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Flower strips as a tool promoting pollinators in agroecosystems

Doctoral Thesis

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Abstract

Declining trend in European pollinator populations is the most concerning in food specialists which species numbers decreased by 30% in the last 40 years. Throughout the European Union, sown flower strips are supported within agri-environment climate schemes (AECS) to mitigate pollinator declines and they are mostly focused on providing food resources for target pollinator groups on farmland. Our study tested pollinator occurrence in sown flower strips corresponding to Czech AECS 'Nectar-rich flower strips' as compared to nearby semi-natural habitats and intensively managed wheat fields. Aculeate Hymenoptera and Syrphidae as two target groups of the AECS with different ecology were chosen for our survey. The goal of our design was to determine whether there is a difference in the quality of pollinator support among habitats highly differing in their flowering plant species diversity as well as in the range of reproduction opportunities.

The study was carried out on seven localities in Central Bohemia, Czech Republic, in 2016 and 2017. Each locality comprised three different habitat types (flower strips, semi-natural habitats and wheat fields) separated by at least 350 m. In each habitat type, occurrence of aculeate Hymenoptera and Syrphidae was sampled by yellow pan traps and transect walks in three summer terms in 2016. During each sampling term, all just flowering plant species were also recorded. Meanwhile, in 2016- 2017, a detailed sampling of flower strips (estimation of plant species cover, number of flowers for each plant species and pollinator sampling by transect walks) was done on all seven localities in three summer terms.

Suitability of the two pollinator groups differing in their degree of philopatry within the pool of our study, sampled by yellow pan traps and transect walks, for local-scale biomonitoring was tested first. Philopatric group represented by aculeate Hymenoptera proved to be suitable for this purpose as it was detected in significantly different species numbers in two most contrasting habitat types (semi-natural habitats and wheat fields), regardless of the sampling method used. In contrast, Syrphidae as a rather non-philopatric group within this study pointed to differences between habitats only in transect walks and thus, showed a mixed pattern. Nevertheless, affinity of Syrphidae towards non-philopatric behavior suggests that they might be a suitable indicator at a landscape scale.

Comparison of the pollinator occurrence in three studied habitats (flower strips, semi-natural habitats and wheat fields) showed that Czech AECS 'nectar-rich flower strips' attracted most species of aculeate Hymenoptera and Syrphidae living at the studied sites despite a significantly lower plant species diversity in flower strips. However, bee food specialists prevailed significantly in semi-natural habitats. Sown flower strips attracted significantly higher abundances of all aculeate Hymenoptera comprising *Apis mellifera*, coming mostly from managed beehives. This potentially local benefit for beekeepers may be in conflict with conservation focus of the AECS as honeybees tend to suppress foraging of other bee pollinators in flowering patches.

'Nectar-rich flower strips' are conceived as a biennial to triennial simple 'pollen and nectar mix' composed of annuals, forbs and other perennials attractive to pollinators. They should be cut once in summer between July 1 and September 15. We tested the effect of early summer and late summer cutting in the establishment year on their development (plant species cover and number of flowers) and pollinator visitation rate of honeybees, bumble bees, other wild bees and hoverflies over a two-year period. It has been found that the date of mowing is not decisive for the subsequent visitation of the flower strips by target pollinator groups but it affects their botanical composition. However, there were other untested factors affecting pollinator visitation rate at least as much as flowering intensity. Early summer cutting significantly supported sown species and simultaneously reduced weed species. Late summer cutting enhanced flowering of 'pollinator-friendly weeds' and their visitation by pollinators in mid-summer of the sowing year. In the tested seeding mix, there is a conflict between the conservation requirements for having as long of a flowering period in summer as possible and the support of perennial plant species in the flower strip requiring early cutting. A split mowing management could be a solution in weed-free flower strips.

While all target pollinator groups were attracted mainly by *Phacelia tanacetifolia* in early summer of the establishment year, in the post seeding year, flower strips were attractive mainly for honeybees and bumblebees due to the flowering of *Trifolium* species. Therefore, plant species suitable for other wild bees and hoverflies (i.e. Asteraceae, Apiaceae) should be added in the seeding mix if the AECS is supposed to support wider pollinator species diversity.

I declare that I am the author of this work. I also declare that I have only used surveys and books cited in references.

On February 22, 2019 in Prague

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CONTEXT OF THE STUDY

Since World War II, wildlife in general has suffered from losses of many animal and plant species. Similarly, species richness and abundance in various groups of flower-visiting insects have decreased considerably. Yet, their role is key for production of entomophilous crops and for reproduction of 90% of flowering plants worldwide. Their decline was driven by consequences of agricultural intensification including landscape and crop rotation simplification and use of agrochemicals in farming. In other words, loss of nesting or reproduction sites, reduction of food resources and exposure to agrochemicals have been responsible for declining pollinator populations throughout Europe. In the 1990s, the European Union (EU) began an investment strategy to mitigate the biodiversity decline and created subsidized schemes with the goal to restore and protect wildlife habitats in the agricultural landscape. Since 2001, Agri-Environment Schemes (renamed as Agri-Environment Climate Schemes or AECS since 2015) as financially supported and wildlife-friendly agroecosystem management practices have included schemes that were designed to promote pollinator populations. In most EU-member countries, the schemes consisted in the establishment of sown flower strips attractive for various flower-visiting insect species around, or, in the middle of the fields. Nevertheless, this simple concept was mainly focused on massive food supply and yet, often omitted to simultaneously providing nesting sites, particularly necessary for the restoration of wild bee populations.

In the Czech Republic, 'nectar-rich flower strips' were introduced in 2015 and their area rose from initial 52 hectares to 452 hectares in 2017. They have been conceived as a mix of nutritionally valuable flowering annual crops, leguminoses and other flowering plants sown in strips on arable land. They are supposed to be cut once in summer and should be maintained for two or three years on one spot and then reestablished at the same place or at a different site of the farm.

Although the interest of farmers in 'nectar-rich flower strips' in the Czech Republic has risen and, their benefit for beekeepers is obvious, their effect for wild pollinators has not been tested yet. Also, their impact on pollinators compared to that of already existing uncultivated semi-natural areas has been rarely studied even at the global scale and needs to be investigated in order to understand the efficacy of such AECS programs as a strategy to mitigate pollinator losses. Moreover, the management of the strips can be essential for their success and suitable recommendations must be given to farmers in order to fulfill the potential of the AECS.

LITERATURE REVIEW

Pollinators as key parts of agroecosystems are in decline

Ecosystem services delivered by pollinators

Principles of pollination by insect vectors

Pollination is a necessary step preceding sexual reproduction of plants. In flowering plants (angiosperms), it consists in transfer of pollen grains, that are actually male gametophytes, from anthers to stigmas, which are structures connected to ovules containing female gametophytes. Some flowering plant species can be self-pollinated, other species need pollen transferred from a different individual to be pollinated. Wind and animals are two major pollinating vectors (Fægri and van der Pijl, 1979). Nevertheless, most of the 250,000, modern species of angiosperms (Heywood, 1993) depend on animal-mediated pollination, especially done by insect vectors (Buchmann and Nabhan, 1996). For this, flowering plants have evolved various mechanisms to allow animals to transfer their pollen grains and ensure effective pollination. Pollen, nectar, oils, odours, visual patterns (colour, structures visible in UV light) etc. are in fact various attractants for mainly insect vectors that contribute to a succesful pollination (Fægri and van der Pijl, 1979).

Plant-pollinator interactions happen often within a mutualistic relationship (Fægri and van der Pijl, 1979). The insect pollinator gains vital food resources such as proteins and sugars (pollen and nectar) and as a reward, the flower gets pollinated.

The structure of the flower determines what insect species can access its energetic resources. While pollen is usually well-exposed and therefore accessible to a wide range of insect species, nectar is often more hidden and available to specialized visitors only (Fægri and van der Pijl, 1979). The fact that an insect species visits flowers does not need to imply it pollinates them. There are many species visiting flowers only for nectar, e.g. most wasps (Aculeata: Chrysidoidea, Vespoidea or Apoidea: Spheciformes). Their bodies do not bear suitable hairs to carry pollen effectively and therefore, they can possibly visit a flower without pollinating it (Thorp, 2000). Similarly, if an insect species cannot access nectar from the inside of the corolla, it may bite a hole from the outside without pollinating the flower. Such individuals (e.g. belonging to some bumblebee species) are called 'nectar robbers' (Goulson, 2010).

Floral constancy is a tendency of an individual insect forager to visit conspecific flowers within its foraging flight. This behaviour is a prerequisite for successful cross-flower pollination. In contrast, pollinator species differ in the range of floral hosts from which they can inherently collect pollen, which is a species-specific trait. The range can vary from a single plant species (monolectic pollinator species), to one botanical genus, tribe or family (female foragers collect at least 90% of pure pollen loads of one such taxonomical entitity; oligolectic), to a broad variety of plant species belonging to different families (polylectic) (Cane and Sipes, 2006).

Pollination of crops

Even though 60% of global crop production comes from crops that do not rely on animal pollination e.g. cereals, for 35% of crop production, animal pollination increases yields (Klein et al., 2007).

