Final report

Effect of weather fluctuation on grasslands: community and species-level approach; PD137632

Principal investigator: Kiss Réka

The aim of the project was to study the effects of weather fluctuation on the resilience of plant communities. To fulfil our aims we used both community-based and species-based approaches in three work packages, which focused on the community seed bank (WP 1), on the response of individual species seeds (WP 2) and on population dynamics and phenology of a model species (WP 3).

WP 1 *Seed bank and weather fluctuation*.

Rationale. Dormancy of seeds is a crucial feature of many plant species, enabling them overcoming unfavourable habitat conditions for germination and/or seedling establishment. In the absence of favourable conditions seeds maintain dormancy for long time periods, forming the persistent soil seed bank. Presence of persistent seed bank enables faster recovery of disturbed habitats than a scarce seed bank composed of short-living (transient) seeds. The resistance and resilience of plant communities may be higher in communities with dense persistent seed bank and lower in communities with predominantly transient seed bank. This may be of crucial importance in face of climate change, which changes precipitation regimes, i.e. the amount and the timing of precipitation events.

To study the effect of precipitation on soil seed bank we joined to the long-term experiment of György Kröel-Dulay, i.e the ExDrain experiment. In this experiment water exclusion and addition was applied on experimental plots yearly from 2015. The design of the experiment provided a great opportunity to study the effect of changing precipitation level during the vegetation period on the level of the soil seed bank. We expected a decreased seed density in plots which experienced drier conditions and increased density with increasing precipitation level. We also expected that the increasing precipitation level will have a positive effect on the proportion of species with persistent seed bank. Lastly, we expected faster and more pronounced changes in vegetation than in soil seed bank; seed banks of the treatment will be more similar to each other than to the aboveground vegetation. The largest differences in soil seed bank was expected to occur between the two most different treatments, the extreme drought and water addition treatments.

Methods. The experimental site is situated near Fülöpháza, Hungary, in an open sand community and the precipitation manipulation experiment was launched in 2014, when 48 permanent plots (3 m × 3 m) were established. Plots were ordered in a full factorial design, with two factors: (1) half of the plots experienced a severe drought in 2014, the other half of the plots served as controls; (2) from 2015 on precipitation was manipulated in the plots in four ways: (i) control, no further precipitation manipulation, (ii) severe (2-months) summer precipitation exclusion, (iii) moderate (1-month) summer precipitation exclusion and (iv) water addition (between June-August, 25 mm/month). The precipitation exclusion was done by covering plots with transparent foil, which enabled the light and wind to circulate freely but excluded rainwater. The water addition was done using sprinklers and rainwater. The eight treatment combinations are repeated in six replications. The composition of the aboveground vegetation was monitored each year in June by Gy. Kröel-Dulay and his colleagues.

We conducted the seed bank sampling in March 2020, before the germination of seed bank. Eight soil samples were taken from each of the 48, six-years old experimental plots with soil corer (4 cm in diameter and 10 cm depth). Soil cores were divided to upper and lower segments, identical segments from the same plot were pooled. Samples were concentrated according to ter Heerdt et al. (1996), concentrated samples were spread in thin sterilized potting soil in trays and germinated for two years (2020-2021) in greenhouse. Seedlings were regularly identified and counted, identified seedlings were removed. Individuals without diagnostic features were transplanted and grown till they became identifiable. The experiment was finalized in 2022. I analysed the data with Poisson distributed generalized linear models (GLMs), with species- and seedlings number as dependent variables and treatment in interaction with soil segment as explanatory variable. I also analysed community weighted mean (CWM) of traits like social behaviour type, life form and CSR strategy as dependent variables and treatment as explanatory variable with Gaussian distributed GLMs.

Results. The results showed that precipitation manipulation treatments had minimal effect on soil seed bank, which in all treatments contained very few seeds and species. These results clearly show that in the studied open sandy grasslands, only few species can rely on the soil seed bank for recovery in case of an extreme weather events. The low regeneration capacity of this habitat type based on soil seed bank is alarming, especially taking into account the observations of the site managers, who claim, that after the severe drought in 2022, when most adult plants died, the revegetation of the Kiskunság region was very slow and limited to few species. More frequent or severe droughts may result even greater time lapses between the revegetation of the habitats or to increasing of open patches, which, in long term, may lead to further degradation and erosion.

Due to the sparse seed bank, the results of seed bank analyses can be better published together with the results of vegetation surveys, therefore we aim to publish these results together in the future. I participated in other studies on the seed bank of other grasslands types, from which three papers were published or in are under revision (Tóth et al. 2022 PeerJ about alkaline grasslands, Tóth et al. Community Ecology, major revision – about wet grasslands, Frei et al. Ecological Applications, submitted – about wood pastures).

WP 2 Seed germination response to weather fluctuation.

Rationale. Given the importance of grasslands in maintaining diversity and providing ecosystem services, more attention should focus on their conservation and restoration. Grassland restoration by species (re)introduction to the target areas, eg. seed sowing, is a widely used method; seed mixtures composed of native plants of local provenance proved to efficiently sustain grassland restoration. However, the amount of available seeds is limited while the demand for restoration increases continuously. Conscious seed use, i.e. sowing in adequate period and use of pre-treatments, that alleviates dormancy could increase seed sowing based restoration efficiency. However, the knowledge gaps related to the germination characteristics of target plant species delays their consideration.

