Theses of the PhD dissertation

EFFECT OF AGRICULTURAL LANDSCAPE STRUCTURE AND THE GREENING FOR COMPOSITION OF ORTHOPTERA AND BOMBUS ASSEMBLAGES

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1. AIMS AND BACKGROUND OF THE DISSERTATION

The intensification of agriculture started in the 20th century is primarily led to biodiversity and habitat loss, fragmentation, transformation, spread of pesticides, and mechanization (*CBD*, 2014; *Batáry*, 2018). In Europe, lowland areas have been grazed and cultivated for millennia, thus majority of those are artificial landscapes, where the most important landscape-forming factor is the agriculture. Consequently, maintenance of biodiversity in agricultural areas is one of the most important aspects of nature conservation in Europe, including Hungary (*Batáry et al.*, 2015). Furthermore, as crop yields largely depend on ecosystem services mediated by biodiversity, preservation of biodiversity in agricultural landscapes is crucial from economical perspective, as well. Contrarily, agricultural intensification strongly reduced the landscape diversity, replaced the flora and fauna of cultivated areas with more common species, and degraded the quality of soil, water and air (*Firbank et al.*, 2008).

These negative effects must be compensated with the intensification of ecosystem services and landscape protection (*IPBES*, 2016). Agri-environmental schemes (AES) have been introduced to Europe for this purpose in the early '90s, providing financial incentives for agricultural producers. Main objectives of those are to reduce nutrient and pesticide emissions, protect biodiversity, restore landscape structure, and prevent rural depopulation. However, despite the high investments, the efficiency of these agri-environmental schemes are not assessable due to the lack of the appropriate studies (*Kleijn & Sutherland*, 2003; *Herzog*, 2005).

For investigations species groups should be selected which can indicate the effects of changes in landscape use on biodiversity (*Jeanneret et al.*, 2003). Interventions can cause different effects by taxa, so investigation of more species groups parallelly is recommended (*Stoeckli et al.*, 2017). Therefore, two groups having significantly different ecological characteristics were selected for the basis of this study.

1.1. Background of Orthoptera research

Orthopterans are widely used in studies of both habitat-naturalness and management (*Báldi & Kisbenedek*, 1997; *Whiles* & *Charlton*; 2006) due to their good habitat indicator abilities. As the majority of Orthoptera communities are herbivores and play an essential role in the diet of vertebrates, they correlate well with the composition of plant assemblages (*Torma et al.*, 2014; *Kenyeres et al.*, 2020).

Orthoptera fauna of grasslands, natural and semi-natural habitats, and protected project and monitoring areas are well-known in Hungary. (*Nagy & Rácz*, 2007). However, data on the Orthoptera fauna of arable- and wastelands and anthropogenic landscape elements closely related to agriculture (e.g., dirt roads, road verges) are poorly studied (*Nagy*, 1943; *Zilahi-Sebess*, 1956; *Garai*, 1995; *Báldi & Kisbenedek*, 1997; *Kenyeres et al.*, 2004; *Kenyeres*, 2006a; *Kenyeres*, 2010; *Kenyeres & Rácz*, 2011) with a few exceptions *(Nagy*, 1953; *Koppányi*, 1957; *Nagy*, 1992; *Nagy*, 1993; *Nagy et al.*, 2009).

Research of Barnabás Nagy has already predicted 70 years ago, that the mandatory stubble cultivation and the introduction of large-scale cultivation will significantly limit the occurrence of orthopterans in agricultural areas (*Nagy*, 1953), and soil tillage will have a negative effect on the reproduction of orthopterans (*Koppányi*, 1957). Changing cultivation methods in a given area can have different impacts by different species (*Nagy*, 1992), and it can lead to the local extinction of the sensitive species (*Kenyeres*, 2006b).

Based on preliminary data collection and literature research, it was revealed that both the studied agricultural areas and landscapes are underinvestigated. Therefore, a 3-year study was started in 2018, during which data were collected on the Orthoptera fauna of various agricultural areas and landscape elements located in the firth region of the Sajó River. The samplings were the basis of the habitat structure- and other comparative analysis of agricultural areas. Since more than 70% of the Hungarian lowland areas are arable lands (*Berényi*, 2011), the expected effects of various landscape elements can be effectively illustrated in a well-designed, representative, smaller area of an agricultural landscape. Beside the conservation aspects, a potential orthopteran pest species, the Italian locust, also needs to be highlighted. The Italian locust (*Calliptamus italicus* Linnaeus, 1758) is a polyphagous species with good colonization skills. Its major cultivated host plants include legumes, carrots, potatoes, tobacco, sunflower, grapes, and raspberries. It requires the presence of exposed rock or soil surfaces and prefers drier habitats with open vegetation and less disturbed cultures (*Nagy*, 1998; *Gavlas et al.*, 2007). In 2018 and 2019, the species occurred in high abundance in several agricultural habitats (*Arnóczkyné Jakab et al.*, 2020).

Climate change in Hungary was resulted in increased air temperatures, a decrease in the number of frosty days, more “heat days” and a higher frequency of extremities along with longer arid periods (*Lakatos et al.*, 2018). All these trends favour the success of the Italian locust and other geobiont grasshopper species (*Zhang et al.*, 2019). Thus, it is necessary to monitor changes in the populations of grasshopper species known as prone to gradation, with a focus on their favoured breeding and feeding habitats (*Nagy*, 1993; *Baybussenov et al.*, 2014).

1.2. Background of bumblebee research

Pollinators are good indicators of the effectiveness of agri-environment schemes (AES) (*Osborne et al.*, 1999; *Sepp et al.*, 2004). In Europe, 84% of cultivated plant species are insect-pollinated, and 76% of the produced food depends on the success of insect pollination (*Potts et al.*, 2015). Environmental problems and excessive use of pesticides threaten the populations of pollinator insects (*Brittain et al.*, 2010). The distribution of several bumblebee species has declined in Europe (*Rasmont*, 1988), which has serious consequences for the success of pollination (*Kerr et al.*, 2015). Bumblebees have adapted well to various nectar sources; different species characterized by different body sizes and tongue lengths, enabling them to be efficient – in some cases exclusive – pollinators of numerous plant species (*Osborne & Williams*, 1996; *Raine & Chittka*, 2007). While the need for pollination is increasing, the decline in the number of pollinators has still not been stopped (*Breeze et al.*, 2011; *European Parliament*, 2019). Due to the decrease and shift occurring in its distribution area, the bumblebee fauna is undergoing continuous transformations (*Soroye et al.*, 2020; *Novotny et al.*, 2021), which may reduce the resilience of pollination networks against environmental changes (*Burkle et al.*, 2013).

Knowing the distribution of given species contributes to the better understanding of their ecological requirements, adaptive abilities and long-term effects of environmental changes (e.g., climate change) on them. Thus, it is vital for the development of appropriate strategies for their protection (*Sárospataki et al.*, 2003, 2004; *Sárospataki*, 2010). Therefore, it is crucial to collect and evaluate the already existing distribution data and supplement those with new investigations.

1.3. Objectives

During the study, the orthopteran and bumblebee fauna of typical lowland agricultural landscapes were investigated. In the case of orthopterans, the less studied fauna of the firth region of the Sajó River was examined. My goal was to complete the missing faunistic data and to investigate the role of agricultural habitats and different cultures – including alfalfa and red clover crops – in the conservation of orthopteran assemblages characteristic to that landscape, and how cultivation affects to the composition of these assemblages.

In the case of bumblebees, the aims were primarily to survey the bumblebee assemblages of cultures requiring insect pollination and the investigation of the effects of the studied cultures on *Bombus* assemblages. Beyond filling the data gap related to agricultural areas, an objective was also to gather and evaluate country-wide occurrence data (re-evaluation of frequencies, identification of trends, review of their distribution areas) in order to the accurately assess those and draw actualized distribution maps for certain species.