The influence of pollinators within one crop can vary, depending on variety. As an example, in oilseed rape, the influence on yield from pollinators varies with variety by 10 to 40%, accross studies (Gallai, 2008). Considering global crops in the human diet, which are not entirely wind- or self-pollinated, or do not reproduce vegetatively, 85% of them are influenced by animal pollination; primarily insects, to achieve yields and, for 40% of crops, this animal pollination service is essential or, highly important. Without pollinators in this latter group of crops, yields are reduced by 40 to 100% (Fig. 1).

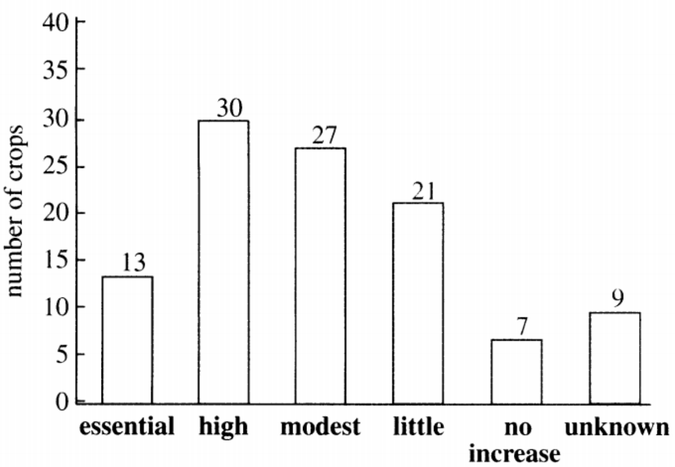


Figure 1. Level of dependency on animal-mediated pollination in crops known as partly entomophilous, according to Klein et al. (2006).

The world's most vulnerable crops, regarding pollinator loss, are stimulant crops (coffee and cocoa), nuts, fruits, edible oil crops and vegetables. The global economic value of pollination service for these crops was calculated to be more than 150 billion Euro. In the EU, this insect pollination value equals 14 billion Euro. Within the European Union, crop yields that would likely suffer from pollinator decline are mainly almonds and fruits (apples, pears, stone fruits, strawberries, blueberries, blackberries, raspberries etc.); edible oils (sunflower, rapeseed etc.); and, vegetables (tomatoes, watermelons, squashes, cucumbers, zucchini etc.) (Galai et al., 2009).

In the Czech Republic, crops needing insect pollination, to a greater or lesser extent, are cultivated on 13% of farmland. Rape, sunflower and mustard grown for seed cover more than 12% of agricultural land. Only around 1% belongs to other unspecified areas for seed production, orchards, caraway fields, strawberries and vegetables such as gherkins, cucumbers and tomatoes (CSO, 2017).

For pollination of crops, domesticated honeybee (*Apis mellifera*) is needed alongside many wild bee species and other insect pollinator species from Syrphidae family (Diptera) and others (Kearns et al., 2008).

Maintenance of ecosystem stability

Insects serve many roles in an ecosystem. They certainly contribute in ensuring crop production as around 90% of wild flowering plants (angiosperms) need insect vectors for pollination and subsequent sexual reproduction (Buchmann and Nabhan, 1996).

Insects are also drivers of nutrient cycling (Yang and Gratton, 2014) and they represent a food source for higher trophic levels such as amphibians, birds and mammals. Therefore, they are responsible for wider ecosystem stability.

Necessary life conditions for the survival of pollinators

Food supply and requirements for its distribution

Pollinating insects are species visiting flowers not in order to pollinate them but to seek their energetic resources. While pollen represents mostly their only source of proteins (essential amino-acids) alongside other nutrients such as lipids, sterols, vitamins, minerals etc. (Herbert and Shimanuki, 1978), nectar is a major source of sugars. Both pollen and nectar are collected by adult pollinators either to feed themselves or to provide food to their offspring. In bees

(Hymenoptera: Apiformes), pollen is provided to larvae and is necessary for their development. The intake of pollen stops when internal organs have been developped (Crailsheim et al., 1992). In contrast, adult hoverflies (Diptera: Syrphidae) do not feed their offspring and pollen is consumed mainly by females to ensure normal function of their reproductive organs (Haslett, 1989).

In different plant species, pollens vary in amino acid and macronutrient composition. Some plant species contain all amino-acids necessary for larval development of the bees, while other plant species are deficient in some nutrients and their pollen needs to be mixed with other pollen sources to cover all the nutritional needs of the larvae (Somme et a., 2016). It is probable that bee preferences for pollen reflect its amino-acid composition (Cook et al., 2003). As long as plant species with insufficient pollen quality are represented by a broad species variety in the landscape, insect pollinators can combine food resources in order to create a balanced diet. Thus, plant diversity is essential for insect health and conservation (Müller et al., 2006).

Likewise, as in pollen, nectar quality differs among plant species and varies in sugar composition and concentration. Therefore, nectar originating from a certain plant species can be suitable for some insect species more than for other (Hicks et al., 2016).

Flower-visiting insects need suitable floral resources within their foraging range throughout their flight period for their survival. In nesting insects such as aculeate Hymenoptera, appropriate flowering plants must occur within the foraging radius of most adult females. This homing distance derives from the body size of the species and can vary from 100 m to more than 10 km in bees (Greenleaf et al. 2007). However, even in the largest solitary bees, vegetation of only 300 m around the nest is crucial for survival of more than 50% of the population (Zurbuchen et al. 2010).

In Syrphidae (Diptera), the needs for distribution of food resources in the landscape differ. These species do not have any nest. Their level of mobility is species-specific but many species living in the open agricultural landscape are very mobile (Speight, 2016). As habitat generalists, they are less dependent on spots with particular habitat conditions within the agricultural matrix as compared to bees (Jauker et al., 2009; Ekroos et al., 2013).

Reproduction sites

Pollinator species differ in their requirements for reproduction sites. In pollinators of aculeate Hymenoptera, the habitat suitable for nesting must contain the following: (a) appropriate nest site meeting species-specific requirements for local conditions, (b) particular nest-building materials in case of certain species, (c) sufficient amount of floral resources providing pollen and nectar. Often, one single habitat does not contain all the required resources and thus, the entire habitat complex of a bee species consists of several partial habitats (Westrich, 1996).

For Syrphidae, that are not nesting insects, sites conducive to the development of larvae are searched by sexually mature females to lay eggs there. These microhabitats such as aphid colonies, mud, small pools and others are necessary for survival of hoverflies in the agricultural landscape (Sommaggio et al., 1999).

Major groups of pollinating insects

Hymenoptera and Diptera are the two most abundant flower-visiting groups in Europe, forming 47% and 26% of the insect flower-visitor community, respectively. Coleoptera and Lepidoptera are represented by 15% and 10%. Hymenoptera is the most numerous group including species considered as the most effective pollinators, mainly bees (Apiformes) (Willmer, 2011) but also wasps (Johnson et al., 2007; Sühs et al., 2009). Although the pollinating role of Diptera has been less well investigated so far, some species of hoverflies (Syrphidae) are key pollinators of particular crops (Klein et al., 2007) and moreover, hoverflies as well as other fly families pollinate wild plants (Janovský et al., 2013).

In both Hymenoptera and Diptera flower visitors, the choice for foraging on a particular plant species is determined by the depth of the flower's corolla and the length of insect's proboscis (straw-like tube tongue) in the insect species (Gilbert, 1981; Branquart & Hemptinne, 2000; Goulson, 2010).

Aculeate Hymenoptera

Even though different families belonging to aculeate Hymenoptera include nectar-consumers and occasional pollinators that are commonly called wasps (Willemstein, 1987; Johnson et al., 2007; Sühs et al., 2009), only adult bees (Apiformes) have branched body hairs that allow pollen grains to stick to them and enable the bees to accumulate considerable amounts of pollen on their bodies that make them effective pollinators (Thorp, 2000). From the widespread species, only bees feed their larvae with pollen and nectar. As a minor exception to this, the 'pollen wasps' (Vespidae: Masarinae), occuring only in desertic areas, also collect nectar and pollen for provisioning their larvae (Macek et al., 2010).

In the Czech Republic, 6 out of 7 bee families (Apiformes) are represented. Alongside honeybee (*Apis mellifera*), bees are represented by numerous families of wild bees comprising bumblebee species and other wild bee species that are often called solitary bees although they include species with different degrees of sociality from solitary to eusocial species (Macek et al., 2010).

All these species are specialized for collecting pollen, nectar and plant oils. The oils are a part of larval diet (in form of propolis) (Tautz, 2008) and are also used for a water-resistant and antibacterial layer on larval cell walls (Neff and Simpson, 1981).

Apis mellifera is highly competitive for floral resources and can suppress other flower visitors mainly in homogenous landscapes (Herbertsson et al., 2016). But, wild bee pollinators are relevant for crop productivity and stability even if honeybees are abundant (Garibaldi et al., 2011). Hoehn et al. (2008) revealed that bee species provide complementary benefits in pollination of a single crop stand. Depending on their body size, bee species differ in time and pollinating height of flowers they choose to visit. Medium-sized and large bees start to forage earlier in the morning than small bee species. Also, very small bees pollinate flowers positioned significantly lower in a canopy than those pollinated by larger bees.