Germination often occurs in different time period than seed dispersal, a time lag overcome by seed dormancy. A set of environmental factors indicate the adequate environmental conditions for germination and seedling establishment; favourable conditions break dormancy and induce germination. However, a fraction of the seeds can remain in dormant state for longer period despite the favourable conditions: this risk-spreading strategy allows species to reduce year-to-year variation in fitness. Seed dormancy is present in 50–90% of the global wild flora and can be categorized into five major dormancy types: the most common are physiological dormancy (PD), i.e., when the embryo possesses an inhibiting mechanism that prevents emergence, and physical dormancy (PY), i.e., when the seed possesses a hard seed coat impenetrable to water. Dormancy breaking mechanisms are different for each dormancy types: a dry period after seed dispersal in enough for some species (dry after-ripening), while others require stratification (exposed to warm or cold temperature, which are signals of summer or winter periods) or scarification (mechanical injury of the seed coat to allow water uptake) or the combination of different conditions and treatments. The optimal length and strength of these conditions are species specific and if not met, instead of germination they can induce secondary dormancy or loss of seed viability.

Despite their importance, dormancy type and dormancy breaking mechanisms are unknown for many species. This knowledge gap not only decreases restoration efficiency by seed sowing, but it also creates a problem in the face of climate change. Climate change is predicted to raise temperatures in Central Europe: the warming will be the greatest in spring periods and lowest in autumns, while great variability in winter warming makes this season very unpredictable. Without the basic knowledge about dormancy and germination characteristics, it is hard to forecast species- and community-level responses to changing environment (i.e. climate change) and to improve the efficiency of seed-based restoration actions.

Methods. I aimed to contribute to filling the knowledge gap regarding the dormancy and germination characteristics of Central European plants that are target species in ecological restoration. I selected 48 plant species and analysed their germination response to three different durations of warm stratification and three different durations of cold stratification treatments, and their combinations in a full factorial design (in total 15 different pre-germination treatments).

Seeds of 48 species (Table 1) were purchased from a seed producer of native species from the Kiskunság region (Central Hungary). For each stratification treatment the seeds of the studied species were placed in zip-lock bags; wrapped in aluminium foil and subjected to one-, two- or three months of warm stratification (W), one-, two- or three months of cold stratification (C) and the full factorial combination of the treatments (WC). Stratification treatments model the changes in the length of the summer and winter periods: in the past short-warm periods and longer cold periods were characteristics of the study region; under climate change the length of warm periods increases while that of cold periods decreases. The combination of treatments is important especially in case of spring-germinating species, which are affected both by the summer and winter conditions.

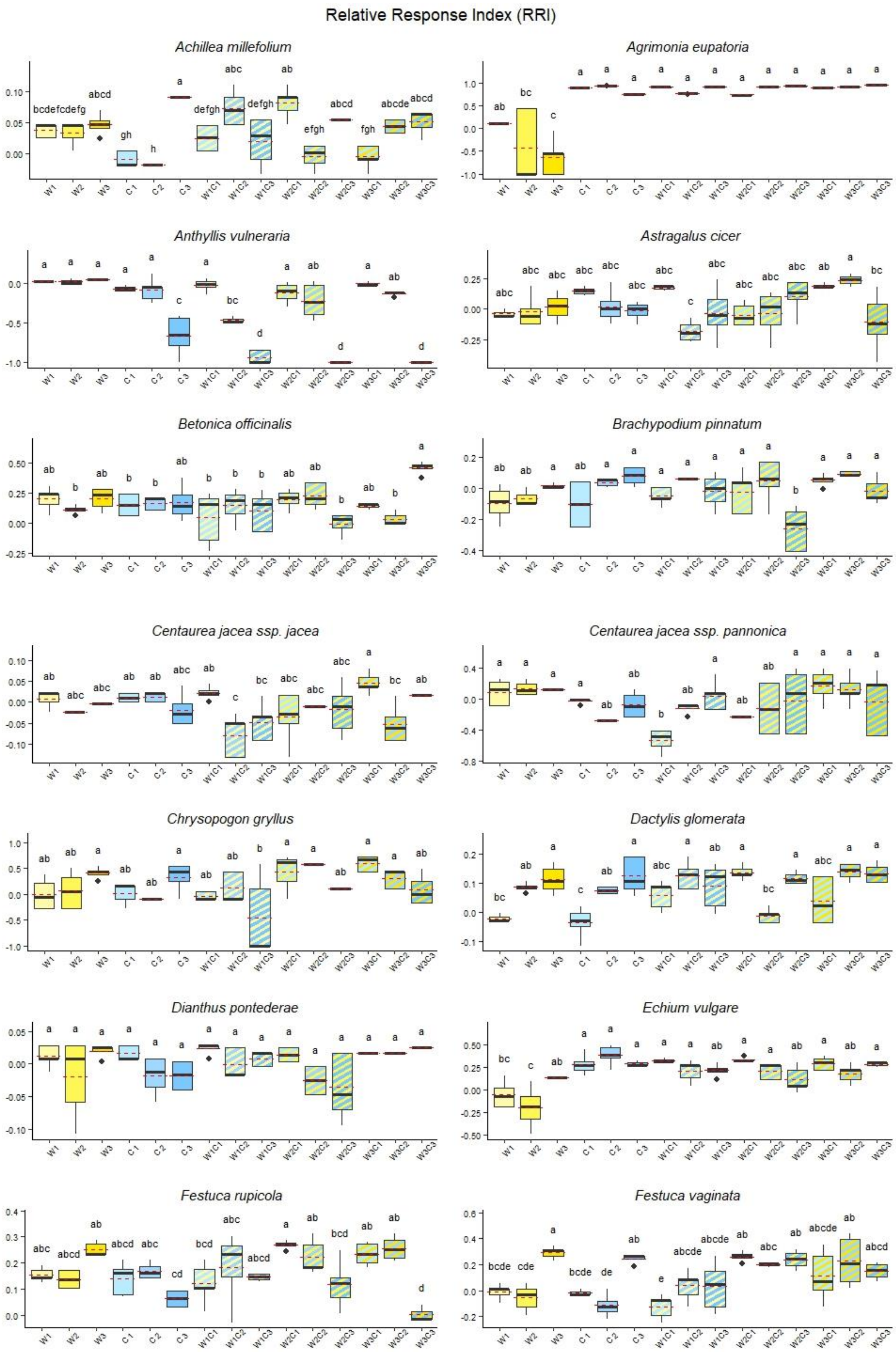
At the end of the stratification periods the seeds were germinated in growing chamber in Petri dishes. As the capacity of the growing chambers was limited, germination took place in four different cycles; in each germination cycle untreated seeds (dry storage in room temperature) were included as control (K). The germination lasted for four weeks, germinated propagules were counted and removed weekly.