2. MATERIALS AND METHODS

2.1. Study of orthopterans

The quantitative faunistic samplings were conducted at 40 sampling sites. The samplings were carried out twice annually (in summer and early autumn), between 2018 and 2020, in the firth region of the Sajó River. Characteristic agricultural landscape elements (habitat types) were studied, such as hayfields, pastures, red clover, alfalfa, wheat, sunflower, and cornfields, as well as stubble-fields, ruderals, roadsides, channel banks, and dirt roads. Samplings were carried out with sweep netting method which was supplemented with direct search. Species-level identification was made in the case of adults. Studied areas are covered by the EU00 and EU01 (10×10 km) UTM cells. For the detailed description of the area's Orthoptera fauna, previously published data of the 10×10 km UTM cells of the sampling sites and their surroundings were processed based on the database of *Nagy and Rácz* (2007). These cells are marked with the codes DU90, DU91, EU00, EU01, EU10 and EU11. The checklist is presented by species (name of the species, code, year of the sampling, habitat).

A database was built from the newly collected and previously published distribution data. The number of individuals belonging to species caught between 2018 and 2020 were arranged into the database, indicating the date and location of the sampling, the type of the vegetation, and the literary data. In the case of the latter, the presence-absence data of the species were listed into the database. To characterizing the fauna, the presence-absence data of species were evaluated according to both the total fauna and the assemblages of the studied habitat types. Based on the newer literary data, I reviewed and revised the registered species and provided the actualised checklist of the area. Additionally, I identified the protected and rare species in the Hungarian fauna and their distributions.

The distribution and abundance of the Italian locust was evaluated based on the data of 36 sampling sites studied in 2018 and 2019. In the analysis, the cumulative relative frequencies (RF%) of species, their relative frequencies by area and their mean relative frequencies by habitat types were used.

The detailed investigation of the assemblages of agricultural landscape elements was conducted by analysing the quantitative samples collected in 36 sites between 2018 and 2020. Each of the sampling sites have been characterized by its current usage for at least eight decades, and the majority of the arable lands have been cultivated for at least 250 years (Military Surveys 1782-1785, 1819-1869, 1941). In the analysis, Orthoptera fauna of the studied habitats was characterized by species-richness, relative frequency of species, life form, and faunal types. Principal Coordinate (PCoA) and cluster analysis were used as ordination methods. To evaluate the composition of the fauna, calculations were made based on relative frequencies. Sampling sites were categorized a priori into three main land use types (semi-natural, arable, linear ruderal habitats), representing varying land-use intensity, vegetation structure, degradation, and disturbance. The correspondence between these *a priori* categories and groups formed based on multivariate analysis was also tested. Considering the crop rotation and changes in habitat use, intensity of land-use of a given site was classified by the mean intensity of habitat use in the three consecutive years. For assessing the conservation value of habitat types, the Grasshopper Conservation Index (GCI') elaborated by *Matenaar et al.* (2015) was used in a modified version made by *Szanyi et al.* (2021) (GCIn'). The correlation between land-use intensity and parameters of different assemblages (number of caught individuals, number of caught species and GCI') was analysed by correlation analysis. Quantitative character species of assemblages ("indicator" species) were identified using the IndVal method (*Dufrêne and Legendre*, 1997), which classifies species hierarchically according to their fidelity to the sites. For the analyses, SynTax 2000 (*Podani*, 1997) and IndVal software packages were used.

2.2. Study of bumblebees

Samplings were carried out at 44 sampling sites during the summer of 2018, from mid-June to early August. The studied habitats were sunflower, oilseed radish, vegetable marrow, alfalfa and red clover fields, alfalfa hedgings (6 m wide margin cropped with pulses and grasses according to requirement of AES (Agócs et al., 2015)) and semi-natural grasslands (hayfields with *Vicia cracca, Lotus corniculatus, Trifolium repens, T. pratense* and *Plantago lanceolate* and dike slopes with *Medicago sativa, L. corniculatus, T. pratense*). Bumblebees were sampled with visual detection along a linear transect during 10 minutes per sample. The number of bumblebees by species were detected. The *Bombus terrestris* and *B. lucorum* (*National Biodiversity Data Centre*, 2012), as well as *B. hortorum* and *B. ruderatus* (*Williams & Hernandez*, 2000) species are morphologically indistinguishable, so these species are handled as species pairs in this study. During the statistical analysis, the total and mean species number of different habitat types, the mean number of individuals, the maximum number of species and individuals, and the Whittaker index (S/Savg) were used. As our sampling sites are covered by the ET44, EU00, and EU01 10x10 km UTM cells, we collected distribution data in those. The work of *Sárospataki et al.* (2003) was used for the evaluation of these data.

Combining the former and the newly collected data, distribution maps of Hungarian bumblebee species (in 10x10 km UTM system) were actualised. The new maps were edited based on the database published in 2003 by *Sárospataki et al.* (2003) and were supplemented with both published and unpublished data.

The relative frequencies of the species (RF%) were calculated based on the formula of Sárospataki et al. (2003), providing information about the spatial constancy of a given species. The results were compared to the findings of *Sárospataki et al.* (2003), then the changes in the relative frequencies of different species were calculated, and the frequency categories (I: rare, II: moderately frequent, III: frequent, IV: common) were also recalculated based on the new data.

Since we have numerous data without detailed locations and the sampling intensities differed among among samplings, another relative frequency indicator (RF’) was also used. In this case, the number of occupied UTM cells by species from a given periods was divided by the total number of bumblebee data from a given period. The country-wide trends were actualised, and the conservation status of each species were established by relative frequencies.

3. RESULTS

3.1. Orthoptera fauna of agricultural areas

A total of 2241 Orthoptera individuals (1762 adults and 479 nymphs) of 30 species were collected at the sampling sites between 2018 and 2020. Thus, the investigation increased the known data on orthopterans of the area to almost ninefold.

According to the database of *Nagy and Rácz* (2007), only 12 sources were found that provided data on the studied area and its surroundings. After data summarization, this meant 70 data records (data of a species in a given area, in a given year, published by a given author). The own samplings enriched the Orthoptera knowledge of the area with another 540 data records. Thus, currently, 610 data records are known from the area.

Published sources mention 29 species from the area, which is almost equivalent to the number of species identified during the study (S=30). However, there are only 14 common species in the two lists. This difference is not surprising because, based on the literature, collectors rarely investigated agricultural areas. The most relevant literature concerns fallow lands and mentions only one species, the *Calliptamus italicus* (*Garai*, 1995).

During the samplings, three protected species were found: *Gampsocleis glabra*, *Acrida ungarica* and *Celes variabilis*. Furthermore, five rare species of the Hungarian fauna were also recorded in the area: *Platycleis montana*, *Melanogryllus desertus*, *Chorthippus dichrous*, *Myrmeleotettix maculatus* and *Dociostaurus maroccanus*,. The majority of the species belonged to the pratinicol life form (90.67%), while the ratio of geophilic species was significantly lower (7.40%). The five most abundant species were *Calliptamus italicus* (14.7%), *Pseudochorthippus parallelus* (13.1%), *Chorthippus dorsatus* (12.7%), *Glyptobothrus brunneus* (11.6%) and *Omocestus rufipes* (9.9%).

The most common species in the sampling areas was the *Calliptamus italicus* (14.7%). Its relative frequency has shown an increasing trend in the recent years (*Arnóczkyné et al.*, 2020). The presence of the Italian locust was detected in all examined habitat types, except cornfields and pastures. The highest mean relative frequency of the species was observed in the alfalfa samples (51.61%) followed by its relative frequencies measured on stubble-fields, in clover fields, and on dirt roads and roadsides. Therefore, the Italian locust should be considered as a significant potential pest again. On endangered areas (fallow lands, areas without soil cultivation or irrigation, and places that offer optimal breeding sites for the species), its populations should be monitored and the preventive measures such as soil cultivation and irrigation should be utilized. Additionally, in necessary cases, chemical pest control should be used.