Aculeate Hymenoptera might be a good small-scale ecological indicator as they are excellent predictors of plant diversity (Billeter et al. 2008) which is one of the key characteristics of a habitat. Moreover, they are a good species for assessing the current state of a habitat because of their capacity to colonize rapidly a site where suitable life conditions have been created (Heneberg et al., 2013), and this even from one year to another (Gathmann et al., 1994).

Apis mellifera

Honeybee is considered as one of the most important pollinators of many crops (Carreck and Williams, 1998). The medium-sized proboscis of 6-7 mm long (Waddington, 1987) enables the workers to visit a wide range of plant species. They show a polylectic foraging behaviour (Macek et al., 2010). Although most European honeybees are domesticated, even wild honeybees occur in the Czech Republic (Macek et al., 2010).

The importance of the only domesticated species does not consists only in pollination service but also in its products such as honey, wax, propolis, royal jelly, pollen and poison (Macek et al., 2010). Nevertheless, the pollination service delivered by honeybees is economically more important than honeybee products. Whereas the total benefit from beekeeping is estimated at 22 billion Euro within the EU, benefit from the sales of honey equal only 153 million Euro (Czech Republic, 2013).

In the Czech Republic, the number of managed colonies has been stable in the last 15 years (Czech Republic, 2017). In 2010, the Czech level of 6,6 colonies per km^2 was the fourth highest in the EU, after Greece, Hungary and Slovenia, exceeding significantly the European average of 4,2 colonies per km^2 (Chauzat et al., 2013). In the Czech Republic, the number of colonies per km^2 can vary from 0 to 80, or more, (Danihlík et al., 2017) and can, on a local basis, greatly exceed the recommended level (Titěra, 2018).

Biology and population dynamics

Several races of *Apis mellifera* are kept worldwide. In Central Europe, comprising the Czech Republic, beekeeping is dominated by *Apis mellifera carnica* (Macek et al., 2010).

Bee colonies consist mainly of workers (40,000 – 100,000), then of males called 'drones' (500 – 2,000), and a single queen. The whole colony depends on workers (sexualy immature females) in terms of food provisioning. The activity of the workers starts in the beginning of spring when the temperature exceeds 16 °C and can stretch even to November if the temperature is still higher than the physiologically necessary minimum (Allan et al., 1994). Heinrich (1979) estimates that the optimum for foraging flights is between 22 - 25 °C, while according to Allan et al. (1994) the range is between 16 and 32 °C and the flight distance decreases if the temperature is lower or higher. Also, workers do not leave the hive under misty weather or rain and they avoid foraging if wind speed is higher than 13 kms/h.

The energetic needs of a colony are continuous throughout the season as larvae hatch from the spring to the autumn. Only workers specialized in foraging (workers older than 21 days) collect pollen and nectar. Most of them collect either one or the other type of resource, only around 15% bring both to the hive (Tautz, 2008). There is a proportion of foragers which locate forage patches by independent scouting. It can raise up to 35%, depending on floral resources availability. The rest of foragers only follow recruitment dances or 'waggle dances' (Tautz,

1996) that scout bees use to communicate the position of forage resources to their fellow forage workers (Seeley, 1982). During summer from 100,000 to 200,000 female foragers caring for the food supply of the colony are grown in the hive (Tautz, 2008). In this period, a female worker lives for 30 or 40 days (Macek et al., 2010) after having flown around 800 km (Haragsim, 2004). Queen and workers survive the winter in the hive and need to have large quantities of honey (condensed nectar transformed by enzymatic activity) and pollen stored beforehand (Tautz, 2008).

Foraging behaviour

On average, a honeybee forager flies up to 2 – 4 kms far from the hive. She needs to visit from 100 to 170 flowers in order to fill her 'honey stomach' (a frontal stomach separated from digestive stomach serving only for nectar storage) which takes her from 5 to 150 minutes. Under suitable weather conditions and abundant floral resources, a forager leaves the hive 20 – 30 times per day (Haragsim, 2004; Tautz, 2008). In total, around 120 kg of nectar and 20 kg of pollen are harvested annually by a single, temperate, European honeybee colony (Seeley, 1995).

Apis mellifera is a generalist flower visitor. The foraging bees show a floral constancy, visiting a single plant species, within their foraging flight. Thus, a plant species occurring in abundant communities represent the most important food source for honeybees. In the Czech Republic, such species comprise oilseed rape (*Brassica napus*), black locust (*Robinia pseudoaccacia*), raspberry (*Rubus idaeus*), lime trees (*Tilia* spp.), clovers (*Trifolium* spp.) etc. (Haragsim, 2004).

According to Allan et al. (1994) and Tautz (2008), foraging honeybees prefer flowers in yellow and blue wave length.

Bumblebees (Bombus spp.)

Bumblebees are an important group of pollinators worldwide. Like honeybee, they are polylectic, but their longer proboscis, as compared to honeybees (in workers of most species its length is around 10 mm; Ranta and Lundberg, 1980) enables them visit also flowers with deeper corolla. Thanks to their high resistance to cold and other inconvenient weather conditions such as strong wind, rain or deficiency of sunlight, they are able to forage and pollinate plants even in times that prevent honeybees from doing so (Goulson, 2010). They are important, or even exclusive, pollinating insects of some legume crops. Bumblebee hives are commercially used for pollination of tomatoes grown in greenhouses (Morandin et al., 2001). In the Czech Republic, they are pollinators of the same crops as honeybees (Krieg et al., 2009).

Přidal (2018) has listed 36 species currently living in the Czech Republic, from which 7 species are considered as critically endangered, 2 as endangered, 3 as nearly threatened and 4 as vulnerable. This corresponds to the statement of Macek et al. (2010) declaring that many of the species are very rare and appear only locally. Krieg et al. (2009) found only 7 bumblebee species in the agricultural landscape of the Czech Republic. According to Goulson (2010), *Bombus terrestris*, *B. lapidarius*, *B. lucorum*, *B. pascuorum*, *B. pratorum* and *B. hortorum* are six most common species in Europe. Carvell et al. (2004) detected exclusively these species in the field margins in the United Kingdom.

Biology, nesting behaviour and population dynamics

Bumblebees are eusocial bees. Likewise in honeybees, their colony includes a queen, female workers and drones. In the Czech Republic, bumblebees spend most of the year in the solitary stage and in the subsocial stage. In the beginning of spring, once the temperature has exceeded 7 °C (Tautz, 2010), the queen leaves her overwintering site and starts to collect and consume pollen and nectar. Meanwhile, she looks for a suitable nesting spot. The period of nest building varies depending on climatic conditions of the year, but in the central European conditions this usually happens at the end of April latest (Krieg et al., 2009).

Bumblebee species differ in their nesting requirements. While two most common bumblebee species of the Czech Republic, *B. terrestris* and *B. lapidarius*, nest in earth cavities such as holes left by small mammals, *B. hypnorum* or *B. pratorum* nest in tree cavities or empty bird boxes, and *B. pascuroum* looks for grass turf or moss to build its nest. Finally, some common bumblebees of Europe have broader nesting preferences and they can nest either underground or above ground, e.g. *B. hortorum* and *B. sylvarum* (Krieg et al., 2009; Macek et al., 2010).

Four weeks after the queen lays eggs in the brood cells of the nest, first workers (sexually immature females) hatch and several days later they are ready for their foraging flight. Since this time, the queen stays in the nest and only lays eggs. In European conditions, at some point between June and August, depending on the species and local conditions, the colony achieves its developmental peak and sexually mature individuals start to hatch. According to Prys-Jones and Corbet (2011), a medium-sized bumblebee colony counts up to 200 individuals, but some species (e.g. *B. terrestris*) can form colonies comprising up to 350 individuals at its peak (Krieg et al., 2009). Subsequently, the former queen dies and sexually mature bumblebees mate with individuals of opposite sex from nearby nests. Then, females keep foraging and later, they find their overwintering site mostly underground, under stones, roots or in various cavities where they spent around 6 months in their dormancy break (Krieg et al., 2009; Goulson, 2010).

Foraging behaviour

Foraging distances can be very different depending on species. While *B. terrestris* or *B. lapidarius*, two most abundant species in agricultural landscape, forage at 2,5 or 3 kms far from their nest (Hagen et al., 2011), *B. pratorum* flies only around 250 m far from the nest (Krieg et al., 2009). Similarly, food preferences vary among species (Svensson, 2002; Goulson, 2010), depending on the length of proboscis (Carvell, 2004; Goulson, 2010). The two most common species in the European agricultural landscape are short-tongued species (Svensson et al., 2002). In general, dominant species are those with broad food preferences. According to Goulson (2010), the most polylectic bumblbebee species is a short-tongued *Bombus terrestris* that is able to feed even on flowers with deep corolla thanks to biting a hole to access to nectar.

Bumblebees prefer perennial plant species because of their higher secretion of nectar (Fussell and Corbet, 1992; Goulson, 2010) including clovers and other *Fabaceae* species.