For the statistical analysis Relative Response Index (RRI) and the germination uncertainty were calculated. RRI shows the effects of the treatments compared to the control; ranges between –1 and +1, zero means that the control and the treatment are not different, while one means that the control and the treatment are totally different. Germination uncertainty measures the degree of germination dispersion, a lower value means a more concentrated germination in time, while a higher number means a prolonged germination period. I used Gamma distributed generalised linear models (GLMs); stratification treatments were used as explanatory variables and RRI and germination uncertainty scores as dependent variables. Mean germination success in the control treatments of the four germination cycles was compared using glms with binomial distribution. All statistical analyses were performed in R statistical environment.

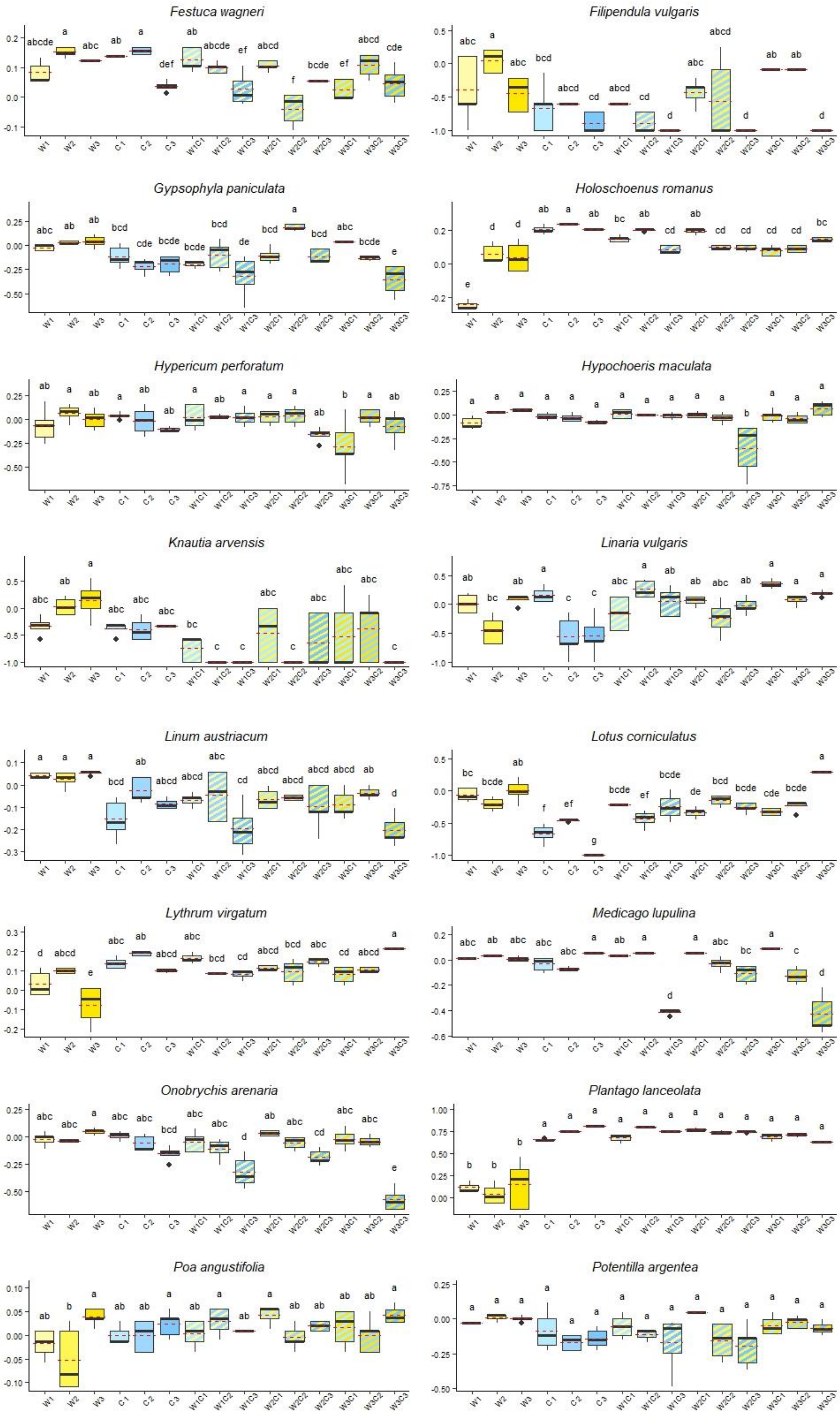
Table 1. List of the studied species. Strikethrough letters indicate species which were excluded from statistical analysis due to the lack of germination.