Based on the quantitative multivariate analysis of the Orthoptera assemblages, four groups of sampling sites were identified. All studied natural habitats (hayfields and pastures) were classified into Group 1, and those were well-distinguished from arable lands and other agricultural landscape elements. Group 4 consisted exclusively of intensively cultivated arable lands with low species-richness, while Group 2 and 3 represented areas with transitional characteristics (Figure 1). Dirt roads, roadsides, and less intensively cultivated cultures were placed in these groups. The hierarchy of the groups is shown by cluster analysis (Figure 2). Thus, the examined agricultural habitats have their characteristic assemblages that have developed over decades of habitat use and differ from the assemblages living in the semi-natural habitats of the same region.

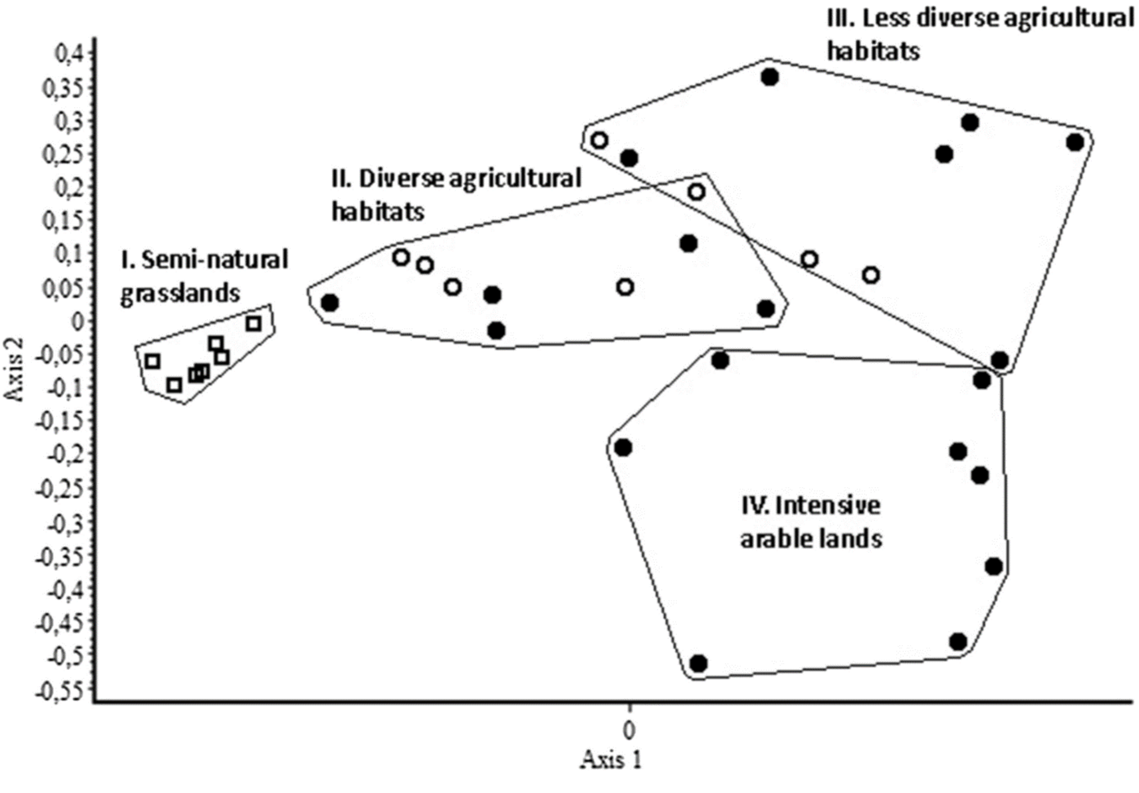

Figure 1 Ordination of Orthoptera assemblages of the 35 sampled sites (Bray–Curtis distance, inf. content: 1st axis = 29.80%, 2nd axis = 14.87%). A priory habitat types: empty square = semi-natural sites; empty dots = linear ruderal habitats; black dots = arable lands

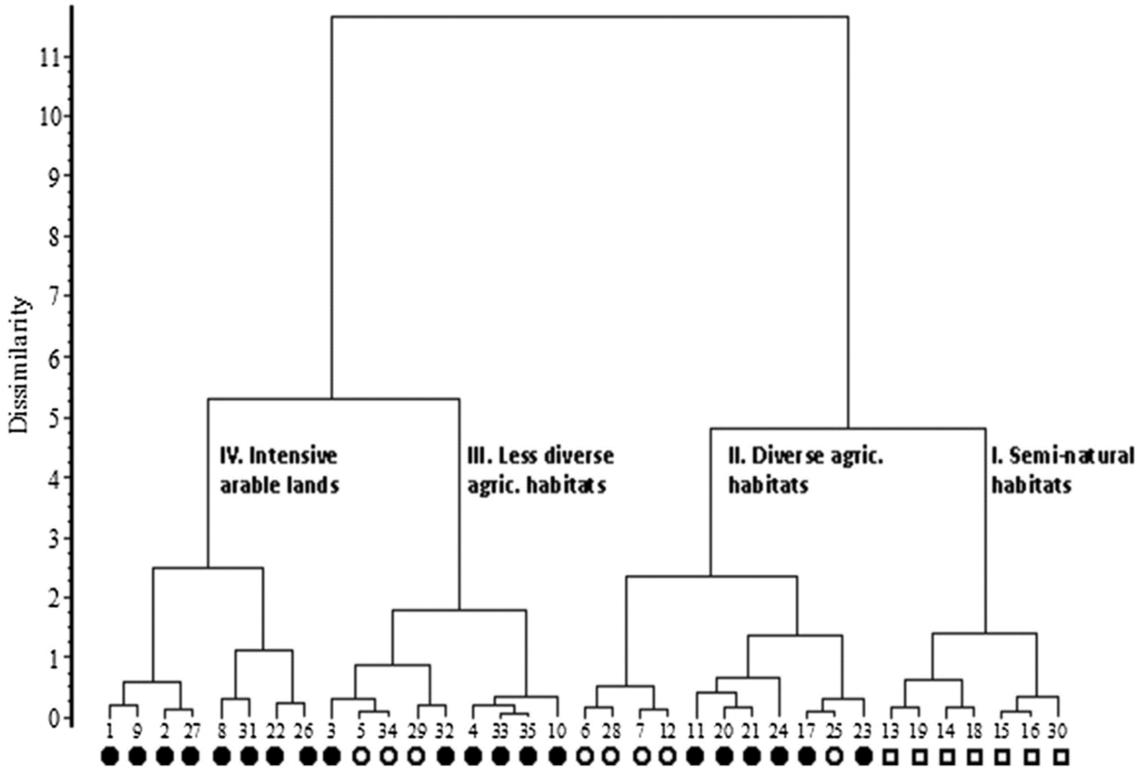

Figure 2 Cluster analysis of Orthoptera assemblages of the 35 sampled sites (Bray–Curtis distance, MISSQ). A priory habitat types: empty square = semi-natural sites; empty dots = linear ruderal habitats; black dots = arable lands

The species-richness of the assemblages decreased from the group of semi-natural sites towards the intensive arable lands along the gradient shown by Axis 1. The mean species-richness and abundance of the Orthoptera assemblages showed the same tendency, and the semi-natural habitats had the highest species-richness. The species-richness of semi-natural and diverse agricultural habitats was significantly higher than the species-richness of intensive arable lands, while the less diverse agricultural habitats had medium values. The diversity of the studied semi-natural habitats’ assemblages and the majority of their natural composition were preserved by the species-rich linear ruderal habitats (e.g., roadsides) and the less intensively cultivated alfalfa and clover fields. The intensive land use of sunflower and cornfields has led to Orthoptera assemblages characterised by lower diversity and conservation value.

Based on the Grasshopper Conservation Index (GCI'), the conservation value of the Orthoptera assemblages living in semi-natural sites was the highest, and this value decreased along the gradient shown by the PCoA 1 axis. The conservation value of intensive arable lands was significantly lower than the values of semi-natural grasslands and diverse agricultural lands, while the less diverse agricultural lands showed an intermediate value. The GCI'n showed the same tendency, but in this case, only the semi-natural sites had a significantly higher conservation value than the intensive arable lands, while the other two types showed intermediate values.