Other wild bees

Other wild bees comprise non-*Apis* bee species (**Aculeata: Apiformes**) excluding bumblebees and they represent most of bee diversity. Rasmont et al. (2005) listed 1965 such species at a European scale, and Westrich (1996) stated that around 560 species lived in the Central Europe. Many of them are specialized pollinators, therefore their importance consists in pollinating wild plants that depend on their service for reproduction. Thus, other wild bees help to maintain plant diversity (Zurbuchen et al., 2010). Besides, they are important pollinators of crops as they mitigate local deficiency of honeybees or they increase the quality of pollination provided by *Apis mellifera* (Garibaldi et al., 2014). In the US, around one third of the pollination service value is estimated to be dependent on wild pollinators (other than honeybees) (Kearns, 1998). In particular crops, their service can be even of higher importance than that of honeybees such as in oilseed rape where a double pollination efficiency in 'solitary bees' compared to honeybees was detected (Woodcock et al., 2013) or in apple where *Osmia rufa* is five times more efficient as a pollinator than *Apis mellifera* (Vicens and Bosch, 2000). Moreover, specific species of other wild bees are intentionally supported to enhance pollination efficiency of some crops, such as alfalfa grown for seed (Pitts-Singer and Cane, 2011) or apple (Vicens and Bosch, 2000).

Biology, nesting behaviour and population dynamics

Non-*Apis* bees differ in their flight period. In the temperate conditions of Central Europe, the early species emerge in early spring and some species can be active until November (Westrich, 1996; Scheper et al., 2014). Nevertheless, the flight period of a species can be very short as it can be connected to the flowering of one particular plant species (Westrich, 1996).

Most non-*Apis* bees exist in a solitary behavior with each female having an individual nest. They can form nesting aggregations of many individuals nesting one next to another, up to thousands of individuals. There are communal species whose nests have a common enterance that divides into separate nests underground (Macek et al., 2010). According to Westrich (1996), around 75% of central European species nest underground. They prefer bare soil or rare vegetation cover. The remaining solitary species build their nest in dead wood, stone walls, rock cavities etc. Some *Osmia* species need empty snail shells for nesting (Macek et al., 2010).

Because of their diverse nesting requirements, their species richness and overall abundance derives from the diversity of the landscape and the proportion of semi-natural habitats (Steckel et al., 2014).

Foraging behaviour

According to Zurbuchen et al. (2010), the distance between the nest and the foraging patches should not exceed several hundred meters. Although the maximum foraging distance in the smallest species can reach 1 km, this capacity is confined only to some individuals. In general, they do not make any food stocks in their nests which makes them dependent on the continuous availability of suitable floral resources. Pollen from between 20 and several thousand flowers is required to rear a single solitary bee larva (Müller et al., 2006).

It is not possible to generalize on foraging preferences of non-*Apis* bees as they vary in their proboscis length and consequently, the range of suitable floral resources. In the Czech Republic, polylectic species include *Osmia*, *Andrena*, *Halictus*, *Lasioglossum*, *Anthidium* or *Anthopora* species (Westrich, 1996).

Syrphidae (Diptera)

Syrphidae are dipterans with bee-mimics that can play an important pollinating role but in general are less effective in pollen transmission than bees as their bodies are not covered with branched hairs. Yet, in some crops, e.g. oilseed rape they are can significantly increase pollination rate (Rader et al., 2009). In meadows, they were registered as the most abundant flower-visitor group before *Apis mellifera* and bumblebees (Janovský et al., 2013).

They can be important agents in pest control as larvae of most species living in agricultural landscape are predators of aphids, spider mites (*Tetranychidae*), beetle larvae, small caterpillars etc. (Rod et al., 2005; Šefrová, 2006).

According to Mazánek (2009), there are 701 hoverfly species living in Europe and 401 species occurring in the Czech Republic.

This group can work well as a large-scale ecological indicator such as demonstrated by Ssymank (2002). In his study, Syrphidae mirrored clearly the local landscape status of two distinct areas (500-600 m x 400 m) located 2 km apart, differing in current land use and prevailing vegetation. This is in line with the example of Serbia where national protected areas based on hoverfly occurrence have been established (Vujić, 2016).

Biology and population dynamics

The flight activity extends from early March to November and is species-specific (Stubbs and Falk, 2002). Adult hoverflies are excellent in flight, some species migrate at very long distances (Speight et al., 2010). In the agricultural landscape of temperate Europe, the peak of their occurrence usually happens in June and July (Carreck and Williams, 2002; Haenke et al., 2009; Földesi and Kovács-Hostyánszki, 2014).

Foraging behaviour

Both males and females feed directly on pollen and nectar during the flower visit without creating any food reserves. Male hoverflies ingest significantly more nectar than females and are at the same time more active than females, spending much of their time hovering. Conversely, their need for pollen is much smaller compared to females. Females are of more lethargic nature than males and need to invest energetic reserves for producing eggs. They tend to feed on nectar only at the beginning and at the end of ovarial development. Similarly, their consumption of pollen is at its highest peak at the time of yolk deposition in the eggs (Haslett, 1989). Therefore, pollen ingestion can increase female hoverflies fecundity (Winkler, 2005).

Some hoverfly species are adapted to feed on flowers with deep corolla, other species can only collect nectar on plants with easily accessible nectaries. The length of their mouthparts varies and can reach 8 mm (Stubbs and Falk, 2002). Most of the species typical for agricultural landscape are polylectic and they prefer *Apiaceae* and *Asteraceae* plant species (Lagerlöf et al.,1992).

Pollinator decline and its causes

Decline of wild pollinators

Many studies have reported decrease of insect diversity and abundance in Europe in the past 60 years (Westrich, 1989; Goulson et al., 2005; Biesmeijer et al., 2006; Kosior et al., 2007;). Although total insect species richness and abundance decline (Hallmann et al., 2017), insect groups differ in their response to environmental changes and the declining trend is unlikely to concern all insect groups equally (Biesmeijer et al., 2006).

In Europe, wild bees have been reportedly declined since 1960s (Westrich, 1989), and in North America research has proved that important loss of bumblebee species happened already between 1940s and 1960s (Grixti et al., 2009).

Based on the comparison of records done before and after 1980, the number of bee species decreased in 52% and 67% of British and Dutch monitored territory, respectively, while shifts in hoverfly species richness were less consistent, with no significant change in the UK and an overall increase in the Netherlands (Biesmeijer et al., 2006).

However, in both pollinator groups a smaller number of species became gradually dominant in the pollinator communities. In the UK, the overall number of species decreased equally by 29% for bees and hoverflies, whereas Dutch bee and hoverfly species richness declined by 32% and 36%, respectively. In both bees and hoverflies of the two countries, habitat specialists have gradually become less abundant which is in line with findings for British bumblebees by Goulson et al. (2008). Moreover, oligolectic species of British bees have declined significantly in the UK. At the same time, British plant species depending on insect pollinators and Dutch bee-pollinated plant species have also declined (Biesmeijer et al., 2006). Similarly, a 28% loss of vascular plants in Britain over 40 years was revealed by Thomas et al. (2004).

Decline of honeybees

Besides declines of wild pollinators, even domesticated pollinator species *Apis mellifera* has suffered from various environmental causes in Europe and the United States. The most severe event of colonies extinction has been called Colony Collapse Disorder (CDD) and was reported during the winter and spring of 2006-2007 in the USA when about one third of honeybees in managed hives died (Stokstad, 2007). More specifically, large numbers of workers died in the field, leaving the queen, brood cells and food reserves in the hive. Real causes of CCD are not yet known but might include: chemical contamination either by bee medicines or agrochemicals, pathogens, parasite load, poor nutritional fitness, stress etc. (Kluser and Peduzzi, 2007).

Causes of the decline

In the 20th century, there have been many changes in landscape management and agricultural practices linked to the intensification of agriculture. In Europe, the important consequences of intensification took place mainly after World War II, both in the former Eastern block as well as, Western countries (Macdonald and Johnson, 2000). However, in the United States, some states have experienced these changes already in 1940s (Grixti et al., 2009).

Industrialization of agriculture that started even before World War II but was accelerated subsequently and led to use of mechanized equipment in farming. Complex landscapes suddenly represented an obstacle to effective labour. Thus, economical motivation was the main reason for farmers to destroy landscape elements such as hedgerows, alleys etc. (Macdonald and Johnson, 2000). From 1950s to 1980s, European landscape was simplified considerably, its former complexity that enabled a diversity of animal and plant species to find their habitat there, disappeared.

In pollinators, **habitat loss** is one of the reasons of their decline (Westrich, 1989; Goulson et al., 2008). Landscape elements around farmland included a variety of nesting sites suitable for aculeate Hymenoptera.