Species name	Species name	Species name
Achillea millefolium	~~*Galium boreale*~~	*Potentilla recta*
Agrimonia eupatoria	~~*Galium verum*~~	~~*Salvia austriaca*~~
Anthyllis vulneraria	*Gypsophila paniculata*	*Salvia pratensis*
Astragalus cicer	*Holoschoenus romanus*	*Scabiosa ochroleuca*
Betonica officinalis	*Hypericum perforatum*	~~*Schoenus nigricans*~~
Brachypodium pinnatum	*Hypochoeris maculata*	*Senecio jacobaea*
Centaurea jacea ssp. *jacea*	*Knautia arvensis*	*Silene conica*
Centaurea jacea ssp. *pannonica*	*Linaria vulgaris*	*Silene vulgaris*
Chrysopogon gryllus	*Linum austriacum*	*Stachys germanica*
Dactylis glomerata	*Lotus corniculatus*	*Stachys palustris*
Dianthus pontederae	*Lythrum virgatum*	*Teucrium chamaedrys*
Echium vulgare	*Medicago lupulina*	*Thymus glabrescens*
Festuca rupicola	*Onobrychis arenaria*	*Tragopogon dubius*
Festuca vaginata	*Plantago lanceolata*	*Trifolium montanum*
Festuca wagneri	*Poa angustifolia*	*Trifolium repens*
Filipendula vulgaris	*Potentilla argentea*	*Verbascum phoeniceum*

Results. Four species were excluded from the statistical analyses, as they did not germinate. Three species (*Dianthus pontederae*, *Potentilla argentea*, *Teucrium chamaedrys*) RRI was not affected by stratification treatments. *D. pontederae* and *P. argentea* had a high germination success even in their controls, as these species may have non-deep dormancy, allowing them to germinate under various settings as soon as the conditions become favourable. *T. chamaedrys* germinated poorly even in controls, possibly because of low seed quality. Differences in RRI were found in all other species (Figure 1).



Relative Response Index (RRI)
Achillea millefolium
Agrimonia eupatoria
Anthyllis vulneraria
Astragalus cicer
Betonica officinalis
Brachypodium pinnatum
Centaurea jacea ssp. jacea
Centaurea jacea ssp. pannonica
Chrysopogon gryllus
Dactylis glomerata
Dianthus pontederae
Echium vulgare
Festuca rupicola
Festuca vaginata


Festuca wagneri
Filipendula vulgaris
Gypsophyla paniculata
Holoschoenus romanus
Hypericum perforatum
Hypochoeris maculata
Knautia arvensis
Linaria vulgaris
Linum austriacum
Lotus corniculatus
Lythrum virgatum
Medicago lupulina
Onobrychis arenaria
Plantago lanceolata
Poa angustifolia
Potentilla argentea

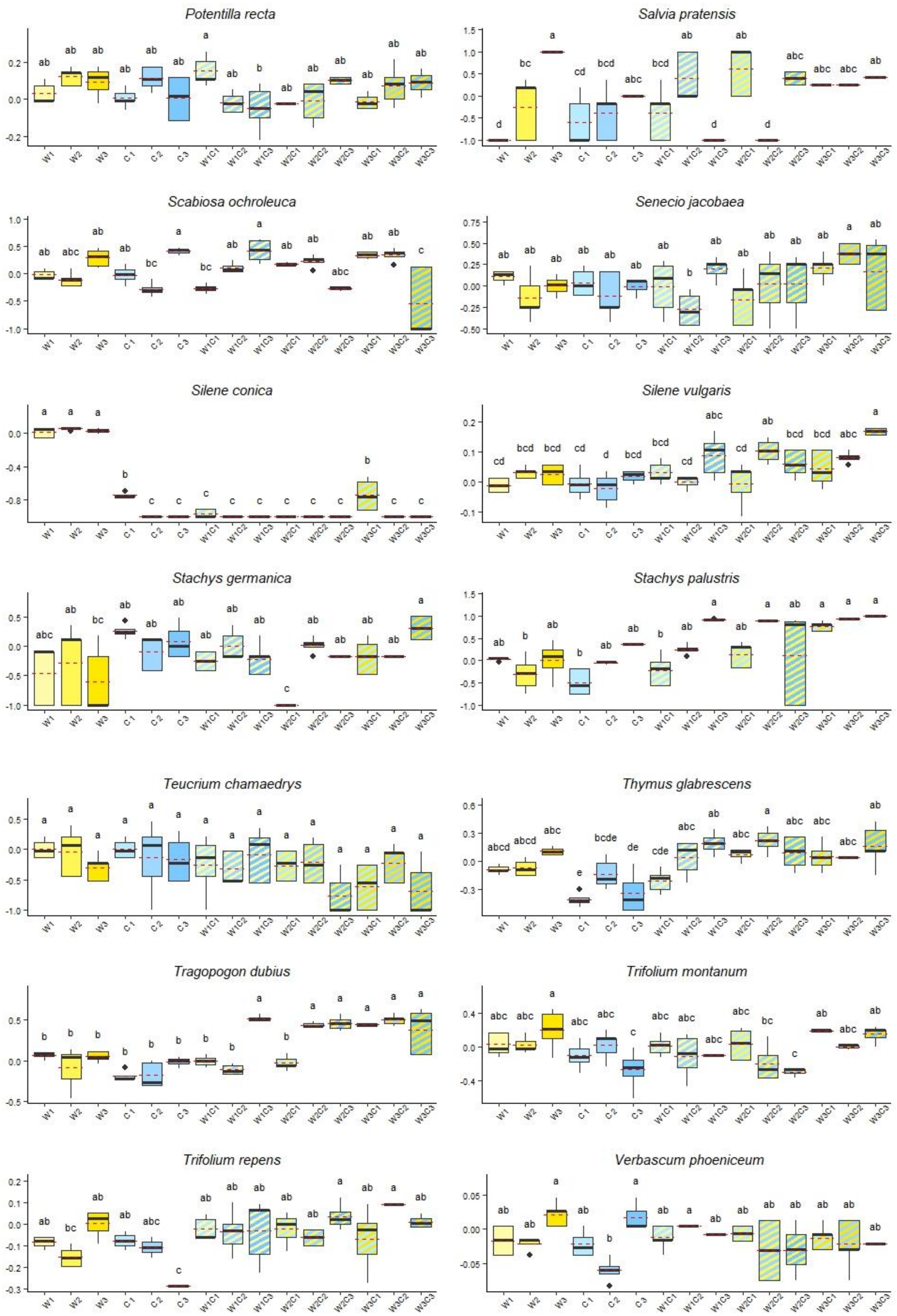


Figure 1. Relative response index (RRI, on y axis) of the studied species by stratification treatments. Lower case letters indicate significant differences between the treatments (glm, $p<0.05$).