In the studied areas, the mean value of land use intensity showed a significantly negative correlation with the number of caught individuals ($r=-0.7429$, $p<0.0001$), with the species-richness ($r= -0.767$, $p<0.0001$), and with the value of Grasshopper Conservation Index (GCI') ($r=-0.7702$, $p<0.0001$) of the studied sites.

According to the results of the IndVal analysis, the most common species of the studied assemblages were *Glyptobothrus brunneus, G. biguttulus*, and *Omocestus haemorrhoidalis*. Semi-natural and diverse agricultural habitats had ten common characteristic species (*Pseudochorthippus parallelus, Chorthippus dorsatus, Omocestus rufipes, Roeseliana roeselii, Euchorthippus declivus, Conocephalus fuscus, Chorthippus dichrous, Mecostethus parapleurus, Ruspolia nitidula*, and *Bicolorana bicolor*), while the semi-natural habitats were characterized only by the fidelity and specificity of the *Chorthippus oschei, Gampsocleis glabra, Aiolopus thalassinus*, and *Dociostaurus brevicollis* species. Diverse agricultural sites had no own character species. The less diverse agricultural habitats and the intensive arable lands had only one mutual character species (*Gryllus campestris*). The less diverse agricultural sites were characterized by *Calliptamus italicus*, whereas the intensive arable lands had no own character species.

The ratio and spatial pattern of various landscape elements (including cultivated crops) have high influence on the diversity, composition, and naturalness of the Orthoptera assemblages. As they are sensitive indicators, this effect can be presumed for many other insect communities living in grasslands. This shows that the role of agricultural landscape elements is more significant than previously assumed. Increasing the ratio of less intensive (3-4 year) cultures and maintaining linear ruderal habitats can increase the abundancy and diversity of orthopterans, as these cultures can serve as transitional habitats, corridors, or stepping stones between the remaining natural and semi-natural habitats. Thus, a sufficiently diverse agricultural landscape can maintain diverse Orthoptera assemblages but is unable to preserve stenotopic characteristic species of natural habitats. Nevertheless, the results prove that this strategy can be effective even in traditionally intensively used areas, such as the Hungarian Lowland, where most of the species-richness and conservation value could be maintained over the last decades.

3.2. Composition of the Hungarian bumblebee fauna and its long-term changes

The national territory of Hungary is covered by 1052 10×10 km UTM cells, from which, 531 cells contain 3716 bumblebee data records (species/UTM cell/period).

During the last 20-year period of the studies, 835 data records of 21 species were collected from 259 UTM cells, while there were no new data collected in the case of eight species.

We also have data in one-one UTM cells from the area Ukraine and Romania, which contributed to the redraw of the area of many species. There were no bumblebee data from the area of the Velyka Dobron’ Game Reserve (West Ukraine) until the samplings of 2013, thus all the eight detected species there (*B. haematurus, B. hortorum, B. humilis, B. lapidarius*, *B. muscorum, B. pascuorum*, *B. sylvarum, B. terrestris*) were new distribution data to that area. Additionally, in Romania, the data of *B. argillaceus* and *B. haematurus* were new to the studied area.

The Hungarian database includes records of 32 bumblebee species (26 *Bombus sp.*) and 6 cuckoo bumblebee species (formerly *Psithyrus sp.*). Among those, *B. fragrans* is strictly protected, while *B. argillaceus, B. confusus, B. humilis, B. laesus, B. muscorum, B. paradoxus, B. pomorum, B. ruderatus, B. sylvarum, B. soroeensis*, and B. *subterraneus* are protected in Hungary (13/2001. (V.9.) KöM decree).

The only Hungarian record of *B. consobrinus* was collected after 1970 from the Gál-rét, in the Börzsöny Mountains (UTM cell: CU51), but the exact date is unknown. Recently, data were not collected from the species in Hungary. *B. cryptarum*, belonging to the *Bombus lucorum* complex, also has only one record, thus its presence in Hungary is dubious. *B. sylvestris* species has only five records from the third data collecting period (1971-2000), and it has no newer data, thus, its relative frequency decreased below 1% in the fauna.

The area of the rare *B. fragrans* species had continuously decreased based on the records, and it was not sampled after 2000. *B. bohemicus* was previously found in the Bakony and the Bükk Mountains, but it has not been detected in the last two decades. *B. subterraneus* only has records before 2001; it was a widely distributed member of the fauna, but only with low abundance. *B. confusus, B. laesus* and *B. paradoxus* neither have records after 2000.

The relative frequencies of *B. humilis, B. muscorum*, and *B. pomorum* have continuously decreased, while this trend only appeared between 1954 and 1970 in the case of *B. rupestris*, and between 2001 and 2021 in the case of *B. barbutellus* (Table 1). These changes did not alter the frequency categories of the species.

Contrarily, the relative frequencies of 15 species have increased since the last survey (*Sárospataky et al.*, 2003): *B. argillaceus, B. campestris, B. haematurus, B. hortorum, B. hypnorum, B. lapidarius, B. lucorum, B. pascuorum, B. pratorum, B. ruderarius, B. ruderatus, B. soroeensis, B. sylvarum, B. terrestris,* and *B. vestalis*. In the case of four species, the increased relative frequency led to changes in the frequency category as well. The category of *B. argillaceus* and *B. haematurus* is changed from I to II, and the changes in their relative frequencies were significant and rapid during the last 20 years. The frequency categories of *B. hortorum* and *B. sylvarum* changed from III to IV, but their relative frequencies increased in smaller extent than in the case of the previous two species.

Considering the long-term trends of the changes in the relative frequencies, from the 15 mentioned species, seven had relatively stable values (*B. hortorum, B. lapidarius, B. pratorum, B. ruderarius, B. sylvarum, B. terrestris, B. vestalis*), while the relative frequency of *B. ruderatus* showed a slightly decreasing trend (Table 1).

The new data redraw the area of several *Bombus* species. Both the northern (Tiszatelek; EU64 cell) and the eastern (Túristvándi; FU22 cell) occurrences of the East-Mediterranean *B. argillaceus* species (the first protected *Bombus* species in Hungary) were recorded after 2000, and new Western Ukrainian records of the species were also documented from Mukachevo (*Konovalova*, 2008). Based on the data, the species has become widely distributed in the country in the last two decades. Its relative frequency decreased between the 1950s and 2000s but has been showing an increasing trend since 2000 (Figure 3).

The intense spread of *B. haematorus* could be also detected. The first records were collected in the 1980s, but until 2003, it was only known from the central and southern parts of Transdanubia (West Hungary). After that, it appeared east from the Danube, and even the Tisza. Data collected by Orsolya Szakács in 2019 from Romania (Szalacs / Sălacea) can be considered as the northernmost occurrence of the species in the country (*Ban-Calefariu & Sárospataki*, 2007; *Rasmont & Iserbyt*, 2013). The first Western Ukrainian record of it (Nagydobrony/Velyka Dobron') was collected by Szabolcs Szanyi in 2015. Previously, it was only known from the Crimean Peninsula, which is located in the southeastern part of the country (*Biella et al.*, 2020) (Figure 4).

There were no Hungarian records from the *B. hypnorum* species since the 1990s. Until then, it was known from the hilly areas of Transdanubia and Northern Hungary. Since 2015, it has reappeared in Transdanubia, and since 2018, it could be also found in the lowlands of Eastern Hungary (Figure 5).

