Improving ecosystem services in farmlands: beginning of a long-term ecological study with restored flower-rich grasslands

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ABSTRACT
Biodiversity declines in an unprecedented way, mostly due to land use change. Restoration interventions proved to be one of the most effective tools to halt the decline, especially in ecosystems such as agricultural fields. Evidence-based, locally adapted recommendations on grassland restoration, however, are often missing, so we present a novel approach for such interventions that can be implemented anywhere and that are based on scientific rigor. In a recently started long-term field ecological study, we established 0.5 ha wildflower parcels, using a diverse local seed mixture of 32 insect-visited plant species in Central European agricultural landscapes in 2020. Our focus is on the landscape-scale effects of this ecological intensification on ecosystem services such as crop yield, pollination and pest control, and the long-term monitoring of the successional processes. The aim is to showcase an effective restoration protocol that could serve as a model for future farm management, and provide much-needed evidence for policy on landscape ecological restoration of international relevance.

INTRODUCTION
Biodiversity declines rapidly, threatening ecosystem functioning and finally human well-being. A major driver behind the decline is land use change due to agriculture. In Europe, about half of the land is used for agriculture (European Environment Agency 2019), much of which has been intensified in the last decades (Emmerson et al. 2016). To counter the decline of biological diversity due to field- and landscape-scale intensification, immense efforts have been made to conserve and restore ecosystems and biodiversity (Kleijn et al. 2011). The target of the current UN Decade on Ecosystem Restoration is to restore 30% of today’s degraded areas (UNEP/FAO 2020), of which grasslands have received the least attention so far (Török et al. 2021). Subsequently, Dudley et al. (2020) and Csákvári et al. (2021) identified restoration as a key research field and called for publications and the showcasing of restoration approaches. Effective restoration protocols based on well-established evidence and an increased understanding among stakeholders of how nature, economy and society can benefit, are badly needed (Díaz et al. 2019; Farrell et al. 2021; Fischer et al. 2021). Despite the enormous amount of money spent on ecosystem conservation, results are rather mixed, probably also due to inappropriate practices (Batáry et al. 2015; Pe’er et al. 2017). That is a major weakness for regions that still hold high biodiversity, such as Central and Eastern Europe (Stoate et al. 2009; Vačkář and Báldi 2016).

Semi-natural grasslands are a prominent target of restoration interventions because of their high biodiversity value (Habel et al. 2013). However, the literature on grassland restoration lacks three major issues: i) landscape-scale studies on ecological intensification (von Holle, Yelenik, and Cornish 2020; Lowe, Groves, and Gratton 2021), ii) the long-term monitoring of successional processes of restored grassland on former cropland (Lengyel et al. 2012; Holland et al. 2017; Lowe, Groves, and Gratton 2021), and iii) restoration with diverse native and local floral seed mixtures (Haaland, Naisbit, and Bersier 2011). Furthermore, research on restored flower-rich grasslands is especially missing from Central and Eastern Europe, and more broadly from the steppe belt stretching from Central Europe to Asia.

The aim of our recently started large-scale and long-term field study is to test the effects of restoring species-rich semi-natural grassland islands in crop fields on biodiversity and ecosystem services, considering landscape context and spatial configuration of restored patches – linked to the single
large or several small (SLOSS) dilemma (Fahrig et al. 2022). In principle, we focus on pollinators and pest control agents as important ecosystem service providers to crops and other plants (Kovács-Hostyánszki et al. 2017). We monitor the successional development and the restoration success of such wildflower parcels and intend to feed research evidence into agricultural policy developments.