Stratification treatments had significant effect on the germination uncertainty of 31 species and had no effect in 13 species. Germination success was significantly different between the four control treatment of the four germination cycles in 21 species while germination uncertainty was significantly different in 8 species.

According to our results, clear trends in response to warm- or cold stratification were present mostly in RRIs. Germination uncertainty in general was high, even when germination success was high, supporting the idea that Central European plant species tend to minimalize the risks occurring during seedling establishment.

There were only few species which had clear responses to the warm or cold stratification treatments, but even in these species, the length of these periods was mostly irrelevant.

Silene conica reacted well to warm stratification, while one-month cold stratification decreased drastically its germination percentage, and longer cold periods hampered germination totally. *S. conica* can be clearly categorized as an autumn germinating species, favouring germination at the end of warm, hot summers, during the favourable growing conditions of the autumn period with increased precipitation level, lower temperature, as well as weaker interspecific competition. Despite the risk of frost damage its seedlings overwinter in rosette form and will have a head-start at the end of winters when they can continue their life cycle with increasing temperature in spring.

Agrimonia eupatoria, *Echium vulgare* and *Plantago lanceolata* reacted well to cold stratification, while warm stratification was ineffective or induced secondary dormancy in their case. The optimal length of cold periods to induce germination is less than one month in these species; they can germinate during mild periods or heat waves of winters. Seedlings similarly to the case of *S. conica*, may be exposed to the risk of frost damage, but overwintering individuals will benefit from favourable growing conditions in spring. Furthermore, they can continue with their life cycle during longer warm periods in winters, shortly after germination. Germination follows a similar trend *Holoschoenus romanus* and *Lythrum virgatum* as well. Contrary to the four other species, in *L. virgatum* germination synchrony is increased by the cold treatment. This may seem as a bad strategy, but considering that the species produces a large quantity of seeds, the persistence of the population can rely on few successful seeds.

The responses of other species were not so clear. The unclear trend found in the members of *Fabaceae* family can be caused by their complex dormancy breaking mechanism: not they only have hard, water-impermeable seed coat, but also a cyclic sensitivity of the embryo for breaking dormancy: if not in a sensitive phase, despite water uptake can take place, seeds can swell but germination does not occur.

Understanding environmental conditions that induce or hamper germination by inducing or releasing dormancy of wild grassland species has practical implications. Seed-sowing based restoration practices should take into account the species-specific seed dormancy type and use appropriate sowing time combined with dormancy-breaking pre-treatments to increase restoration efficiency. This is of great importance especially in the face of the climate change, when well know environmental conditions change, and therefore restoration measures should be flexibly adapted to the changing climate. We found that in general the grassland species included in our study can cope with climate warming in the phenological stage of germination. Although their aboveground abundance will show great year-to-year variability, their seeds will be able to germinate thanks to their risk spreading strategy which can support the persistence of the populations.

The results of this work package are submitted to Applied Vegetation Science and also made available as a preprint (https://biorxiv.org/cgi/content/short/2024.09.26.615133v1). They were presented in form of poster in the 19th Eurasian Grassland Conference (Bolzano/Bozen, Italy) and in the 13th Hungarian Ecological Congress (Szeged, Hungary).

WP 3 Population-level responses of an early spring geophyte to weather fluctuations.

Rationale. Climate change, i.e. increasing temperature, reduction of frost days and nights, changes of precipitation regimes, changes phenological events of plants, and may also affect plant fitness. Earlier snowmelt and reduced number of frost days may result earlier start of vegetation period, but it may have a more pronounced effect on spring geophytes, whose whole life cycle depends on weather conditions during spring period. The effects of different weather parameters have been studied on geophytes phenology, and it was found, that most of the phenological events are related to temperature, while leaves withering was dependent on the number of rainy days.

I used as a model species the endangered and strictly protected early spring geophyte, *Colchicum bulbocodium* Ker-Gawl., to study the population dynamics of geophytes in relation to actual and lagged weather effects. I addressed the following questions: i) Do the number of individuals show fluctuations in different life stages across years? ii) Which weather parameters have the largest influence on the number of individuals in certain life stages?

Methods. To study the population dynamics of the species, the largest population in East-Hungary was selected, enabling to follow the demography in a representative number of plots. In the study both actual and lagged weather parameters were considered (Figure 3), to study their effects on population dynamics on *C. bulbocodium*.