Original natural or semi-natural habitats also contained floral resources: flowering shrubs, trees and flowering plants providing pollen and nectar throughout the season (Banaszak, 1992; Mänd et al., 2002). Therefore, their loss meant also a **reduction of floral resources** for pollinators and especially the loss of their continuous character. Nevertheless, food resources became locally scarce also because of other causes. Permanent unimproved grassland was replaced by artificially fertilized monocultures of grasses that were grazed or cut for silage. This shift of the agricultural landscape occurred, decreases in natural plant diversity represented an extremely important loss of floral resources as it concerned very important areas: e.g. in the United Kingdom, over 90% of unimproved lowland grassland was lost between 1932 and 1984 (Howard et al., 2003). Similarly, the use of artificial fertilizers caused the abandonment of legumes in the crop rotation. Such species are preferred by many long-tongued bee species such as some bumblebee species (Goulson et al., 2005). In the Czech Republic, legumes cultivated for forage were reduced by 30% even after 1990 to 4% of arable land last year (CSO, 2018) due to the decline in cattle breeding for economical reasons. Rasmont and Mersch (1998) and Goulson and Darvill (2004) estimate that the abandonment of leguminous crops, notably *Trifolium* spp. may be one of the primary factors causing the decline of long-tongued bumblebee species. In many European countries, oilseedrape is currently one of the most important crops for flower-visiting insects, massively attracting honeybees, bumblebees, other non-*Apis* wild bees, hoverflies and other insect species (Westphal et al.,2003; Rader et al., 2009; Woodcock et al., 2013) and occupying an important proportion of arable land, e.g. 16% in the Czech Republic (CSO, 2018). However, to promote abundance and diversity of flower-visiting insects, a continuous succession of flowers from March to November is required. Moreover, flowering crops grown on a massive scale can do a key service to insects dependent on pollen and nectar (Westphal et al., 2003). Yet, this is not sustained by the current crop rotation, dominated by cereals, at least in most of Europe. After the flowering of oilseed rape, there are only a few flowering crops that are attractive for pollinators. In the Czech Republic, they are mainly: poppy, sunflower and mustard, and these together constitute only 2.5% of arable land (CSO, 2018).

Thirdly, the use of **pesticides** that has been a part of post-war agricultural intensification in Europe, is considered as another major reason for the decline of pollinator populations (Goulson et al., 2008; Godfray et al., 2015). Flower-visiting insects risk their exposure to agrochemicals via (1) direct contact with sprays, (2) contact with contaminated foliage and (3) uptake of chemicals into pollen and nectar (Goulson et al., 2008). Nectar can be contaminated with metabolites of systemic pesticides (Davis and Shuel, 1988). Although EU policy has gradually aimed at reducing pesticides representing an environmental risk and has been favoring target-specific compounds, the long-lasting problem was that all the pesticide environmental safety has been tested only on honeybees and not on other flower-visiting species that might be more sensible to the compounds. Also, there was no obligation to study sublethal effects of pesticides on any bees. However, in 2009, a regulation of the European Parliament and Council that should aim at a new approach to pesticide evaluation including tests on other non-*Apis* bees was adopted (European Commission, 2009). On request of European Commision, in 2013, European Food Safety Authority published a major guidance document on the risk assessment of pesticides in relation to honeybees, bumblebees and solitary bees (EFSA, 2013). Nevertheless, it is still nearly impossible to study the effects of agrochemicals sprayed in mixes that can be of a greater risk than a single pesticide.

Agri-Environment Climate Schemes as mitigators of pollinator decline

In reaction to global wildlife decline, 168 countries signed a Convention on Biological Diversity in 1992. Since then, subsidized programmes whose goal was to mitigate impacts of intensive farming on wildlife have been adopted in the EU. More specifically, in response to the Convention on Biological Diversity, EU adopted a Habitat Directive conservation strategy that introduced subsidized habitat protection in farming practice (Ledoux et al., 2000). In 2001, Action Plan for Biological diversity for 2001-2010, including protection of pollinators, was adopted by the European Commision. In practice, Agri-Environment Schemes (AES), such as sown field margins, were financially supported. The Action Plan was later updated for 2011-2020 as the 2020 *Biodiversity* Strategy, renaming AES as Agri-Environment Climate Schemes (AECS) (EU, 2011). While in some EU-25 countries, sown field margins promoting pollinators were financially supported since 2001 or even earlier. In the Czech Republic, AECS 'nectar-rich flower strips' ('nektarodárné biopásy') were introduced only in 2015. Their area in the Czech Republic rose from 52 hectares in 2015 to 452 hectares, split across 70 farms, in 2017 (Makovský, 2017).

Possible approaches to AECS designed to promote pollinator populations

In most EU states, the AECS aimed at pollinators are conceived as a food supply for flower-visiting insects. Therefore, they are annual or perennial seed mixes rich in pollinator-friendly plant species that are mainly sown in strips around, or in the middle of, fields (Haaland et al., 2011; Wood et al., 2015). They usually contain attractive and economically accessible species such as *Phacelia tanacetifolia*, *Trifolium* spp., *Fagopyrum esculentum* and others (Tschumi et al., 2015; Wood et al., 2015). Only in some member countries, e.g. Belgium, these strips are designed in a way to last up to 10 years or even more and substitute former unimproved meadows what encourages bee nesting in the strips. Similarly, though not identical in all countries involved, the management of the strips ensures continuous flowering such as in Wallonia (Belgium), where the perennial pollinator strips are split into 3 parts with different cutting management (no cut, early cut, late cut) (Natagriwal, 2018). In the Czech Republic, AECS 'nectar-rich flower strips' are designed as a food supply for honeybees and other flower-visiting insects that should be maintained for two or three years on one spot and then reestablished at the same place or at a different site of the farm. Once a year it should be cut any time between July 1 and September 15. No split management is required. Thus, the flowering period is not continuous throughout the season. Although split cut management of the strip has been recommended to Czech farmers since 2014 (Šrámková et al., 2014; Šrámková and Nerad, 2016), additionnal costs of this management discourages farmers from following it. Moreover, the labour that comes 3 years, at latest, after the establishment of the strip is likely to destroy eventual wild bee nests built during the three previous years. Therefore, future optimization of the AECS could increase the ecological benefit for the targeted species.

Impact of AECS promoting pollinators on farmland

There are numerous studies evaluating the attractiveness of flower strips for various flower-visiting insects such as honeybees, bumblebees, 'solitary bees' or hoverflies (Carreck and Williams, 2002; Carvell et al., 2004; Wood et al., 2015). However, surveys focused on their impact on pollinator diversity and abundance at a farm level are still scarce. Wood et al. (2015) monitored for 2 years, 9 farms implementing flower strips on 2% of their area and another 9 farms without flower strips. They discovered that these measures did not have any effect on the diversity of bees and wasps on the farms. While honeybees and bumblebees foraged strongly on the sown flowering species, other non-*Apis* bees preferred wild plant species. This is in line with Westrich (1996) highligting that the protection of bees must always give special attention to all the resources a given species needs. In non-*Apis* bees, which are more specialized foragers and needing various nesting opportunities, the AECS focused on the food supply to pollinators alone cannot meet their objective. The AECS should also provide for simultaneous restoration of habitats offering broad diversity of nesting sites, along with a great diversity of plant species flowering successively from early spring to late autumn.

AIM AND HYPOTHESIS

Aim of the Thesis

The aim of the Thesis is to evaluate benefits of sown flower strips as of a Czech agri-environment climate scheme 'Nectar-rich flower strips' to pollinators in agroecosystems:

(1) Are the selected insect groups and sampling methods together a suitable tool to compare the atractiveness of contrasting habitats within the agricultural landscape (semi-natural habitats, wheat fields) for pollinators?

(2) Can sown flower strips support pollinator populations more effectively, than common habitats of agricultural landscape contrasting in food resources and reproduction opportunities: semi-natural habitats and wheat fields?

(4) To what extent do flower strips attract aculeate Hymenoptera and Syrphidae species occurring on the studied sites? What is the distribution of pollinator species in the habitats?

(5) Does the population of aculeate Hymenoptera in flower strips significantly differ from that of nearby source semi-natural habitats in terms of ecological and morphological traits prevailing among the species?

(6) To what extent does the cutting date in the establishment year impact both on, the development of the sown flower strip (species cover and flower abundance) and, flower visits by honeybees, bumblebees, other wild bees and hoverflies over two years?

Hypothesis

> Sown flower strips as a Czech agri-environment climate scheme 'Nectar-rich flower strips' are an efficient tool to support pollinators in agroecosystems.

SUITABILITY TEST OF ACULEATE HYMENOPTERA AND SYRPHIDAE FOR LOCAL-SCALE BIOMONITORING

Introduction

Recently, local changes in climate or land use have been causing transformations of habitats and therefore, new repartition of species in the landscape (Parmesan et al., 1999; Falcucci et al., 2007). This trend is expected to continue (Bellard et al., 2012).

