FINAL REPORT

HOW CAN PLANT ECOLOGY SUPPORT GRASSLAND RESTORATION?

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Overall research progress

Because of the COVID 19 situation the proposal has been extended two times, with a total of two years. This also subjected the financial background of the proposal. The costs allocated for the participation on international conferences and for some consumables have been reallocated for personal costs supporting researchers to participate in the elongated period of the proposal. At the beginning of the research, this testing subjected only alkali and loess grassland habitats, but later with the join of new researchers (V. B-Béres, L. Erdős) the range of the studied communities have been extended with the involvement of sand grasslands, forest-grassland complexes and some type of aquatic habitats and species groups (phytoplankton and benthic diatom assemblages in lakes and small streams). Beside of these changes all works were executed following the proposed research plan.

Overview of the publications according to the proposed research plan

In the proposal, the publication of 10 impacted publications were planned for the 2016-2020 period. The additional two years enabled for us to publish more papers linked to the proposal. In the reporting period with the support of the project altogether 44 papers with an impact factor were published (Cumulative IF: 143.353), and further 6 manuscripts were submitted and are in various stages of revisions in impacted journals. Most of the papers were published either in open access journals, open access by country agreement or provided in public repositories (REÁL or Library of the University of Debrecen). Out of these publications, altogether 19 primary research papers are linked closely to the proposed research topics and questions, in addition 6 review and overview papers were published either on the subjected habitats or theoretical considerations. Further 5 papers tested the proposed research questions in aquatic communities.

In our research we aimed to test plant ecological theories in pristine and restored habitats to explore how theoretical findings can support a cost-effective and successful grassland restoration in agriculture-driven landscapes. This approach in restoration is very novel and well connected to the mainstream of restoration ecology and theoretical plant ecology research. We aimed to study the above- and belowground species and trait composition of pristine and restored grasslands as model habitats. We wanted to study the following topics more in detail in the proposal:

A) Which grassland species can disperse into the restoration sites spontaneously? Spontaneous dispersal processes are increasingly involved in restoration by the assessment of spontaneous regeneration processes in grasslands. In the assessment of dispersal capacity (i) both the local species pool of vegetation and seed bank, (ii) the regional species pool of the landscape, and (iii) the landscape-scale habitat patterns should be considered.

B) How effective is the species immigration and establishment in restoration sites? In restoration of grassland habitats, the time factor and the progress of species composition

development towards the reference stage are very important. Thus, it is good to know how high the dispersal capacity is, propagule availability, the pressure of spontaneously immigrating species and the establishment success of target species mediated by abiotic habitat properties.

C) Which species can be successfully assembled in restoration sites? Beyond dispersal processes and environmental filtering, which species can successfully coexist is a crucial question in restoration? In technical restoration, for example, it helps to assess whether a low or high diversity seed mixture should be used, or which species should be included in the mixture.

In these three topics in nine theoretical consideration groups, we aimed at to answer six key questions of species dynamics, succession and species assembly in spontaneous succession and technical grassland restoration. Below we list these questions and add supporting key publications dealing with the respective question.

(i) Which plant species contribute to the species pool of the studied landscape and grasslands above- and belowground?

Key publications:

Deák B., Valkó O., Török P., Tóthmérész B. (2016): Factors threatening grassland specialist plants - A multi-proxy study on the vegetation of isolated grasslands. *Biological Conservation* 204: 255–262.

Sonkoly J., Deák B., Valkó O, Molnár V.A., Tóthmérész B., Török P. (2017): Do large-seeded herbs have a small range size? The seed mass – distribution range trade-off hypothesis, *Ecology & Evolution* 7: 11204–11212.

Kiss R., Deák B., Török P., Tóthmérész B., Valkó O. (2018): Grasslands and climate change? How can soil seed bank support community resilience? *Restoration Ecology* 26: S141–S150.

(ii) How is the success of grassland restoration and post-restoration dynamics influenced by the species pool of the surroundings?

Key publications:

Török P., Kelemen A., Valkó O., Miglécz T., Tóth K., Tóth E., Sonkoly J., Kiss R., Csecserits A., Rédei T., Deák B., Szűcs P., Varga N., Tóthmérész B. (2018): Succession in soil seed banks and its implications for restoration of calcareous sand grasslands. *Restoration Ecology* 26: S134–S140.

Kiss R., Deák B., Tóthmérész B., Miglécz T., Tóth K., Török P., Lukács K., Godó L., Körmöczi Zs., Radócz Sz., Borza S., Kelemen A., Sonkoly J., Kirmer A., Tischew S., Valkó O. (2021): Zoochory on and off: A field experiment for trait-based analysis of establishment success of grassland species. *Journal of Vegetation Science* 32: e13051.

Kiss R., Deák B., Tóthmérész B., Miglécz T., Tóth K., Török P., Lukács K., Godó L., Körmöczi Zs., Radócz Sz., Kelemen A., Sonkoly J., Kirmer A., Tischew S., Švamberková E., Valkó O. (2021): Establishment gaps in species-poor grasslands: artificial biodiversity hotspots to support the colonization of target species. *Restoration Ecology* 29: e13135.

