Trait-based effects of invasive plant species on native plant and pollinator communities and their usage by beekeepers at different spatial and temporal scales

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BACKGROUND

Pollinators, including wild species and the domesticated honeybees, face numerous threats and respond to them with steep decline worldwide. One of the main drivers of their status and trends is the availability of foraging and nesting resources that are often decreased by local- and landscape-scale agriculture intensification and urbanisation. The extension and diversity of foraging sites (i.e., bee pastures) have been changed a lot in the last decades, having significant effects on honey bees and consequently on beekeepers, but also on wild pollinator communities.

Non-native invasive plant species (NIS) can have profound effect on both the native plant and the related pollinator insect communities in both anthropogenically disturbed territories and semi-natural habitats. As a consequence of establishment and dominance of NIS, the impoverished vegetation often results in the decline of native pollinator diversity, and may have negative effect on flower-visitation of the native plant and crop species. There might be, however, trait-specific differences both in the effects of NIS and in the response of plants and pollinator insects.

In our project we conducted two parallel research approaches: 1) a fieldwork based study on the effects of non-native invasive plant species (NIS) on the plant and pollinator communities, and 2) a questionnaire and interview based study on the current status, past and future trends of bee pastures (including NIS) from the beekeepers' point of view.

CONDUCTED RESEARCH

1. Fieldwork based study on the effects of non-native invasive plant species

By studying invaded and similar, but non-invaded areas, we aimed to assess the effects of NIS on the richness, functional and taxonomic diversity and possible biotic homogenisation of plant and pollinator communities in the function of plant invasion and plant/pollinator traits. We performed an extensive field study involving 12 herbaceous NIS, using the same protocol in the different project years that enabled us to perform a wide-scale ecological impact assessment on both the native plant and the related pollinator insect communities. Our project was performed in collaboration with a Romanian partner form the Babes-Bolyai University, conducting field research in both countries that enabled us to widen the scope and the number of studied NIS and affected ecosystem types.

Before the starting of the current project, we studied the effects of invasion by Canadian goldenrod (*Solidago canadensis*; fieldwork in 2012) and giant goldenrod (*Solidago gigantea*; fieldwork in 2017) on plant and pollinator communities. The results about Canadian goldenrod were published in *Basic and Applied Ecology* that was the start of the later fruitful joint work with the Romanian partner. We found that the invasion reduced the native plant species richness throughout succession of Transylvanian old fields, and had a negative effect on the abundance of bees and reduced visitation of native flowers. Overall, our results suggested that the invasion of this perennial plant species diverted the trajectory of vegetation succession and altered the mutualistic links between the native elements of the studied old fields. Using a very similar, further developed sampling protocol, we performed a pilot study of the current FK project on

the effects of giant goldenrod in Hungary in 2017. In the first year of the FK project we identified the pollinator specimens, analysed the data and presented the results at conferences from this pilot year. Our results suggested that sites invaded by *S. gigantea* could host less pollinators due to the lack of native wildflower resources, while later in the season the flowering patches of *S. gigantea* were attractive for honeybees and hoverfly species. The invaded, impoverished vegetation could attract and maintain, however, only some native pollinator species at high abundance as a result of the low diversity of nectar and pollen resources.

Between 2018 and 2021 thanks to the support of the current project we were able to complete an intensive field work with a further 10 NIS: *Ambrosia artemisiifolia, Asclepias syriaca, Erigeron canadensis, Gaillardia aristata, Symphyotrichum lanceolatum* in Hungary and *Erigeron annuus, Helianthus tuberosus, Impatiens glandulifera, Reynoutria japonica, Rudbeckia laciniata* in Romania. By a standard field sampling protocol, we compared 7-12 invaded (high relative cover of NIS) with 7-12 uninvaded (<5% NIS, control) paired sites, depending on the possibilities meant by the distribution of the study species. Bees and hoverflies were sampled along two transects per study site, twice: before and during the peak flowering of NIS, in net 20 minutes. We recorded floral resources at ten 1×1 m quadrates/transect. Botanical survey of the study sites was conducted in three 3*3 m quadrats each site once in June, and several plant traits were measured in the laboratory based on collected leaves of all plant species of >1% coverage. Soil samples were taken from one of the botanical quadrats at the time of the botanical survey, and pH, nitrate, soil carbon, phosphor, etc. were measured in the lab. Various trait data of plants and pollinators were collected from databases, or measured from collected specimen in a few cases.