Several insect groups are commonly used as indicators of ecological conditions to describe recent habitat transformation. They are usually insect orders or families that are numerous and widespread and can be identified with a reasonable effort, e.g. wild bees (Papanikolaou et al., 2017) and butterflies (Parmesan et al., 1999). For the same reasons, hoverflies are also included in many studies (Sommaggio et al., 1999; Billeter et al., 2008). Duelli and Obrist (2003) suggest that biodiversity indicators must be chosen according to the specific goal of a biodiversity study, and its value system. We propose that the degree of philopatry is a key ecological characteristic in biodiversity research as it determines the scale an indicator tells us about. Here, philopatry is considered as a fidelity of an individual to a habitat providing reproduction sites (and also nesting sites in case of nesting animals) as well as food resources. It is a trait that derives from the biology of the species. We suggest that only groups with high degree of philopatry are suitable indicators of local ecological conditions for surveys on a small scale as within this study where tiny portions (approximately 100 m^2) of two different habitats placed only several hundred meters apart were investigated.

In this survey, we focused on two mainly pollinator groups of open agriculture landscape differing in their degree of philopatry within the species pool of our study. Aculeate Hymenoptera are mostly strongly attached to their nest and look for floral resources, or invertebrate prey as close to it as possible (Westrich, 1996). Their flight distance derives from their body size with typical homing distance varying from 100 m to more than 10 km (Greenleaf et al., 2007). However, even in the largest solitary bees, vegetation of only 300 m around the nest is crucial for survival of more than 50% of the population (Zurbuchen et al., 2010). Aculeate Hymenoptera have species-specific habitat preferences and, within the life of an individual, they show a strong site fidelity to a very limited area of only a few hundred square meters around the nest where most of them return daily. In contrast, hoverflies do not have any nest. Sexually mature females lay eggs in an environment conducive to the development of larvae e.g. close to aphid colonies, in mud, etc., depending on ecology of the species (Sommaggio et al., 1999) and do not need to return to that area as they do not feed their offspring. Even though hoverflies are not nesting insects, they also show a habitat fidelity with the range of habitat preferences and general mobility differing among species. There are many mostly spring to mid-summer species requiring specific habitat conditions e.g. alluvial forest or open ground in wetland and moreover, some showing even strong site fidelity (Speight, 2016). These narrow habitat preferences can make them good indicators of local ecological conditions in biodiversity studies (Ssymank, 2002). Nevertheless, most common summer generalist species typically inhabiting open agricultural landscapes, what was actually the pool of our study, are highly mobile and even migrant species (Speight, 2016) that can be found in wide range of habitats within this landscape type (Marshall and West, 2006). Therefore, what may differentiate the philopatric and non-philopatric group within this study is the scale that is referred to as its habitat. While philopatric behavior is here considered as a fidelity to a specific habitat within the open culture landscape (e.g. wheat field, open herbaceous uncultivated semi-natural habitat around fields), non-philopatric behavior is actually a fidelity to the whole open culture landscape comprising a variety of smaller distinct habitats.

The objective of this study was to determine whether both insect groups with low and high degree of philopatry are suitable for indicating inter-habitat differences in ecological conditions within a very restricted territory. More specifically, we test if there exists any difference in aculeate Hymenoptera and mainly common generalist hoverfly species richness obtained by pan trap and transect walk sampling between a rather rich and a non-viable habitat in terms of foraging and nesting opportunities.

We suppose that philopatric species will point to a significant difference between a rich and a non-viable habitat while, based on the occurrence of non-philopatric species, the two contrasting habitat types should appear as identical.

Materials and methods

Study site and design

The experiment was carried out in 2016 at seven localities in the Czech Republic (50.0360, 14.6192; 50.0878, 14.2990; 50.1187, 14.2311; 49.5496, 14.9579; 49.6029, 14.2545; 49.5478, 14.3584; 50.0086, 14.8779) (Fig.2). At each locality, we chose two sites representing two habitat types that contrasted in foraging and nesting opportunities for pollinators: a flower-rich, semi-natural habitat and a winter wheat field as an example of nearly non-viable agricultural habitat typical for Central European landscape. Only strictly weedless wheat fields with no presence of aphids observed were chosen for the study in order to avoid additional food resources for the insect groups studied. The selected semi-natural habitats were non-cultivated areas providing both relatively high species-richness of dicotyledonous plants and a variety of different nesting opportunities. More specifically, they were patches of open uncultivated herbaceous areas around fields with occasional shrubs or trees that are not managed and are left unmown. We selected the closest semi-natural habitat meeting our criteria that was above the minimal distance of 350 m from the sampling area in wheat field - just above the distance of 300 m from the nest that is considered as vital for most individuals within bee populations (Zurbuchen et al., 2010) - in order to minimize any interference between the habitat types within one locality but by maintaining the same general character of the surrounding landscape.

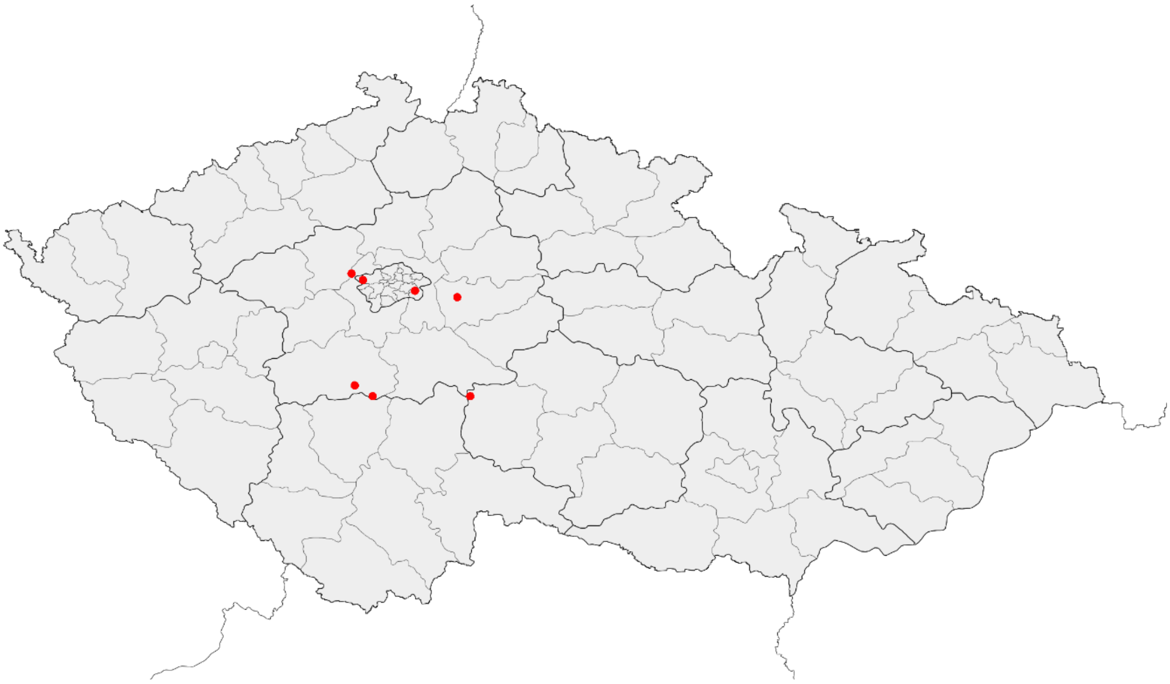


Figure 2. Map of the Czech Republic with seven study localities.

Insect sampling

We analyzed the performance of two commonly used sampling methods: (1) yellow pan traps (2) standardized transect walks. Pan traps are considered as the most efficient sampling method for bees and wasps with the highest species coverage in agricultural and semi-natural habitats and transect walks were determined as the second most powerful sampling method showing complementarity to pan traps in species coverage (Westphal et al., 2008). Yellow pan traps showed to be convenient also for sampling hoverflies (Bowie, 1999; Laubertie et al., 2006). Transect walks are likewise a commonly used method for assessing local species richness of both groups also because of the possibility to detect plant-pollinator interactions (Dicks et al., 2002; Jauker et al., 2009).

The sampling took place at monthly interval three times during the summer from the end of June (mostly milk stage of wheat) to the beginning of September (harvested wheat). At each site, the sampling methods were used on the same days.

In the wheat fields, the corridor where the sampling took place was 90 – 130 m far from any field edge in order to minimize the effect of the surrounding vegetation on sampling. While in the semi-natural habitats, we focused on spots with the highest plant diversity providing most floral resources. The sampling was carried out during suitable weather conditions for studied insects: minimum of 18 °C, low wind, no rain, and dry vegetation.

The standardized transect walks took place in a corridor of 100 m x 1 m. All transect walks were done by one surveyor in order to have uniform collector bias throughout the study. Species that could not be identified in the field were collected with a sweep net for later identification.

At the same corridor where standardized transect walks were done, 8 non UV-bright yellow pan traps were placed 3 m apart, with eventual higher distance in semi-natural habitats where spots with flowering plants were preferred. Pan traps were mounted on a plastic pole and placed at the vegetation level, filled with water and detergent, and left active for 48 hours.

All collected specimens were identified to species except for individuals from *Syrphus* spp. In transect walks, individuals of *Bombus terrestris* and *B. lucorum* were not differentiated. As only about 0.2% specimens sampled were identified as *Bombus lucorum*, all observed individuals from the *Bombus terrestris/lucorum* group during transect walks that were not collected and identified were considered as *Bombus terrestris* for data analysis.