Table 1 Bumblebees present in Hungary (29 species) with their modified relative frequency (RF'%) calculated for consecutive periods of samplings based on the revised database and the trend of frequency changes till 2005 (based on *Sárospataki et al.*, 2005) and between 2005 and 2021. d = decreasing frequency, i = increasing frequency, u = unchanged

	Modified relative frequency (RF'%)				**Trend**	
Species	**-1953**	**1954-1970**	**1971-2000**	**2001-2021**	**-2005**	**2005-2021**
B. argillaceus	2,38	0,73	0,90	6,64	d	i
B. confusus	2,97	2,67	2,37	0,00	d	d
B. consobrinus	0,00	0,00	0,06	0,00	-	-
B. cryptarum	-	-	-	0,12	-	-
B. fragrans	2,97	0,12	0,06	0,00	d	d
B. haematurus	0,00	0,00	1,03	5,34	i	i
B. hortorum	4,75	8,13	8,34	8,19	u	u
B. humilis	9,31	9,59	6,35	3,68	d	d
B. hypnorum	0,20	0,12	1,67	2,85	i	i
B. laesus	5,94	0,24	0,45	0,00	d	d
B. lapidarius	10,10	9,10	13,09	11,39	u	u
B. lucorum	1,98	4,37	1,35	3,32	u	i
B. muscorum	6,34	3,64	2,82	1,78	d	d
B. paradoxus	1,78	0,12	0,58	0,00	d	d
B. pascuorum	9,90	11,29	9,37	11,86	u	i
B. pomorum	4,55	1,46	1,54	0,83	d	d
B. pratorum	2,18	1,94	3,08	2,02	u	u
B. ruderarius	4,75	6,92	8,28	6,64	u	u
B. ruderatus	5,94	3,76	1,86	2,14	d	d
B. soroeensis	0,20	0,00	0,32	0,36	i	i
B. subterraneus	1,98	0,97	1,67	0,00	u	d
B. sylvarum	8,51	10,19	6,74	7,59	d	u
B. terrestris	9,90	13,11	15,92	15,30	u	u
B. barbutellus	0,79	0,85	2,95	0,24		d
B. bohemicus	0,00	1,09	1,09	0,00		-
B. campestris	0,00	1,09	1,22	1,42		i
B. rupestris	0,40	5,70	3,40	0,12		d
B. sylvestris	0,00	0,00	0,32	0,00		-
B. vestalis	0,20	2,79	3,15	1,42		u

