article

PETI E., SCHELLENBERGER J.*, NÉMETH G., MÁLNÁSI CSIZMADIA G., OLÁH I., TÖRÖK K., CZÓBEL SZ., BAKTAY B. (2017): Presentation of the HUSEED^{wild} – a seed weight and germination database of the Pannonian flora – through analysing life forms and social behaviour types. Applied Ecology and Environmental Research 15(1): 225—244.
(Print ISSN: 1589 1623, Online ISSN: 1785 0037, DOI: http://dx.doi.org/10.15666/aeer/1501_225244, Impact Factor 2017: 0.721, SJR Quartile Score 2017: Q3)

1.1.2. International publisher

1.2. Without impact factor, in English

1.2.1. Hungarian publisher

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