Data analysis

For each site (7 localities, 2 sites on each), numbers of species were counted for four studied groups: Syrphidae from pan traps, Syrphidae from transects, aculeate Hymenoptera from pan traps and aculeate Hymenoptera from transects. These data were analyzed with Redundancy Analysis (RDA) in R software, package "vegan" (Oksanen et al., 2015). Data were standardized by groups so each of four groups has the same weight in the analysis. Type of habitat was used as a predictor for the RDA analysis. Further, differences in species richness between two habitat types were tested by Mann-Whitney U test for each group.

Results

In total, collections from both habitats using both sampling methodologies, 179 and 26 species of aculeate Hymenoptera and Syrphidae, respectively, were identified from 3966 and 2071 specimens detected in this study.

For aculeate Hymenoptera sampled by pan traps and by standardized transect walk significantly higher species richness was found in semi-natural habitats as compared to wheat fields. For Syrphidae this trend existed only in transect walks while samples from pan traps did not show any difference between the habitat types (Table 1).

Table 1. Inter-habitat differences in aculeate Hymenoptera and Syrphidae species richness sampled by pan traps and transect walk in semi-natural habitats (N) and wheat fields (W) on 7 different localities. P values are results of Mann-Whitney U test, significant values are boldfaced (P < 0.05).

Method		Transect walk				Pan traps			
Insect group		Aculeata		Syrphidae		Aculeata		Syrphidae	
Habitat type		N	W	N	W	N	W	N	W
Species richness on sites	1	20	0	4	1	63	16	7	7
	2	4	0	4	1	29	21	10	9
	3	5	0	5	0	28	14	8	10
	4	17	0	4	1	52	19	7	6
	5	7	0	5	1	24	13	10	10
	6	12	0	5	0	44	12	12	9
	7	9	0	6	1	44	14	13	10
P		**0.001058**		**0.001528**		**0.002117**		0.5111	

The most significant differences in species richness among sites were found for aculeate Hymenoptera and then for Syrphidae sampled by standardized transect walks in semi-natural habitats. Significant difference with a little less robust pattern was detected for aculeate Hymenoptera sampled by pan traps in semi-natural habitats while for Syrphidae, this method did not reveal any difference among sites in this habitat type. In wheat fields both entomological methods showed almost no difference in species richness among sites both for aculeate Hymenoptera and Syrphidae (Fig. 3).

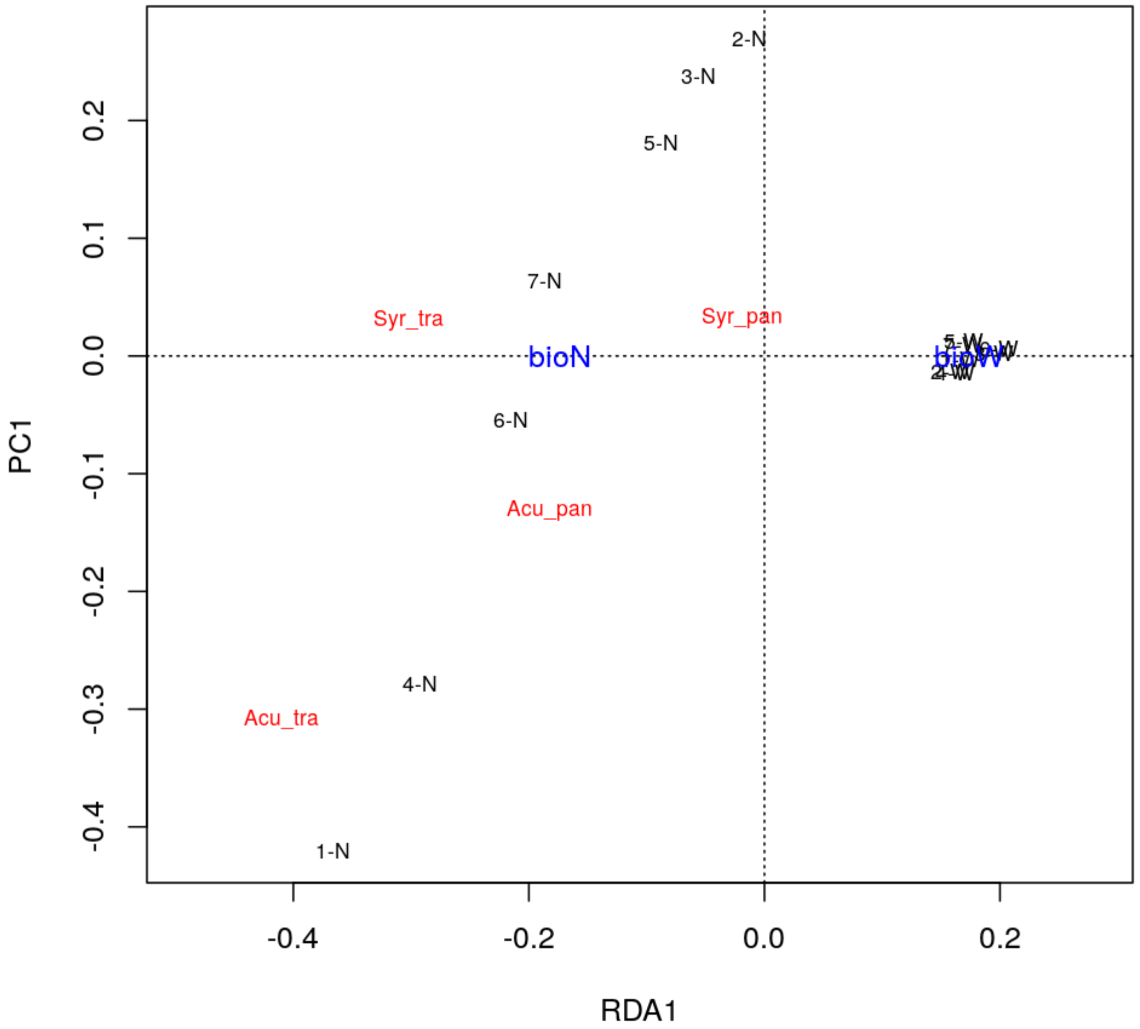


Fig. 3. Effects of habitat type (semi-natural habitat -N, bioN, wheat field -W, bioW) on aculeate Hymenoptera and Syrphidae species richness sampled by pan traps (Acu_pan, Syr_pan) and transect walk (Acu_tra, Syr_tra) on 7 different sites (1, 2, 3, 4, 5, 6, 7). Results of RDA analysis.

According to Speight (2016), the majority of species within the sample of our survey were seasonal migrants and habitat generalists, which are traits of non-philopatric species as we defined them in our study (Table 2). Their proportion was almost equal in the two habitat types. In transects, 100% of detected individuals in both habitat types were non-philopatric. In pan traps, these species represented 65% and 64% of species richness found in semi-natural habitats and wheat fields, respectively.

Table 2. List of hoverfly species per habitat type (semi-natural habitat - N, wheat field - W) and sampling method with the proportion of migratory species and species showing wide habitat range: habitat generalists (Speight 2016).

	Transects		**Pan traps**		**Non-philopatric species**	
Species	**N**	**W**	**N**	**W**	**Migrant**	**Habitat generalist**
Chrysotoxum festivum				x		
Chrysotoxum verralli			x	x		
Didea intermedia			x			
Episyrphus balteatus	x	x	x	x	x	x
Eristalis arbustorum	x		x	x	x	x
Eristalis nemorum	x		x	x	x	x
Eristalis tenax	x		x	x	x	x
Eupeodes corollae	x		x	x	x	x
Eupeodes luniger	x				x	x
Helophilus hybridus				x		
Helophilus pendulus	x		x		x	x
Helophilus trivittatus			x	x	x	
Lapposyrphus laponicus			x		x	
Melanostoma mellinum	x		x	x	x	x
Myathropa florea			x	x		x
Parhelophilus versicolor			x			
Scaeva pyrastri			x	x	x	x
Sphaerophoria scripta	x	x	x	x	x	x
Syrphus spp.			x	x	x	x
Syritta pipiens	x					x
Tropidia scita			x			
Volucella pellucens			x			
Xantogramma pedissequum			x			
Xylota segnis			x			x
Total species richness	10	2	20	14		
Proportion of non-philoparic species	**100%**	**100%**	**65%**	**64%**		

Discussion

Our test of suitability of insect groups for indicating inter-habitat environmental differences on a small scale based on biomonitoring significantly show that philopatric groups are better than non-philopatric groups for this purpose. Of course, we have to consider the effect of methodology and landscape for final generalization of our results. Our study was conducted in open agricultural landscape with relatively low biodiversity. So, we do not generalize on unsuitability of all Syrphidae for habitat characterization, but summer species living in open habitats represent a good model of non-philopatric insects within recorded species pool in our study. There are many biotope specialists and ecological indicators among these dipterans which are rare in agricultural landscape (Speight, 2016), and, as expected, they were scarce in our samples. The comparison of results obtained by two applied sampling methods indicates that non-philopatric mobile groups are unsuitable for local-scale biomonitoring in open agricultural ecosystems.