Results

Pollinators and flower resources

We analysed the whole dataset of 12 NIS (including the two *Solidago* species) according to two major story lines in the case of pollinators and floral resources. First we analysed the species richness, abundance, diversity and community composition of bees, hoverflies and flowering plants in the function of plant invasion before and during the flowering of NIS, through the pooled and species specific patterns of the 12 NIS. We tested the effects of NIS cover, flowering time and life span as well. The pooled analyses showed lower abundance and species richness of flowering plants and pollinators before, and higher abundance of both during the flowering of invasive plants in invaded sites. However, invasive plants had significant species specific effects. Perennial invasive plants had a stronger negative impact on floral resources and pollinators already before their flowering compared to annuals. Flowering time of invasive plants affected the pollinator guilds differently. We suggest that for a short time period, invasive plants might provide the dominant foraging resources for pollinators, but, they cause significant losses in native floral resources over the year. Therefore, instead of simple eradication, careful preparation and consideration might be needed during removal of invasive plants. The manuscript was published in *Basic and Applied Ecology* (Kovács-Hostyánszki *et al*. 2022).

Another major manuscript focused on the impact of invasion on functional diversity and on trait-based community composition of floral resources and pollinators. We analysed the floral trait dissimilarities between invasive and native plant species, the assembly of floral and pollinator communities via effect of trait-invasion interaction, the differences between invaded and control sites in trait distribution and functional diversity. We found that plant invasion caused species-specific changes in functional diversity and trait distributions of communities. For instance, plant invasion decreased the functional diversity of hoverflies before flowering of

invasive species. Smaller bees were associated with invasive plants with shallow flowers, while larger and long-tongued bees were associated with two invasive species with flowers having deep corolla. Pollinator traits showed mostly mixed or neutral responses to plant invasion that is probably due to the high integration capability of invasive plants into plant-pollinator systems, or limitations in sampling, trait resolution, and unrevealed environmental factors. It was published in *Insect Conservation and Diversity* (Szigeti *et al*. 2023).

In the earlier phase of the project, we made separate analyses on common milkweed, where beside the common protocol two additional samplings were conducted after its flowering in July and September. Our results suggested that common milkweed had basically a neutral effect and did not affect importantly the flowering plant and wild bee communities in sandy old fields. This neutral effect might be explained by the long-term, wide scale distribution of milkweed and/or its typically relatively low coverage compared to many other invasive plants, enabling the persistence of some native flowering species. However, its special flower structure offers nectar only for a few common pollinators, including honey and bumblebees. The results were published in *Biological Invasions* (Szigeti *et al*. 2020).

We prepared a manuscript on the effects of plant invasion and soil properties on ground-nesting bee species. We found that although invaded plots had altered vegetation composition and structure, as well as soil chemical characteristics compared to control plots, these had no effects on ground-nesting bees. This ms was submitted to *Ecological Entomology*, but rejected after review. We submitted it to *Journal of Insect Conservation* and wait for editorial feedback.

Vegetation

We published a paper about the invasion effects on the native flora and plant species of different traits and on soil attributes. We explored the type of cover–impact relationships across impact metrics and their consistency across species and studied whether the cover–impact relationship depends on functional traits of invasive species. We found that herbaceous invasive plant species had a cover-dependent impact on resident plant communities, but we found specific patterns across impact metrics and invasive species. The paper was published in *Journal of Ecology* (Fenesi *et al*. 2023).

A paper about the invasion potential, effects on vegetation and traits of a newly spreading plant species, *Galliardia aristata* was published in *Neobiota* (Süle *et al*. 2023). Common blanketflower is a newly appeared invasive species, distributing within the whole country by casual escape, but also by invasive behaviour at some locations. Our analyses on the traits associating with invasiveness revealed that the invasive potential of *G. aristata* is backed by a wide germination niche breadth, extremely long flowering period, small shoot-root ratio, large seeds and dispersal by epizoochory of grazing livestock, probably helping the species' survival and spreading in the disturbed, species-poor, sandy, open habitats. These functional traits, as well as the ornamental utilisation, may act together with the climate and land-use changes in the success of *G. aristata*.