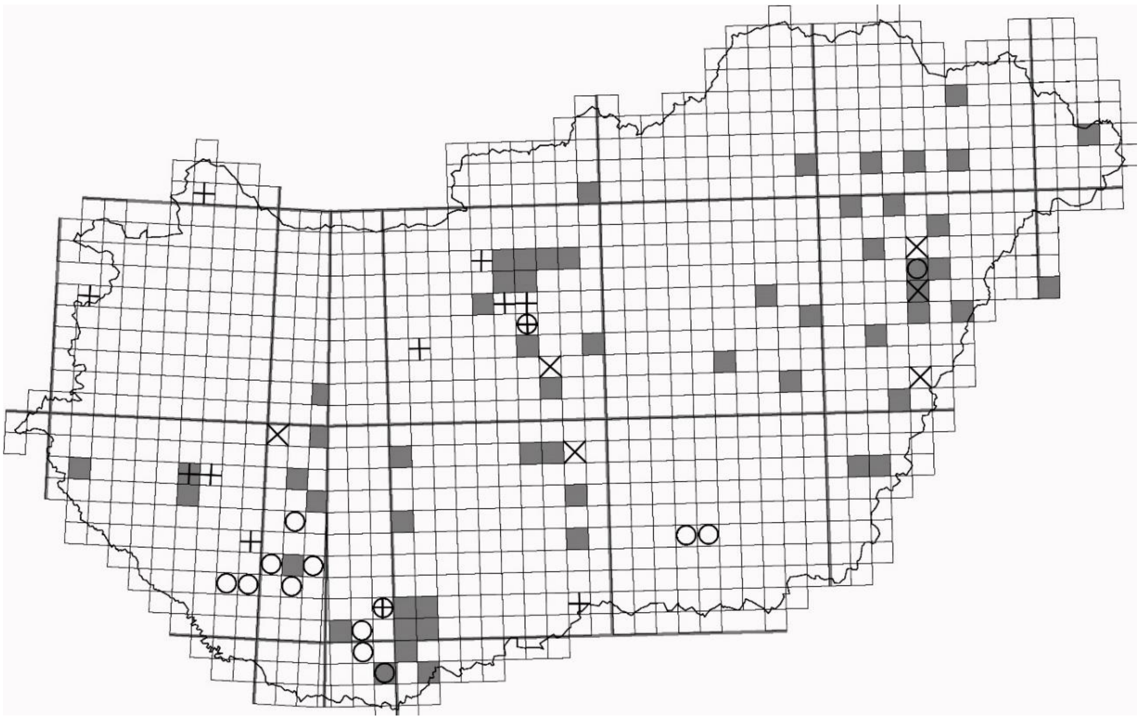

Figure 3 *Bombus argillaceus distribution map*

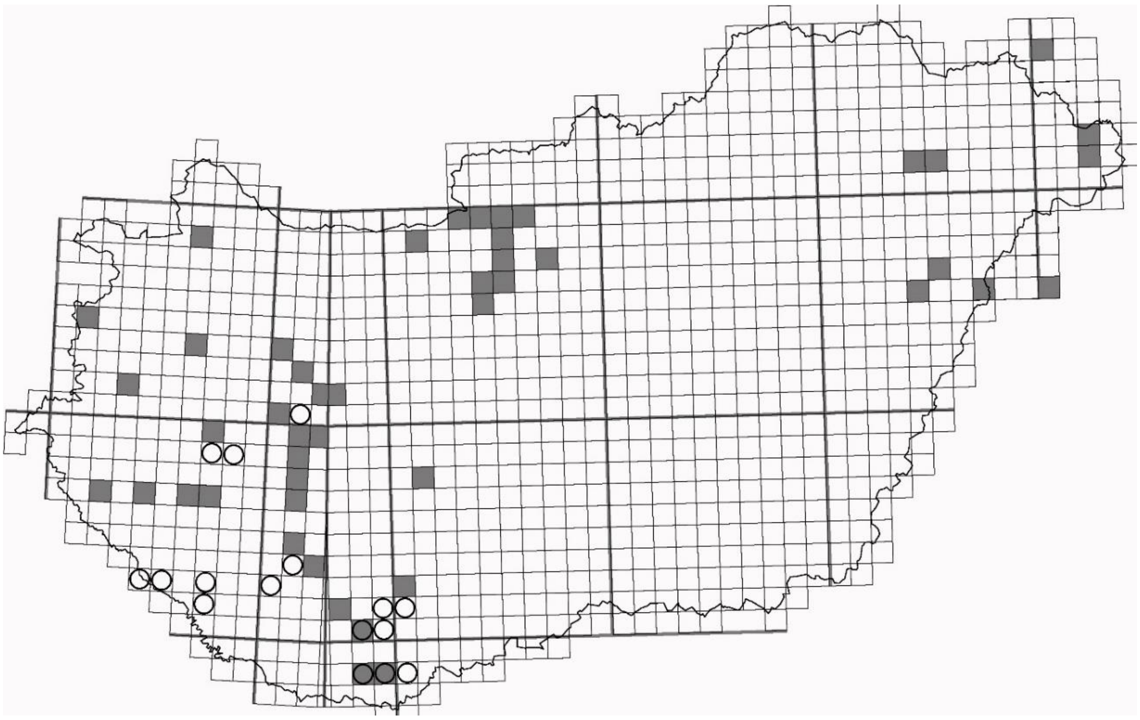

Figure 4 *Bombus haematurus distribution map*

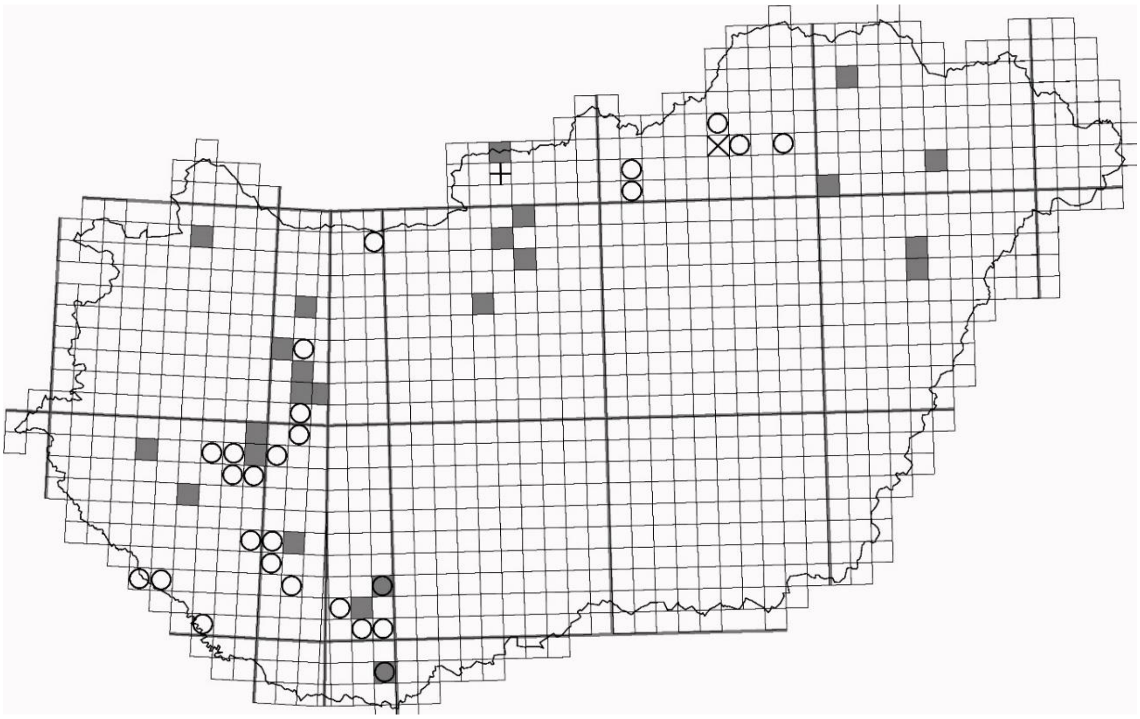

Figure 5 *Bombus hypnorum distribution map*

Based on the results, the trend in the relative frequency of *Bombus* species in Hungary are the following: from the 32 species described from the area of Hungary, three species are extinct, and four are data-deficient. The relative frequencies of 11 species are decreasing, and data were not collected from four of these in the last 20 years. In the case of nine species (*B. bohemicus, B. confusus, B. consobrinus, B. cryptarum, B. fragrans, B. laesus, B. paradoxus, B. subterraneus, B. sylvestris*), it is necessary to verify the presence of stable populations in Hungary.

Relative frequencies of seven species are constant, while relative frequencies of seven others showed an increasing trend. In the last 20 years, the trend of relative frequency has changed in the case of five species: the trend of *B. subterraneus* has changed from stable to decreasing, the trend of *B. sylvarum* from decreasing to stable, the trend of *B. pascuorum* and *B. lucorum* from stable to increasing, and the trend of *B. argillaceus* from decreasing to increasing.

Although Sárospataki et al. (2005) did not study cuckoo bumblebees (*Psithyrus ssp.*), based on our data, it can be stated that the relative frequency trends of *B. barbutellus* and *B. rupestris* have changed from increasing to decreasing, and the trend of *B. vestalis* from increasing to stable. Considering their decreasing relative frequencies and rarity in the Hungarian fauna, their protection is recommended.

The previously detected increase in the frequency of *B. hypnorum* and *B. soroeensis* could be confirmed. Besides the *B. haematurus* species, *B. argillaceus* has also spread intensively in the country in the last 20 years. The northwestward expansion of *B. haematurus* in Central Europe was already known (*Biella et al.*, 2020) but we provided the first data about the northeastward spread of the species. Consequently, its area should be investigated northeast from Hungary as well. 20 years ago, *Bombus argillaceus* was categorized as critically endangered, rare species with a shrinking distribution area (*Sárospataki et al.*, 2005, *Kosior et al.*, 2007). In the last 20 years, its relative frequency has increased outstandingly, and currently, in Hungary, it belongs to the moderately frequent category. Similarly to *Bombus haematurus,* the northern limits of its area should be reconsidered.

Climate change, warming winters and changes in the landscape structure could significantly influence the distribution of other bumblebee species (*Biella et al.*, 2020, *Novotny et al.*, 2021). Therefore, continuous monitoring of *Bombus* assemblages is recommended. The actualized distribution maps provide a strong basis for its effective planning. The investigation of the areas uninvesigated before, the review of the UTM cells having only archaic data, and the confirmation of the data related to species with dubious data should be prioritized.

3.3. Data on the bumblebee (Apidae: *Bombus spp.*) assemblages of the crops included in the greening

During the samplings, 269 individuals of eight bumblebee species were recorded (*Bombus terrestris/lucorum, B. lapidarius, B. ruderarius, B. hortorum/ruderatus, B. sylvarum, B. pascuorum, B. humilis, B. hypnorum*). From the studied habitat types, bumblebees could not be found only in the vegetable marrow fields, which cause requires further investigation. The total species number was the highest (S=6) in the dike slopes, which can be explained by its mosaic landscape structure and the composition of flowering plants occurring there.

The *B. terrestris/lucorum* and *B. lapidarius* species were found in all habitat types with the exception of the vegetable marrow. The *B. lapidarius* was the most abundant species (N=156), followed by *B. terrestris/lucorum* with 52 individuals. The *B. ruderarius* species was represented by only three individuals, while both *B. humilis* and *B. hypnorum* had only one-one individual.

The dike slopes showed the highest values based on the mean and maximum species number as well, while the less species-rich habitats were the vegetable marrow and oilseed radish fields. The total number of species and maximum number of species were equal in all habitat types, except the alfalfa (5 and 4, respectively) and red clover (4 and 3, respectively) fields. Although sunflower had the same species-richness (4) as red clover and hayfields, its mean species number (1.8) was substantially lower than theirs. Excluding vegetable marrow, oilseed radish, and sunflower, the mean species number exceeds the summarized value in all cases. Based on the mean number of individuals, the highest value belonged to the dike slopes as well (13.3), but alfalfa (10.3), red clover (10.0), and hayfields (9.5) also showed relatively high values. The vegetable marrow (0.0), oilseed radish (0.7), and alfalfa hedging (3.0) have significantly lower mean number of individuals, while sunflower, despite having the highest abundancy (20), considering the mean number of individuals, it has only a moderate value (6). The maximum abundancy values (after sunflower fields) showed a similar order: dike slopes (18), alfalfa (16), hayfield (13), red clover (12), alfalfa hedging (4), oilseed radish (2), and vegetable marrow (0). Based on the Whittaker index (S/Average), the areas are well differentiated.

Thus, among the studied habitat types, the dike slopes surpassed all the others in both number of species and mean number of individuals. Hayfield, red clover, and alfalfa fields were also provided a suitable food source for several bumblebee species and showed high abundances as well. The alfalfa hedging offered more limited opportunities as food source, but due to its low disturbance, under intensive land use, it could provide a suitable habitat for a few species. Although sunflower showed high abundances in some cases, considering the mean values, it was below average both in species-richness and abundance. Although vegetable marrow and oilseed radish could be significant food sources for bumblebees based on literature (Goulson, 2003), our study did not confirm that.

Alfalfa, included in the greening program as a nitrogen-fixing species, red clover, belonging to the category of ecologically important secondary crop, and alfalfa hedging, included in agri-environmental schemes as grass verge, can help to protect the bumblebee fauna. Additionally, the study provides an opportunity to the better understanding of the distribution and habitat requirements of various bumblebee species, enhancing the effectiveness of the conservation efforts.