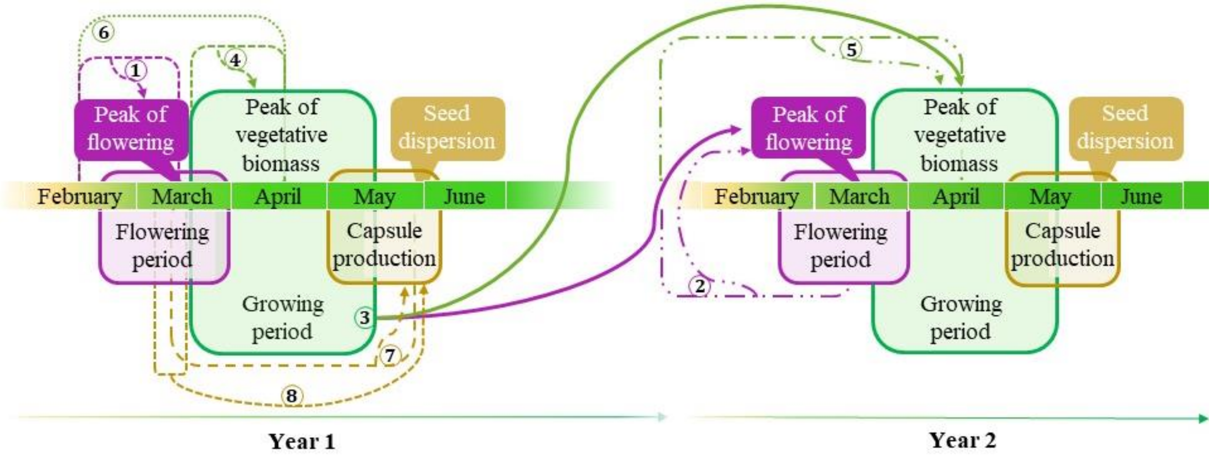


Figure 3. Main life cycle stages of *C. bulbocodium* in two consecutive years (marked with polygons with solid line contour) and the study periods, whose weather parameters affects the life stages (marked with numbers and polygons with non-solid line contours (except no. 3)). Numbers: (1) early spring – peak flowering period, (2) fall – flowering period, (3) growing period of the previous year, (4) leaf growing period, (5) fall – peak growing period (6) early spring – peak growing period, (7) period between flowering and fruiting and (8) flowering period. Arrows indicate which period (start) was studied in case of each of the three life stage (end). Colour of the polygons and of the arrows indicate to which life stage is related the studied period (except in case of no. 3, which may have a lagged effect on multiple life stages, so the colour of the polygon is different than that of related life stages). The line type of the polygons with the same colour represent different period affecting the same life stages.

Three survey events took place yearly starting from March 2018, when in the peak of flowering period the twenty 2 m × 2 m permanent survey plots were established.

Survey I, in mid-March (peak of flowering period): counting the flowering individuals and marking them
Survey II, in mid-April: recording the total number of individuals with leaves present in each plot. As leaf number is an indicator of development stage of individuals, the leaf number of each individual was recorded (from one-leaved, young individuals (1L); to four-leaved older individuals (4L)).
Survey III, in late May or early June: on the peak of capsules maturation capsule-production success was recorded by checking the previously flowering individuals (using bead-marks, photo-records) for capsule production.

Based on the photos taken during Survey II, unique IDs were assigned to each individual starting from 2018 based on their positions on the photos. Individuals in the same position across the years were marked with the same ID, while new IDs were given to the newly appeared individuals. Based on coloured markings on the photos, presence-absence data of each individual was recorded and individuals were assigned to one of the four leaf-number categories (1L, 2L, 3L, 4L) in each year. Based on yearly presence-absence data and leaf-number categories of individuals we also distinguished dormant individuals, that were not detectable in certain years.

Weather parameters originating from the closest meteorological station (Debrecen Airport) were derived from the Meteorological Database of the Hungarian Meteorological Service (OMSZ) and Operational Drought and Water Scarcity Management System of the General Directorate of Water Management (OVF). The following weather parameters were calculated for eight time periods (Figure 3): temperature (daily mean (T_{mean}), mean of daily maximums (T_{max}), mean of daily minimums (T_{min}), diurnal temperature range (DTR), maximum of DTR (DTR_{max}), minimum of DTR (DTR_{min})), precipitation (sum of daily precipitations (P_{sum}), number of days with precipitation (D_p)), number of frost days (D_f) and drought index. The periods considered were: (1) early spring – peak flowering period, (2) fall – flowering period, (3) growing period of the previous year, (4) leaf growing period, (5) fall – peak growing period, (6) early spring – peak growing period, (7) period between flowering and fruiting and (8) flowering period. These periods were chosen as they are expected to have a main influence on dormancy breaking (1, 2, 5), on bulb growth (3, 4, 6) and on reproduction (7, 8).

Statistical analyses were performed in the R statistical environment (version 4.3.2); dependent variables were number of flowering and detectable individuals, number of individuals in the behaviour categories, ratio between flowering and total number of individuals, number of capsules and capsule production success; explanatory variables were the weather parameters of different periods.

Results. The six-year long survey revealed a stable population size with differing number of individuals representing the life stages studied across the years: the number of flowering- and fruiting individuals, as well as the number of individuals belonging to the different leaf number categories, i.e. that compose the total number of detectable individuals, was different between the years. The largest part of the studied population consisted of individuals with actual or possible regenerative potential. These differences can be associated with the studied weather parameters, especially to the ones of the study years. Increasing mean, minimum, and maximum temperatures, as well as drought in general decreased the chance of individuals to break dormancy, while the presence of frost days increased the proportion of dormancy breaking *C.*

bulbocodium individuals. Increasing temperature preceding and during flowering period slightly decreases number of flowering individuals as well, while warm springs significantly decrease capsule production success. In geophytes flowering occurs only in a given bulb size, which is determined of the conditions of the growing period. Interestingly in case of *C. bulbocodium* no relation was found between flowering and growing period. It is likely that bulb size is not a limitation for flowering initiation of the species; however, sufficient bulb growth may be achieved only on the expense of capsule- and seed production: in unfavourable years (i.e warm springs) seed production is more likely aborted, as photosynthetic products from the leaves are directed and accumulated in the bulbs. Measures of capsule length further supports this finding. Lagged weather effect was also found to have fewer effect: the number of detectable individuals was decreased in the year following a warm growing period. Besides, a larger amount of precipitation promoted the increase of leaf number and hampered its decrease, and also hampered the individuals to enter prolonged dormancy. When individuals were already in dormant state drought seemed to prolong this state.