2. A questionnaire and interview based study on the current status, past and future trends of bee pastures

In the third project year we prepared a very detailed questionnaire for Hungarian beekeepers from their preferred plant species as bee pasture, opinion from and usage of different bee pastures, difficulties in the present and foresights for the future of apiculture primarily focused on the bee pastures. We visited several beekeeper meetings and made the questionnaire available also online. Between January and May 2020 more than 400 beekeepers filled it in.

Based on the experiences from this questionnaire we conducted 35 interviews with beekeepers in 2020/21 to get deeper insight and more detailed information about bee pastures, the effects of land-use change, spread of NIS, climate change and more on honey bees and beekeeper industry in the past, present and future based on the knowledge of beekeepers.

In cooperation with colleagues from the Hungarian University of Agriculture and Life Sciences, we revealed the conflicts around 3 main invasive bee pasture species between sectors. We organised an online workshop with 20 stakeholders in February 2022 about their knowledge and perceptions regarding the invasion of milkweed and invasive goldenrod species.

Results

One manuscript summarising the main messages of the questionnaire study was submitted recently to *Ecology and Society*. Our results show that apiculture in Hungary was suffering from extensive challenges, such as conflicts with farmers and other beekeepers, agrochemicals, diseases, weather disturbances and lack of specific bee pastures. The three most favoured bee pastures were an invasive tree species (black locust), and two mass-flowering crops (sunflower and oilseed rape). Many other plant species and habitats were important periodically, regionally, and during migration. Beekeepers were quite pessimistic about the future of bee pastures, and articulated several suggestions for development: re-considering invasive plants' eradication, sowing flowering parcels, planting trees, and introducing new subsidies. Most of these practices, however, are depending on other land-users and stakeholders, highlighting the need for joint efforts.

Based on the questionnaire data another manuscript is in preparation about the spatio-temporal patterns of bee-pastures in Hungary. We started to summarise the experiences and knowledge from the beekeeper interviews that can be the source of several scientific publications. The first manuscript is in preparation about the effects of land-use change and agriculture on bee pastures and consequences on beekeeping. The results of the organised workshop with multiple stakeholders were presented at the Hungarian Congress of Conservation Biology, and are planned to be published in the coming year, while our cooperation with the university colleagues gained a co-authored paper in *Journal of Landscape Ecology* (Meinhardt *et al*. 2022).

Related to the bee pasture focus of the project, the evaluation and development potentials of greening measures (Cole *et al*. 2020), foraging and nesting potentials of set-aside fields (Kovács-Hostyánszki *et al*. 2021) and orchards (Bihaly *et al*. 2019) and the effects of land-use intensity on grasslands as bee pastures (Ekroos *et al*. 2020) was published.

3. Further studies

3.1. Integration of non-native plant species into plant-pollinator networks in a botanical garden

As an addition to the original project plans, we conducted a study about plant-pollinator networks in a botanical garden with the contribution of a visitor guest scientist, Mohamed Shebl in 2018. We were interested in the integration of non-native plant species in plant-pollinator networks in the view of floral traits, national occurrence and origin. We observed bees on 130 flowering plant species during four months. Honey bees preferred North American plants over Europeans and it had the highest number of connections. In contrast, the species richness and abundance of wild bees did not differ among the plants with different origins and traits. Plant species of different origin, nationwide distribution, and flower color and type had the highest

number of direct and indirect links. Therefore, we suggest that non-native plant species can integrate well in diverse botanical gardens and bees can adopt these new foraging resources. The results were published in *Urban Ecosystems* (Kovács-Hostyánszki *et al*. 2022).