**Experimental setup**

We selected 24 circular landscape plots of 500 m radius with either homogeneous (<10% of semi-natural habitats) or heterogeneous (40-60% of semi-natural habitats) landscapes in Central Hungary (Figure 1). Within 16 landscape plots, we sowed 0.5 ha with a wildflower seed mixture (Appendix 1) in February 2020. These sown parcels either consist of a single large field or three smaller, spatially associated strips about 100–150 m apart (see also here), yet of consistently 0.5 ha in total area. Further eight landscape plots without sown treatments serve as control sites. With this setup, we not only study the sown parcels, but also their landscape-scale effects. The setup of compact and diverse islands differs from the commonly used setup of long, narrow strips at the edge of agricultural fields with few species (Haaland, Naisbit, and Bersier 2011; Ouvrard, Transon, and Jacquemart 2018; Schmidt et al. 2022). Well-composed, high diversity seed mixtures have been shown to support higher habitat quality for pollinators (Williams et al. 2015; Meissen et al. 2019; Hyvönen et al. 2021) and enhance the reestablishment success of the target vegetation (Török et al. 2021). Yet they are often compiled irrespective of their nativeness and are questionable in terms of their sufficiency for potential pollinators and the risk of plant invasion. Therefore, our seed mixture consisted of 32 local insect-visited plant species flowering additively during the whole vegetation period (Appendix 1) and providing morphologically manifold flowers to offer food resources to diverse pollinator guilds (see also Nichols, Goulson, and Holland 2019). Grasses were omitted to avoid their swift dominance due to their higher germination and quick colonization rate (Meissen et al. 2019). We apply adaptive management to the parcels, continuously monitoring the development of the vegetation, and applying necessary mowing (e.g., against weedy or invasive plants) or reseeding if its growth is hindered (e.g., extreme drought in 2020; see also Meissen et al. 2019).

**Monitoring protocol**

The successional development of the sown vegetation is being monitored with biannual botanical surveys. Species richness and coverage, vegetation cover and height, litter and bare soil cover are recorded in twelve \(1 \times 1\) m permanent quadrats per field and strip triplet (Figure 2) in early June and late September.

Pollinators and other flying insects are sampled with a wide array of methods in the sown parcels (transect sampling and malaise traps in late May and late July) and at the landscape scale (trapnests throughout the season, pan traps in July) (Fig. 2–5). Along two parallel transects, we record bees and wasps (Aculeata), hoverflies (Syrphidae) and diurnal butterflies (Macrolepidoptera), their activity and visited flower species. We catch observed wild bees and hoverflies with sweep nets for identification in the lab. Along the pollinator transects, the floral resources (i.e., insect-pollinated flowering species and their number of flower units) are recorded in \(1 \times 1\) m quadrats. We establish a malaise trap in the center of each field (Figure 2, right) and one of the strips twice a year for a week each (Figure 3, right).

![Figure 1](image-url). The study design consists of 24 circular landscape plots in Central Hungary (left). They are grouped into trios with a sown wildflower field, a triplet of sown wildflower strips and a control (right). Based on images from Google Earth (2021).
These non-attractant mesh tents target most flying insects and represent the majority of present insect guilds (Matthews and Matthews 1971). Trapnests are set up at increasing distance from the center of the landscape plot (every 80 m, up to 400 m) (Figure 2, left) to monitor the landscape-scale effect of the wildflower parcels during the whole vegetation season. At each distance, two trapnests are mounted on a pole and covered by a simple roof (Figure 4, left). Trapnests consist of a bunch of reed stems which provide nesting opportunities for cavity-nesting bees and wasps (Figure 4, right) (Staab et al. 2018). For the pan trap survey, 24 equally distributed sampling points are established per landscape plot in late July (576 in total, Figure 2, left). At each location, a painted yellow plastic pan filled with water and a drop of detergent is mounted on top of a pole and left standing for 48 hours (Figure 5). The bright color attracts flower-
visiting insects such as *Diptera, Hymenoptera* and *Coleoptera*, among others (Taylor and Palmer 1972; Templ et al. 2019). The floral resource abundances and richness, habitat type (including crop type) and vegetation attributes are recorded during the establishment of the pan traps as local environmental factors.

**Perspectives**

Two years after setting up the wildflower parcels, the vegetation is well established (Fig. 3 and 6) and buzzing with insects (Figure 7). In the coming years, our wildflower parcels are expected to further develop into biodiverse islands that serve as refuges

**Figure 5.** Pan trap mounted on a pole in a harvested oilseed rape field (left) and collected insects after 48 hours (right). Photographer: Andráš Báldi (left), Raoul Pellaton (right).

**Figure 6.** Close-ups of the wildflower parcel show the successional development from the first year (left) and the second year (right). In the first year, the vegetation was dominated by fast-growing agricultural weeds, which were largely outcompeted in the second year by the sown plant species. Photographer: Viktor Szigeti.