4. NEW SCIENTIFIC RESULTS

1. I described and characterized the Orthoptera fauna of the firth region of the Sajó River. I collected 30 species (3 protected), of which the data of 16 (2 protected) species are new for the area. I have described the assemblages of crops (red clover, alfalfa, wheat, sunflower, cornfields and stubble) that have hardly been studied so far. According to my results, the analyzed agricultural habitats have their own characteristic ensembles. These were formed during several decades of habitat use and differ from the assemblages of semi-natural habitats in the same region.
2. I proved the positive effect on diversity of AKG elements of controversial effectiveness. I detected an average of 43% of the fauna species in the red clover fields, while 53% in the alfalfa fields (the maximum was 73% in the hayfields, while 13% of the detected species occurred in the sunflower and 6% in the corn).
3. I proved the significant diversity-maintaining role of linear agrarian landscape elements in the intensive agricultural landscape, which, in contrast to previous research on semi-natural habitats, was investigated with arable matrix areas. The distribution between the groups of diverse (N_{mean}: 54.09; S_{mean}: 11.64; GCI': 6.42) and less diverse (N_{mean}: 45.89; S_{mean}: 8.67; GCI': 4.74) agricultural habitats the average number of individuals (N_{mean}), average number of species (S_{mean}) and Grashopper Conservation Index (GCI) of linear areas were significantly higher than those of intensive fields (N_{mean}: 12.25; S_{mean}: 4.25; GCI': 2.22).
4. I quantified the local growth of the Italian locust (*Calliptamus italicus*) in the investigated areas. Based on the average relative frequency of over 13% - which exceeded 50% in lucerne - the Italian locust appears again as a potential pest in the Great Plains.
5. I updated the distribution database of the Hungarian Bombus fauna with 900 new data records and prepared distribution maps of all 32 species, as well as UTM maps illustrating the age of the data for the entire country and the number of species. I determined the current frequency of the species, showed area changes and identified the trends of the changes. In the case of 9 species, I proposed further tests to prove the presence of stable populations, and in the case of 3 species, legal protection.

6. I proved that red clover (N_{mean}: 10.0; S_{mean}: 2.5) and alfalfa (N_{mean}: 10.3; S_{mean}: 2.8) contribute significantly to agricultural areas (total N_{mean}: 6.1; S_{mean}: 1.9) to protect the bumble bee fauna. This is supported by the fact that among the identified assemblages, red clover areas are the most diverse, while alfalfa areas are grouped into the transitional type.
7. I determined the composition of the bumblebee assemblages of typical semi-natural habitats and agricultural areas in the firth region of the Sajó River. According to my results, the composition of the Bombus assemblages of the studied agricultural areas is primarily determined by the quality of the food.

5. PRACTICAL APPLICABILITY OF THE RESULTS

1. Based on my results regarding the Orthoptera assemblages, I recommend maintaining the linear elements of the lowland agricultural landscapes, such as roadsides and dirt roads, as well as increasing the proportion of permanent undisturbed cultures (e.g.: alfalfa, red clover) and planning their presence at the landscape level.
2. Due to the significant increase in the damage risk of the *Calliptamus italicus*, I recommend treating the species as a current pest, organizing monitoring primarily in perennial crops and their surroundings, and informing farmers.
3. Based on the serious distribution of *Bombus* species and their long-term rarity trends, I recommend the legal protection of *B. barbutellus, B. rupestris* and *B. vestalis*.
4. According to my results, the Hungarian Bombus fauna has been significantly rearranged in the last two decades and the trends indicate further changes. It is important for both nature conservation and agriculture to help the species that migrate to the north to survive with tree rows and groups of trees that help avoid heat stress, and which can act as stepping stones when inserted mosaic into the agricultural landscape. The chances of survival of pollinators that can adapt to the local climate and migrate to our country from the south must be improved by creating flourishing crops, margins, and preserved or planted wild flower areas.
5. Based on the updated data on the distribution and frequency of Bombus, I recommend examining the area- and species-related priorities of fauna research and protection, which I have identified in detail in the thesis and illustrated with the summary maps in the Appendix.
6. I have verified the effectiveness of the AKG and the investigated *Fabaceae* elements of greening, therefore I recommend the maintenance, expansion and further support of the affected areas.

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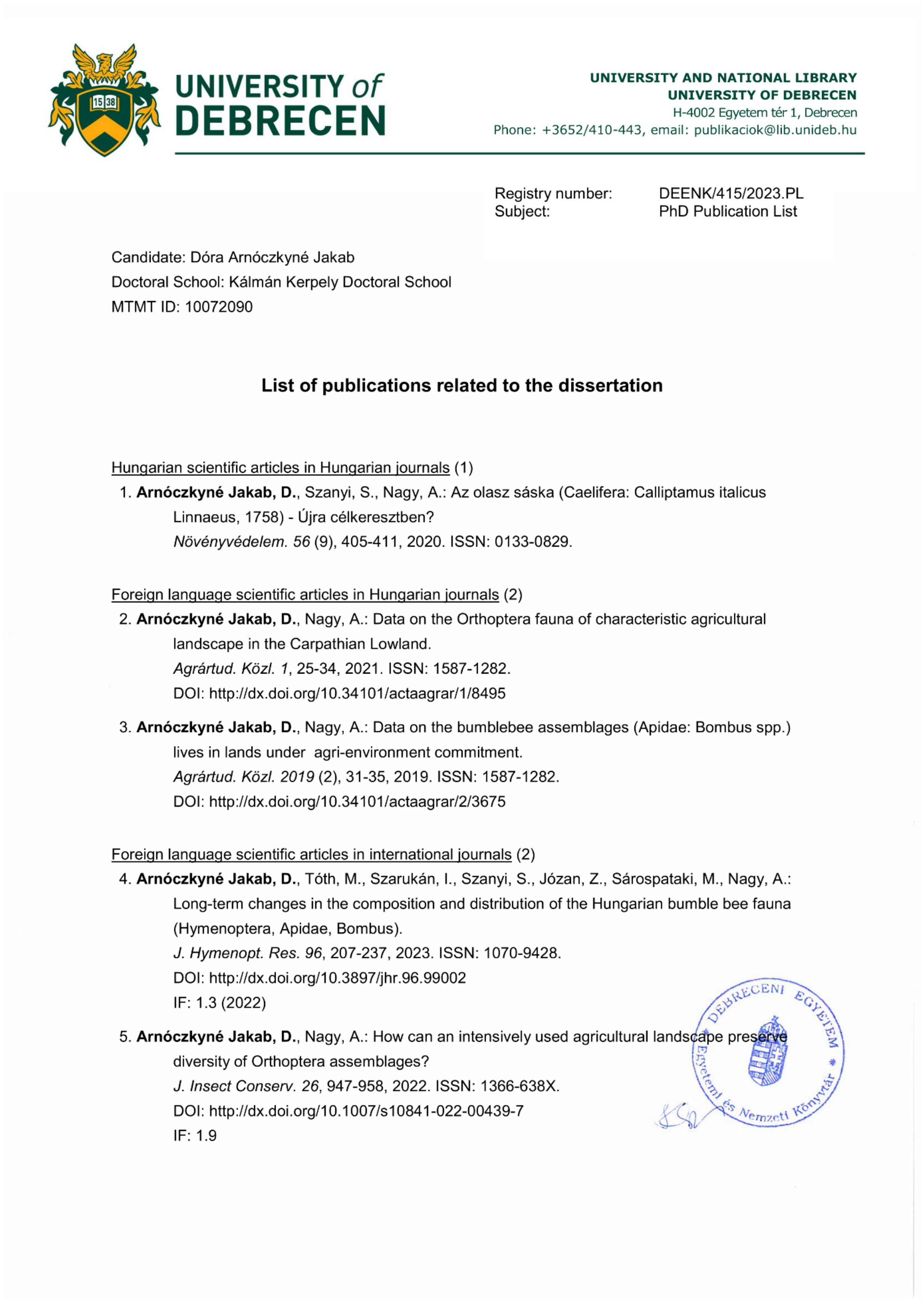
7. PUBLICATIONS IN THE TOPIC OF THE DISSERTATION



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Subject:	PhD Publication List

Candidate: Dóra Arnóczkyné Jakab
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10072090

List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (1)

1. **Arnóczkyné Jakab, D.**, Szanyi, S., Nagy, A.: Az olasz sáska (Caelifera: Calliptamus italicus Linnaeus, 1758) - Újra célkeresztben?
   Növényvédelem. 56 (9), 405-411, 2020. ISSN: 0133-0829.