3.2. Use or avoidance of invasive plant species by beekeepers in 22 European countries

In the framework of the Super-B COST project in 2016 the PI took part in a questionnaire study that completed a European-scale dataset about the use or avoidance of different plant species by beekeepers in 22 European countries. Based on this dataset we planned to investigate the position of invasive plant species in the diet of honey bees at European level. Background data were collected about invasion status of the plant species in each country that were mentioned by the beekeepers. We planned to complete the analyses and publish the results during the FK project, however, we could not succeed within this timeframe. Publication of this study is still planned after the PI's return from maternal leave.

3.3. The effects of plant invasion on soil decomposition

A side-study was designed to measure soil decomposition activity and decay of invasive plants' organic material influenced by giant goldenrod, milkweed and *Aster* spp. invasion We found that plant litter different from the invasive species' litter generally decomposed poorly on invaded sites. A manuscript was prepared from this study that is planned to submit to *Biological Invasions*.

3.4. Further related publications

With the contribution of the project by data collecting during our field works, there was a paper published in *Botanikai Közlemények* about the distribution of *Oenothera pycnocarpa* and other invasive plant species in Hungary (Molnár *et al*. 2020).

Anikó Kovács-Hostyánszki took part at a workshop (Reading, UK, November 2017) in the first year of the FK project that targeted a global-scale expert assessment on the drivers and risks of pollinator decline, including invasion. The workshop was followed by an online Delphi process and the results were published with her co-authorship in *Nature Ecology & Evolution* (Dicks *et al*. 2021).

We took part in further works with the help of the current FK project related to pollination services in crops (Garratt *et al.* 2021) and in the case of wild plants (Herbertsson *et al*. 2021), and the vulnerability of plant-pollinator communities to honeybee decline (Kovács-Hostyánszki *et al*. 2019).

5. Students

Two MSc students joined to the field project in 2017, supervised by the project leader, Anikó Kovács-Hostyánszki and Viktor Szigeti, and defended their thesis in 2019. Another MSc thesis was successfully defended from the side project about soil decomposition at invaded sites, supervised by Gergely Boros, a group member of the same research group. In 2020, a further BSc student defended a thesis on the invasion effects of ornamental plants escaping from botanical and private gardens.

6. Alteration from the project proposal workplan and changes in project participants

We followed the workplan of the project proposal during the first three project years without any major changes. All the field works were successfully conducted, and we were ready with the beekeeper questionnaires. Submission of the manuscript about the European beekeeper questionnaire dataset has not been finished yet due to the maternal leave of the PI in the last half year. We planned to present our results at several Hungarian and international conferences in autumn 2020 and in 2021, however, these conferences were cancelled/postponed due to covid-19 pandemic.

Thanks to the remaining financial resources, owned to the amount of work that was still to be finished and the covid-19 pandemic, we prolonged the project with a further two years until 31 August 2023. Since we could not spend all the planned money for conferences (due to covid-19) and consumables, we could use the remainings for personal costs to prolong the hired researchers for an additional one year (the last year these colleagues were financed from other projects, but they could still continue the work in this project as well). This additional time period helped us to present our results at several conferences and publish them in international journals. In parallel we won a consortia project (National Laboratory for Health Security) focusing on invasion ecology that enables us to continue our work and publish further papers from the collected datasets of this finished FK project.

7. Coming publications

Manuscripts submitted:

Kovács-Hostyánszki, A., Tőkés, T. A., Arany, I., Molnár, Z., Szigeti, V. Challenging times for beekeepers in the heart of Europe with special focus on bee pastures. *Ecology and Society*

Pellaton, R., Szigeti, V., Fenesi, A., Roberts, S., Török, E., Kovács-Hostyánszki, A. Plant invasion affects ground-nesting bees through their foraging resources, but not through altered vegetation structure or soil chemical characteristics. *Journal of Insect Conservation*

Manuscripts in preparation:

Boros, G., Becker, B., Szigeti, V., Báldi, A., Kovács-Hostyánszki, A. The relationship between invasive plant litter and decomposition rate.

Szigeti, V, Tőkés, T., Arany, I., Kovács-Hostyánszki, A. Spatio-temporal patterns of bee-pastures in an Eastern-Europe country - based on beekeeper's knowledge.

Arany, I., Szigeti, V., Kovács-Hostyánszki, A. The effects of land-use change and agriculture on bee pastures and consequences on beekeeping.