The results highlight that temperature related weather parameters are more important than precipitation related ones to determine population dynamics of geophytes. However, a six-year-long data is still not enough to precisely determine the fate of undetected plants (prolonged dormancy or deceased), we can only account for prolonged dormancy. To determine which is the key mechanism that drives the population dynamics of *C. bulbocodium*, further monitoring of seedlings and dormant individuals is needed.

- The results of this work package was submitted to the journal *Scientific Reports* with the title "Understanding the effects of weather parameters on the population dynamics of an endangered geophyte supports monitoring efficiency" where it received a major revision decision on 21 Aug 2024 and two constructive and favourable reviews. The manuscript is also available as a preprint (10.21203/rs.3.rs-4345243/v1). The results were presented in the XIV. Advances in the Research of Flora and Vegetation of the Carpathian Basin international conference (Gödöllő, Hungary), in the 24th Biology Days in Cluj-Napoca (Romania) and the 7th European Congress of Conservation Biology (Bologna, Italy) in form of short-presentation and in poster form in the 18th Eurasian Grassland Conference (Szarvas, Hungary).

Key results of the project

- Restoration of open sand plant communities cannot rely on soil seed bank, as both its diversity and density are low. Active interventions are needed.
- Grassland specialist plant species can cope with changing temperature regimes during rest periods. Even when stratification treatments breaks dormancy and induces germination, germination uncertainty is in general high, suggesting that grassland plant species possess the risk spreading ability, which enables their long-term survival even in case when a fraction of seeds dies.
- A warm-cold-warm sequence is required by *C. bulbocodium* to successfully finish its life cycle. Warm springs decrease its fitness, while drought results prolonged dormancy of the individuals.

Publications, awards during the study period

Papers

2 first-authored submitted manuscripts, 1 first authored published paper, 8 co-authored published and submitted papers

Core papers related to the project

- Kiss, R., Lukács, K., Godó, L., Tóth, Á., Miglécz, T., Szél, L., Demeter, L., Deák, B., Valkó, O. (2024). Understanding the effects of weather parameters on the population dynamics of an endangered geophyte supports monitoring efficiency. Scientific Reports (major revision, link to preprint: 10.21203/rs.3.rs-4345243/v1).

- Kiss, R., Lukács, K., Tóth, Á., Tóth, B., Samraoui, K.R., Engel, R., Deák, B., Valkó, O. (2024). Effect of pre-germination temperature conditions on germination characteristics of temperate grassland species (submitted to Applied Vegetation Science, link to preprint: https://biorxiv.org/cgi/content/short/2024.09.26.615133v1)

Other papers submitted and/or published about seed-based restoration and soil seed bank, and closely related to the project

- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai., Z., Kelemen, A., Miglécz, T., Tóth, Á., Valkó, O. (2022). Co-seeding grasses and forbs supports restoration of species-rich grasslands and improves weed control in ex-arable land. Scientific Reports 12:21239. https://doi-org/10.1038/s41598-022-25837-4. [IF2023: 4.996]*
- Tóth, Á., Deák, B., Kelemen, A., Kiss, R., Lukács, K., Bátori, Z., Valkó, O. (2024). Restoration potential and vertical distribution of the soil seed bank in wet meadows. Community Ecology (major revision).*
- Frei, K., Tölgyesi, C., Kelemen, A., Bátori, Z., Hábenczyus, A.A., Sonkoly, J., Kiss, R.; Tóth, K., Havadtői, K., Varga, A., Tóth, B., Erdős, L., Török, P. (2024). Vegetation patterns and dynamics of silvopastoral systems: the interactive role of succession, disturbance and seed bank. Ecological Applications (submitted).
- Tóth, Á., Deák, B., Tóth, K., Kiss, R., Lukács, K., Rádai, Z., Godó, L., Borza, S., Kelemen, A., Miglécz, T., Bátori, Z., Novák, T.J., Valkó, O. (2022). Vertical distribution of soil seed bank and the ecological importance of deeply buried seeds in alkaline grasslands. PeerJ 10: e13226. doi: 10.7717/peerj.13226. [IF2023: 3.061]*

Other co-authored papers published in the reporting period

- Lukács, K., Tóth, Á., Kiss, R., Deák, B., Rádai, Z., Tóth, K., Kelemen, A., Bátori, Z., Hábenczyus, A.A., Tölgyesi, C., Miglécz, T., Godó, L., Valkó, O. (2024). The ecological footprint of outdoor activities: Factors affecting human-vectored seed dispersal on clothing. Science of The Total Environment 906:1-8. https://doi.org/10.1016/j.scitotenv.2023.167675. [IF2023: 8.200]*
- Deák, B., Botta-Dukát, Z., Rádai, Z., Kovács, B., Apostolova, I., Bátori, Z., Kelemen, A., Lukács, K., Kiss, R., Palpurina, S. Sopotlieva, D., Valkó, O. (2024). Meso-scale

environmental heterogeneity drives plant trait distributions in fragmented dry grasslands. Science of the Total Environment, 947, 174355. https://doi.org/10.1016/j.scitotenv.2024.174355. [IF2023: 8.200]*