**Figure 7.** A large pollinator community visits the flowers of the wildflower parcels and will find suitable permanent habitat in the agricultural landscape, among them *Halictus eurygnathus* on *Centaurea cyanus* (left) and *Lycaena thersamon* on *Matricaria chamomilla* (right). Photographer: Raoul Pellaton (left), Viktor Szigeti (right).
in the agricultural landscape for an increasing number of species (Lowe, Groves, and Gratton 2021). The spatial arrangement and design of the experiment provides a firm basis to test hypotheses, for example, regarding the direct and interactive effects of spatial heterogeneity and effects of landscape context on biodiversity. The success of the restoration intervention will be measured along time with special attention to pollinator richness and abundance, pest control effectiveness and stable or increasing yield. The experiment further brings future opportunities for scrutinizing exciting questions from individual behavior (e.g., butterfly movement) to key ecosystem services (e.g., pollination, pest control, soil decomposition).

We intend to demonstrate an effective restoration practice to farmers with benefits beyond crop area reduction (e.g., pollination, pest control, wildlife management). Furthermore, we strive to provide evidence to policymakers that such comparably small parcels have a positive effect on the landscape scale, and they can be worth integrating into farm management or rural and urban development policies. Diversified agricultural ecosystems can support food production while harboring rich biodiversity (Emmerson et al. 2016), a win-win strategy that this experiment can demonstrate.

**Conclusion**

The long-term experiment we started will support sustainable farming as it demonstrates the viability of ecological intensification, where both yield and biodiversity can flourish. The continuous monitoring of the effects of a local wildflower seed mixture on the landscape scale will provide evidence on grassland restoration of international relevance. Beyond that, it may serve as a starting point for the establishment of other similar experiments in other farming systems across Europe and globally, contributing to the goals of the EU Green Deal and the UN Decade on Ecosystem Restoration.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**Funding**

This work was stimulated and partly funded by the European Union Horizon 2020 SUPER-G project (https://www.super-g.eu) under grant agreement No. 774124.

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Appendix 1. Sown plant species and their primary (dark green) and secondary (light green) flowering season

| Sown plant species          | March | April | May | June | July | August | September | October |
|-----------------------------|-------|-------|-----|------|------|--------|-----------|---------|
| Agrimonia eupatoria         |       |       |     |      |      |        |           |         |
| Anthericum ramosum          |       |       |     |      |      |        |           |         |
| Astragalus vulgaris polyphylla |     |      |     |      |      |        |           |         |
| Astragalus australis        |       |       |     |      |      |        |           |         |
| Astragalus onobrychis       |       |       |     |      |      |        |           |         |
| Centaurea cyanus            |       |       |     |      |      |        |           |         |
| Cephalanthera transylvanica |       |       |     |      |      |        |           |         |
| Dianthus pontederae         |       |       |     |      |      |        |           |         |
| Dorycnium herbaceum         |       |       |     |      |      |        |           |         |
| Echium vulgare              |       |       |     |      |      |        |           |         |
| Eryngium campestre          |       |       |     |      |      |        |           |         |
| Falcaria virens             |       |       |     |      |      |        |           |         |
| Filipendula vulgaris        |       |       |     |      |      |        |           |         |
| Fragaria vina              |       |       |     |      |      |        |           |         |
| Melandrium viscosum         |       |       |     |      |      |        |           |         |
| Onobrychis arenaria         |       |       |     |      |      |        |           |         |
| Pimpinella saxifraga        |       |       |     |      |      |        |           |         |
| Potentilla recta            |       |       |     |      |      |        |           |         |
| Prunella laciniata          |       |       |     |      |      |        |           |         |
| Rapistrum perenne           |       |       |     |      |      |        |           |         |
| Rumex thyssiflorus          |       |       |     |      |      |        |           |         |
| Salvia austriaca            |       |       |     |      |      |        |           |         |
| Salvia nemorosa             |       |       |     |      |      |        |           |         |
| Salvia pratensis            |       |       |     |      |      |        |           |         |
| Salvia verticillata         |       |       |     |      |      |        |           |         |
| Sanguisorba minor           |       |       |     |      |      |        |           |         |
| Scabiosa ochroleuca         |       |       |     |      |      |        |           |         |
| Seseli vavimum              |       |       |     |      |      |        |           |         |
| Stachys recta               |       |       |     |      |      |        |           |         |
| Thymus glabrescens          |       |       |     |      |      |        |           |         |
| Trifolium montanum          |       |       |     |      |      |        |           |         |
| Veronica orchidea           |       |       |     |      |      |        |           |         |