Foreign language scientific articles in Hungarian journals (2)

2. **Arnóczkyné Jakab, D.**, Nagy, A.: Data on the Orthoptera fauna of characteristic agricultural landscape in the Carpathian Lowland.
   Agrártud. Közl. 1, 25-34, 2021. ISSN: 1587-1282.
   DOI: http://dx.doi.org/10.34101/actaagrar/1/8495
3. **Arnóczkyné Jakab, D.**, Nagy, A.: Data on the bumblebee assemblages (Apidae: Bombus spp.) lives in lands under agri-environment commitment.
   Agrártud. Közl. 2019 (2), 31-35, 2019. ISSN: 1587-1282.
   DOI: http://dx.doi.org/10.34101/actaagrar/2/3675

Foreign language scientific articles in international journals (2)

4. **Arnóczkyné Jakab, D.**, Tóth, M., Szarukán, I., Szanyi, S., Józan, Z., Sárospataki, M., Nagy, A.: Long-term changes in the composition and distribution of the Hungarian bumble bee fauna (Hymenoptera, Apidae, Bombus).
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5. **Arnóczkyné Jakab, D.**, Nagy, A.: How can an intensively used agricultural landscape preserve diversity of Orthoptera assemblages?
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6. **Arnóczkyné Jakab, D.**, Tóth, M., Szarukán, I., Szanyi, S., Józan, Z., Sárospataki, M., Nagy, A.: A hazai Bombus fauna összetétele és hosszú távú változásai meglepő adatokkal Magyarországról, Nyugat-Ukrajnából és Északnyugat-Romániából.
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7. **Arnóczkyné Jakab, D.**, Tóth, M., Szarukán, I., Nagy, A., Szanyi, S.: Poszméh (Bombus spp.) fajok új elterjedési adatai Kelet-Magyarországon és Kárpátalján.
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10. **Arnóczkyné Jakab, D.**, Tóth, M., Szarukán, I., Nagy, A.: Adatok agrárterületek poszméh (Bombus spp.) faunájához illatanyag csapdák fogásai alapján.
    In: 23. Tiszántúli Növényvédelmi Fórum : 8th International Plant Protection Symposium at University of Debrece : Program-Összefoglalók, DE MÉK, Debrecen, 46-46, 2018.

11. **Arnóczkyné Jakab, D.**, Nagy, A.: Adatok a Tiszaújváros környéki agrártájak Orthoptera faunájához.
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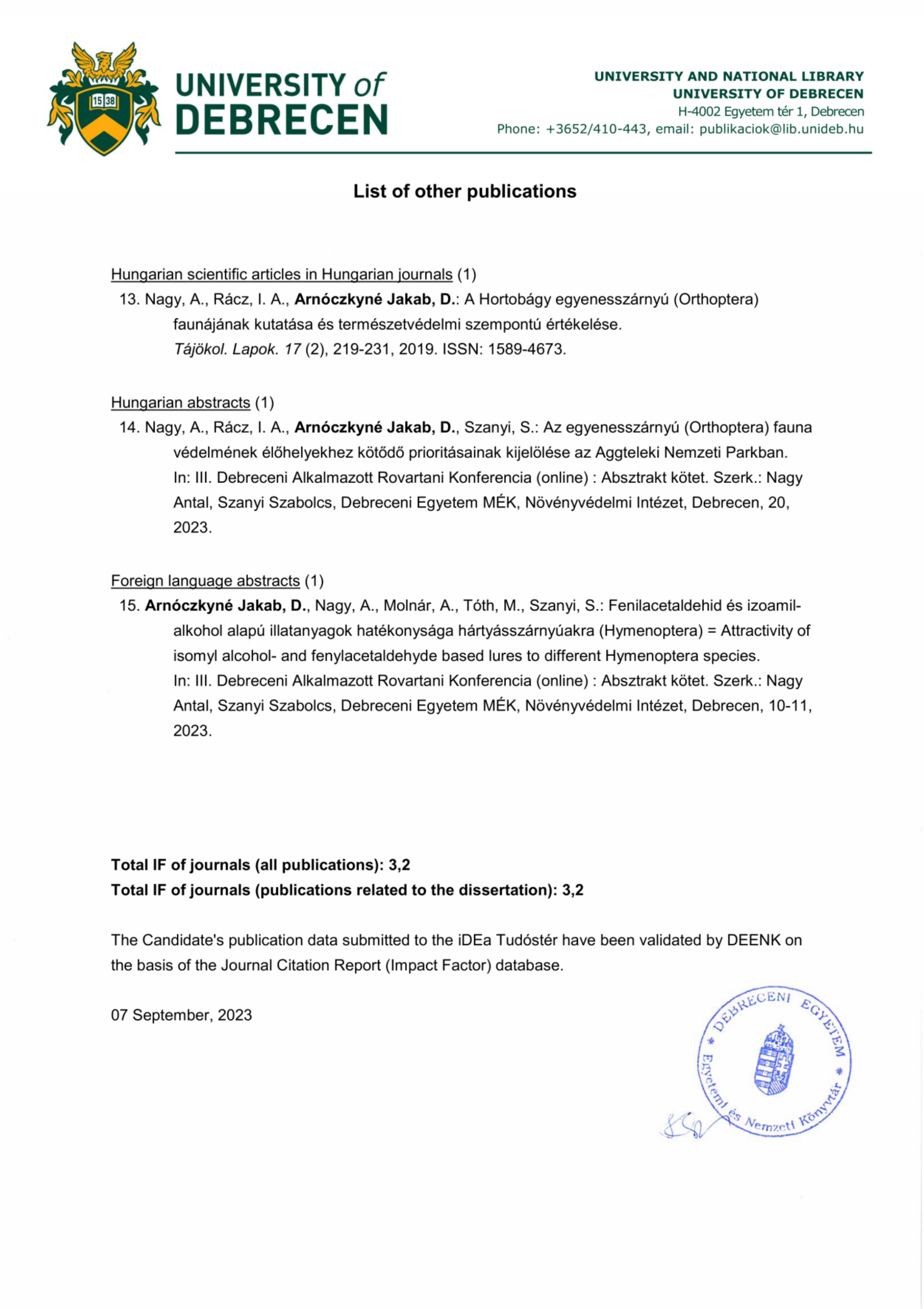
12. **Arnóczkyné Jakab, D.**, Nagy, A.: Conservation value of Orthoptera assemblages of a historically intensively used agricultural landscape: a case study in the Carpathian Lowland (East Hungary).
    In: Scientific Conference of PhD. Students of FAFR and FBFS SUA in Nitra with international participation : Proceedings of abstracts, Slovak University of Agriculture, Nitra, 52, 2021.



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List of other publications

Hungarian scientific articles in Hungarian journals (1)

13. Nagy, A., Rácz, I. A., **Arnóczkyné Jakab, D.**: A Hortobágy egyenesszárnyú (Orthoptera) faunájának kutatása és természetvédelmi szempontú értékelése. *Tájökol. Lapok. 17* (2), 219-231, 2019. ISSN: 1589-4673.

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14. Nagy, A., Rácz, I. A., **Arnóczkyné Jakab, D.**, Szanyi, S.: Az egyenesszárnyú (Orthoptera) fauna védelmének élőhelyekhez kötődő prioritásainak kijelölése az Aggteleki Nemzeti Parkban. In: III. Debreceni Alkalmazott Rovartani Konferencia (online) : Absztrakt kötet. Szerk.: Nagy Antal, Szanyi Szabolcs, Debreceni Egyetem MÉK, Növényvédelmi Intézet, Debrecen, 20, 2023.

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15. **Arnóczkyné Jakab, D.**, Nagy, A., Molnár, A., Tóth, M., Szanyi, S.: Fenilacetaldehid és izoamil-alkohol alapú illatanyagok hatékonysága hártyásszárnyúakra (Hymenoptera) = Attractivity of isomyl alcohol- and fenylacetaldehyde based lures to different Hymenoptera species. In: III. Debreceni Alkalmazott Rovartani Konferencia (online) : Absztrakt kötet. Szerk.: Nagy Antal, Szanyi Szabolcs, Debreceni Egyetem MÉK, Növényvédelmi Intézet, Debrecen, 10-11, 2023.

Total IF of journals (all publications): 3,2
Total IF of journals (publications related to the dissertation): 3,2

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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