(iii) How is the speed and success of grassland restoration influenced by the initial species composition of the restoration site and the area and spatial configuration of grassland habitats?

Key publications:

Török P., Matus G., Tóth E., Papp M., Kelemen A., Sonkoly J., Tóthmérész B. (2018): Both trait-neutrality and filtering effects are validated by the vegetation patterns detected in the functional recovery of sand grasslands. *Scientific Reports* 8: 13703.

Sonkoly J., Valkó O., Balogh N., Godó L., Kelemen A., Kiss R., Miglécz T., Tóth E., Tóth K., Tóthmérész B., Török P. (2020): Germination response of invasive plants to soil burial depth and litter accumulation is species-specific. *Journal of Vegetation Science* 31: 1081–1089.

(iv) How is the species pool of embedded natural and restored grasslands affected by the landscape-scale habitat diversity and configuration?

Key publications:

Deák B., Valkó O., Török P., Kelemen A., Bede Á., Csathó A., Tóthmérész B. (2018): Habitat and landscape filters jointly drive richness and abundance of grassland specialist plants in terrestrial habitat islands. *Landscape Ecology* 33: 1117–1132.

Deák B., Valkó O., Nagy D. D., Török P., Torma A., Lőrinczi G., Kelemen A., Nagy A., Bede Á., Mizser Sz., Csathó A. I., Tóthmérész B. (2020): Habitat islands outside nature reserves – threatened biodiversity hotspots of grassland specialist plant and arthropod species. *Biological Conservation* 241: 108254.

(v) How are the species and trait composition of restored and natural grasslands related to aboveground species richness and biomass

Key publications:

Kelemen A., Tóthmérész B., Valkó O., Miglécz T., Deák B., Török P. (2017): Old-field succession revisited - New aspects revealed by trait-based analyses of perennial-crop-mediated succession. *Ecology and Evolution* 7: 2432–2440.

Valkó O., Kelemen A., Miglécz T., Török P., Deák B., Tóth K., Tóth J. P., Tóthmérész B. (2018): Litter removal does not compensate detrimental fire effects on biodiversity in regularly burned semi-natural grasslands. *Science of the Total Environment* 622-623: 783–789.

Sonkoly J., Kelemen A., Valkó O., Deák B., Kiss R., Tóth K., Miglécz T., Tóthmérész B., Török P. (2019): Both mass ratio effects and community diversity drive biomass production in a grassland experiment. *Scientific Reports* 9: 1848.

Bátori Z., Kiss P. J., Tölgyesi Cs., Deák B., Valkó O., Török P., Erdős L., Tóthmérész B., Kelemen A. (2020): River embankments mitigate the loss of grassland biodiversity in agricultural landscapes. *River Research and Applications* 36: 1160–1170.

(vi) How are the plant species and trait composition related to biotic interactions and abiotic habitat conditions?

Key publications:

Sonkoly J., Valkó O., Deák B., Miglécz T., Tóth K., Radócz Sz., Kelemen A., Riba M., Vasas G., Tóthmérész B., Török P. (2017): A new aspect of grassland vegetation dynamics: Cyanobacterium colonies affect establishment success of plants. *Journal of Vegetation Science* 28: 475–483.

Török P., Penksza K., Tóth E., Kelemen A., Sonkoly J., Tóthmérész B. (2018): Vegetation type and grazing intensity jointly shape grazing effects on grassland biodiversity. *Ecology & Evolution* 8: 10326–10335.

Erdős L., Török P., Szitár K., Bátori Z., Tölgyesi Cs., Kiss P. J., Bede-Fazekas Á., Kröel-Dulay Gy. (2020): Beyond the forest-grassland dichotomy: the gradient-like organization of habitats in forest-steppes. *Frontiers in Plant Science* 11: 263.

Teleki Balázs, Sonkoly Judit, Erdős László, Tóthmérész Béla, Prommer Mátyás, Török Péter: High resistance of plant biodiversity to moderate native woody encroachment in loess steppe grassland fragments, Applied Vegetation Science 23: 175–184., 2020.

Tölgyesi Cs., Torma A., Bátori Z., Šeat J., Popović M., Gallé R., Gallé-Szpisjak N., Erdős L., Vinkó T., Kelemen A., Török P. (2022): Turning old foes into new allies—Harnessing drainage canals for biodiversity conservation in a desiccated European lowland region. *Journal of Applied Ecology* 59: 89–102.

Beside answering the key research questions, we also developed several synthesis papers summarising the state of art of knowledge of various habitat types studied in the project. We completed 11 overview chapters and review papers (please see the publication list).

Data papers and databases

Related to the project several primary research data have been collected on plant traits. During the implementation of the project, we made attempts to make this data publicly available for the use of further research in Hungary and for international research. We published a data paper to *Folia Geobotanica* from our trait measurements – nearly 1,000 individual trait measurements were included (E-Vojtkó et al. 2020), and an additional one where in addition measurements for 1,100 species were given (McIntosh-Buday et al. 2022). We compiled also an open access database with trait measurements of the Pannonian flora with the name PADAPT (Pannonian Database of Plant Traits), which were completed in the first part of 2022 (See: https://padapt.eu/hu).