- Valkó, O., Kelemen, A., Kiss, O., Bátori, Z., Kiss, R., Deák, B. (2024). Grassland restoration on linear landscape elements–comparing the effects of topsoil removal and topsoil transfer. BMC Ecology and Evolution, 24, 112. https://doi.org/10.1186/s12862-024-02299-y. [IF2023: 2.3]*
- Deák, B., Bede, A., Rádai, Z., Dembicz, I., Apostolova, I., Batáry, P., Gallé, R., Tóth, C.A., Dózsai., J., Moysiyenko, I.I., Sudnik-Wójcikowska, B., Nekhrizov, G., Lisetkii, F.N., Buryak, Z.A., Kis, S., Borza, S., Godó, L., Bragina, T.M., Smelansky, I., Molnár, Á., Bán, M., Báthori, F., Árgay, Z., Dani, J., Kiss, R., Valkó, O. (2023). Contribution of cultural heritage values to steppe conservation on ancient burial mounds of Eurasia. Conservation Biology e14148. https://doi.org/10.1111/cobi.14148 [IF2023: 5.2]
- Tölgyesi, C., Kelemen, A., Bátori, Z., Kiss, R., Hábenczyus, A.A., Havadtői, K., Varga, A., Erdős, L., Frei, K., Tóth, B., Török, P. (2023). Maintaining scattered trees to boost carbon stock in temperate pastures does not compromise overall pasture quality for the livestock. *Agriculture, Ecosystems & Environment* 351:108477. https://doi.org/10.1016/j.agee.2023.108477. [IF2023: 6.0]*

*NKFI support indicated

Conferences

Presentation (7 presented, 22 co-authored)

- Kiss, R., Lukács, K., Godó, L., Tóth, Á., Miglécz, T., Szél, L., Demeter, L., Valkó, O., Deák, B. (2024). Challenges in population censuses of endangered species: what we learned from dormant geophytes. 7th European Congress of Conservation Biology. Bologna, Italy.
- Kiss, R., Lukács, K., Godó, L., Tóth, Á., Miglécz, T., Szél, L., Demeter, L., Deák, B., Valkó, O. (2024). Rejtőzködő geofiton: valóban annyi amennyi? Az egyhajúvirág-monitoring nehézségei. 24. Kolozsvári Biológus napok-24th Biology days. Cluj-Napoca, Romania.
- Kiss, R., Lukács, K., Godó, L., Tóth, Á., Miglécz, T., Szél, L., Demeter, L., Valkó, O., Deák, B., (2024). Időjárási elemek hatása a *Colchicum bulbocodium* populációdinamikájára (Effect of climatic parameters on the population dynamics of *Bulbocodium vernum*). XIV. Aktuális Flóra- és Vegetációkutatás a Kárpát-medencében (XIV. Advances in the Research of Flora and Vegetation of the Carpathian Basin). Gödöllő, Hungary.
- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai, Z., Kelemen, A., Miglécz, T., Tóth, Á., Godó, L., Borza, S., Valkó, O. (2022). Timing seed-sowing properly facilitates restoration of species-rich grasslands. 17th Eurasian Grassland Conference. Tolosa, Spain.
- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai, Z., Kelemen, A., Miglécz, T., Tóth, Á., Godó, L., Valkó, O. (2022). Effective restoration of species-rich grasslands: the importance of timing in sowing target species seeds. 6th European Congress of Conservation Biology. Prague, Czech Republic.
- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai, Z., Kelemen, A., Miglécz, T., Tóth, Á., Godó, L., Borza, S., Valkó, O. (2022). Aki késik, elmúlik: A kétszikűek késői vetése

csökkenti sikerüket a restauráció során. 22. Kolozsvári Biológus napok-22th Biology days. Cluj-Napoca, Romania.

- Kiss, R., Deák, B., Tóthmérész, B., Miglécz, T., Tóth, K., Török, P., Lukács, K., Godó, L., Körmöczi, Z., Radócz, S., Borza, S., Kelemen, A., Sonkoly, J., Kirmer, A., Tischew, S., Valkó, O. (2022). Gyepi növényfajok megtelepedése és terjedése zoochória jelenlétében és hiányában. Kvantitatív Ökológiai Szimpózium. Vácrátót, Hungary.

Poster (5 first author, 15 co-authored)

- Kiss, R., Lukács, K., Tóth, Á., Korom, E., Engel, R., Tóth, B., Samraoui, K. R., Deák, B., Valkó, O. (2024). Germination capacity of Central-European dry grassland species after warm and cold conditions: a laboratory experiment. 19th Eurasian Grassland Conference, Bolzano/Bozen, Italy.
- Kiss, R., Lukács, K., Tóth, Á., Korom, E., Engel, R., Tóth, B., Samraoui, K. R., Deák, B., Valkó, O. (2024). Szárazgyepi fajok csírázási sikerének változása meleg és hideg sztratifikációt követően. 13. Magyar Ökológus Kongresszus (13th Hungarian Ecological Congress). Szeged, Hungary.
- Kiss, R., Lukács, K., Godó, L., Tóth, Á., Miglécz, T., Szél, L., Demeter, L., Valkó, O., Deák, B. (2023): Effect of climatic parameters on the population dynamics of *Bulbocodium vernum*. 18 th Eurasian Grassland Conference, Szarvas, Hungary.
- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai, Z., Kelemen, A., Miglécz, T., Tóth, Á., Godó, L., Borza, S., Valkó, O. (2023). Timing seed-sowing of grasses and forbs can support grassland restoration. 14th Biennial ISSS Conference. Paris, France.
- Kiss, R. (2022). A magbank gyepregenerációban betöltött szerepe a klímaváltozás tükrében. XIII. Magyar Természetvédelmi Biológiai Konferencia (13th Hungarian Conference on Conservation Biology). Pécs, Hungary.

Awards, other activities

- 2023: One of the winners of the ELKH Researcher Mobility Program 2023 (Eötvös Loránd Research Network Secretariat)
- 2023: One of the winners of the Environmental Science Youth Prize of the Hungarian Academy of Sciences.
- 2023: Member of the organizing committee of the 18th Eurasian Grassland Conference (EGC), organized in Szarvas, 25-28 September 2023.