E-Vojtkó A., Balogh N., Deák B., Kelemen A., Kis Sz., Kiss R., Lovas-Kiss Á., Löki V., Lukács K., Molnár V. A., Nagy T., Sonkoly J., Süveges K., Takács A., Tóth E., Tóth K., Tóthmérész B., Török P., Valkó O., Vojtkó A., Lukács B. A. (2020): Leaf trait records of vascular plant species in the Pannonian flora with special focus on endemics and rarities. *Folia Geobotanica* 55: 73–79. doi:10.1007/s12224-020-09363-7

McIntosh-Buday A., Sonkoly J., Takács A., Balogh N., Kovacsics-Vári G., Teleki B., Süveges K., Tóth K., Hábenczyus A. A., Lukács B. A., Lovas-Kiss Á., Löki V., Tomasovszky A., Tóthmérész B., Török P., Tóth E. (2022): New data of plant leaf traits from Central Europe. *Data in Brief* 42: 108286. doi:10.1016/j.dib.2022.108286

International collaborations

With an international collaboration of the Global Arid Zone Project (GAZP network, https://www.drylandrestore.com/) a paper was considered with major revisions to publication in Nature Ecology and Evolution, the PI is one of the 20 core authors. An international LIFE Proposal - Sustainable Viticulture for Climate Change Adaptation (LIFE19 CCA/DE/001224) LIFE VineAdapt (Germany, France, Austria and Hungary), was started in early September 2020, where the PI is one of the coordinators of the sampling in Hungarian project sites. We started a collaboration in LIFE-IP Grassland-HU project (LIFE-IP GRASSLAND-HU - Long term conservation of Pannonian grasslands and related habitats through the implementation of PAF strategic measures, LIFE17 IPE/HU/000018), which falls strongly in the subject of the present proposal, in which the PI is the coordinator of the large-scale monitoring of shrub clearing and invasion species suppression actions.

We participate in the global network of dark diversity project (DarkDivNet, https://macroecology.ut.ee/en/darkdivnet/) and participated between 20-23 November, 2019. at the DarkDivNet workshop in Tartu, Estonia organised by the University of Tartu (Meelis Pärtel and colleagues). Papers from this network collaboration initiated during the reporting period can be expected in the near future.

In the reporting period four special issues were coordinated and/or co-edited by the PI in international journals. These were the following:

2017-2018 Lead guest editor - Restoration Ecology, special issue: „Seed dispersal and seed banks"
2018-2020 Lead guest editor – Flora (Q2), special issue: "Ecology and Evolution of Steppe Biodiversity"
2018-2020 Lead guest editor – Journal of Vegetation Science (D1), special issue: "Dispersal and establishment as drivers of vegetation dynamics and resilience"
2019-2021 Lead guest editor – Restoration Ecology, special issue: „State of the art and future of grassland restoration"

Further three special issues are still in progress coordinated and/or co-edited by the PI in international journals. These are:

2021-2023 Lead guest editor – Applied Vegetation Science, special issue: „Grazing effects on vegetation"
2021-2023 Guest editor – Frontiers in Ecology and Evolution, special issue: „Origin, Conservation, and Restoration of the Threatened European Grassland Ecosystem in the Anthropocene"
2021-2023 Guest editor – Global Ecology and Conservation, special issue: „Restoration of open ecosystems in the face of climate change".

Communication of results in conferences and for the public

The project results were presented in 82 oral or poster presentations at national and international conferences. We participated at the Annual Symposium of the International Association for Vegetation Science (IAVS, 60th, Palermo – Italy; 61st Bozeman – USA, 62nd Bremen – Germany, 63rd Online, 64th Madrid – Spain), at the Eurasian Grassland Conference (14th Riga – Latvia, 16th Graz – Austria, the 1st International Conference on Community Ecology (Budapest), at the 11th SER Europe 2018 Conference (Reykjavik – Iceland), at the European Congress for Conservation Biology (2018: Jyväskylä – Finnland, 2022: Prague – Czech Republic), at the 48th Annual Meeting of the Ecological Society of Germany, Austria and Switzerland (2018: Wien, Austria), at the DarkDivNet Workshop (2019: Tartu – Estonia) conferences. We also participated at the Kolozsvári Biológus Napok (18th: 2017, 19th: 2018, Kolozsvár, Romania), at the Magyar Ökológus Kongresszus (11th: 2018 Nyíregyháza, 12th 2021 Vác), at the Aktuális Flóra- ésVegetációkutatás a Kárpát-medencében (2018: Debrecen, 2021: Debrecen) conferences

We considered very important to communicate the scientific results in translation for the public, thus, we communicated our results frequently in popular writings, press releases and press interviews. The detailed list of this type of communications you may find at the homepage of the research group (http://grassland-restoration.eu/). The PI also runs a blog, where all publications and other linked actions are provided. You find the blog at http://grassland-restoration.blogspot.hu/.