Transect walk is a method closely related to the vegetation compared to pan traps. Accordingly, differences in species richness between the habitat types were more significant in data obtained in transect walks, and this for both groups. Even though transect walks seem to be suitable for assessing local pool of species because they only detect individuals present in the vegetation [in contrast with pan traps that sample a wider area as shown by Russell et al. (2005) and can attract even individuals that are not related to the surrounding vegetation (Laubertie et al., 2006)], this assumption can be misleading for highly mobile non-philopatric species as their occurrence in the sampling area can be only accidental with no relation to the character of the studied habitat. Conversely, in philopatric groups such as aculeate Hymenoptera, there is high probability of their living in the sampling area if containing both nesting (or reproduction in general) and foraging sites suitable for the species observed. Jauker et al. (2009) and Ekroos et al. (2013) who investigated vegetation in open agricultural landscapes using transect walks revealed that species richness of wild bees declined with decreasing proportion of semi-natural habitats while hoverfly species richness was independent of the quality of agricultural matrix. Moreover, abundance of wild bees increased with proximity to semi-natural habitats whereas hoverflies were represented by even higher numbers with increasing distance to semi-natural habitats, which is actually very similar to our result. The difference is in combination of observational (transects) and color attractant-based (pan traps) methods simultaneously in a single research design. Pan traps placed in non-viable habitat significantly show that non-philopatric species can be attracted at any place in the landscape and the difference in summer generalist hoverfly species numbers sampled by transect walks in wheat field and semi-natural habitat may probably be caused only by presence of attracting flowers in semi-natural habitat.

In contrast, pan traps showing a significant difference in species richness between habitats for aculeate Hymenoptera might be explained by the fact that semi-natural habitats probably contained nests of most aculeate Hymenoptera detected in the study. In contrast, wheat fields comprised no source populations and only species with higher flight distance or eventual migrating individuals might have flown over them while heading to, or returning from, foraging sites. Pan traps proved to be an efficient method to assess local species richness of aculeate Hymenoptera what is consistent with previous studies. Moreover, Hymenoptera and aculeate Hymenoptera sampled by yellow pan traps was shown to be one of the most suitable groups for evaluating site specific biodiversity out of 26 studied groups of Arthropods (Duelli and Obrist, 1998). Our study reveals that they are successful in species richness differences even among spatially very close habitats (350 m apart) which is very likely caused by their philopatric lifestyle. Recently, Carey et al. (2017) also concluded that habitat fidelity is a key factor for Sciomyzidae´s (Diptera) capacity to mark differences in habitat environmental conditions on small scale, contrary to Syrphidae that are more mobile and are therefore more suitable for biomonitoring at a landscape scale. In Ssymank (2002), Syrphidae mirrored clearly the local landscape status of two distinct areas (500-600 m x 400 m) located 2 km apart, differing in current land use and prevailing vegetation. The example of Serbia where national protected areas based on hoverfly occurrence have been established (Vujić, 2016) might suggest, that this group works well as a large-scale ecological indicator. Affinity of a group towards non-philopatric behavior in general can decrease any probability of local disturbances in biomonitoring what might be an advantage for ecological surveys at a landscape scale.

To conclude, the philopatric group within this study represented by aculeate Hymenoptera proved to be convenient for indicating differences in ecological conditions of habitats on a small area, regardless of sampling method used. Also, high species numbers of this particular group seem to be an important factor of its suitability for local-scale biomonitoring. Aculeate Hymenoptera might be a good ecological indicator of local conditions in general as they are excellent predictors of plant diversity (Billeter et al., 2008) which is one of the key characteristics of a habitat. Moreover, they are good at assessing the current state of a habitat because of their capacity to colonize rapidly a site where suitable life conditions have been created (Heneberg et al., 2013), and this even from one year to another (Gathmann et al., 1994).

Conclusion

Philopatric group represented by aculeate Hymenoptera proved to be convenient for indicating differences in ecological conditions of habitats on a small area as it was detected in significantly different species numbers in two selected contrasting habitats using both sampling methods, yellow pan traps and transect walks. Also, high species numbers of this particular group seem to be an important factor of its suitability for local-scale biomonitoring. Aculeate Hymenoptera might be a good ecological indicator of local conditions in general as they are excellent predictors of plant diversity (Billeter et al. 2008) which is one of the key characteristics of a habitat. Moreover, they excel at assessing the current state of a habitat because of their capacity to colonize rapidly a site where suitable life conditions have been created (Heneberg et al. 2013), and this even from one year to another (Gathmann et al. 1994).

In contrast, highly mobile non-philopatric species represented by Syrphidae within this study pointed to differences between habitats only in transect walks and thus, showed a mixed pattern. We assume that these species can be attracted at any place if containing a suitable attractant (flowers or pan traps in this case) what may not indicate their actual living in the habitat. However, their affinity towards non-philopatric behavior suggests that they might be a suitable indicator at a landscape scale.

ATTRACTIVENESS OF SOWN FLOWER STRIPS FOR POLLINATORS AS COMPARED TO THE SURROUNDING HABITATS

Introduction

Flower strips sown on arable land have been financially supported across Europe within the Agri-Environment Schemes (AES), renamed as Agri-Environment Climate Schemes (AECS) since 2011 (EU, 2011), as a reaction to a continuous wild pollinator decline and insufficient floral resources for domesticated honeybee colonies on farmland. A decrease in insect diversity and abundance in the past 60 years have been reported from many studies (Westrich, 1989; Biesmeijer et al., 2006; Kosior et al., 2007; Goulson et al., 2008). An alarming decline of 76% in flying insect biomass has been detected in Germany only in the last 27 years (Hallmann et al., 2017). However, insect groups differ in their response to environmental changes and the population decline trend is unlikely to concern all insect groups equally. Yet, partly divergent trends have been recorded for two important pollinator groups, aculeate Hymenoptera and Syrphidae (Biesmeijer et al., 2006). Nevertheless, based on data before and after 1980, both insect groups have shown decreases of around 30% in the overall species richness that was positively correlated with loss of insect-pollinated plant species, both in the Netherlands and the UK. Moreover, these two communities became gradually dominated by a small number of species. Habitat specialists from both groups have become less abundant which is in line with findings for British bumblebees by Goulson et al. (2005). Also, oligolectic species of bees have declined significantly in the UK (Biesmeijer et al., 2006).

Even though loss of reproduction sites and reduction of food resources are two equally important manipulative factors responsible for the decreasing trends in pollinator populations, many other factors exist (e.g. exposure to agrochemicals and climatic changes) (Westrich, 1996; Goulson et al., 2008). Agri-environment climate schemes for mitigating population declines, such as sowing of flower strips have been focused mainly on providing and improving food supply.

The design of sown flower strips focused on pollinators in EU member countries vary in durability: from annual to perennial strips lasting up to 20 years; plant mix compositions (from simple and cheap „pollen and nectar mixes“ containing several cultivars of very attractive species such as, *Phacelia tanacetifolia*, *Fagopyrum esculentum*, *Sinapis alba*, *Trifolium pratense* to multi-componential and expensive wildflower mixes composed of grasses and native dicotyledons); and, management levels: from un-mown, annual flower strips; to, perennial strips managed by mixed mowing (Haaland et al., 2011; Nowakowski & Pywell, 2016; Le Roi et al., 2010).

Many studies have demonstrated sown flower strips attractiveness for high abundances and relatively high species richness of flower-visiting insects (Carreck & Williams, 2002; Fründ et al. 2010), yet common species seem to profit most from this measure (Pywell et al., 2005; Ouvrard et al., 2018) and their benefit for more threatened species is rare (Scheper et al., 2013). To our knowledge, all surveys operate with taxonomically defined units (i.e. honeybees, bumblebees, hoverflies). However, benefits of flower strips for ecologically distinct categories, i.e. habitat or food specialists have not been tested yet. Similarly, most studies were focused only on occurrence of flower-visiting insects in the flower strips alone, or eventually, compared different types of sown strips among themselves or, to a flowering crop (CIT). Attractiveness of sown flower strips to pollinators as compared to that of surrounding uncultivated areas around farmland attracted less attention until recently (Wood et al., 2015; Gresty et al., 2018).

Therefore, we focused our study, carried out in the Czech Republic, on comparing sown flower strips, wheat fields, and semi-natural habitats, in terms of their attractiveness to pollinators. Our focal groups were (1) **aculeate Hymenoptera** that are pollen collectors and predatory pollinator species and (2) adult hoverflies (**Syrphidae**) that are pollinating insects but larvae of most species of agricultural landscape are aphidophagous predators (Speight, 2016). These insect groups differ highly in their ecological characteristics and thus, in their demands on the design of successful mitigating schemes. Moreover, aculeate hymenopterans within this landscape type comprise many species with distinct morphological and ecological traits (Macek et al., 2017) that could result in their unequal response to different characteristics of the studied habitats, independently of their taxonomic category.

Flower-visiting bees and wasps, in general, are nesting insects whose distribution in the landscape depends on occurrence of nesting habitats meeting needs of the particular species and on patches with sufficient amounts of appropriate floral resources within the foraging radius of most adult females (Westrich, 1996). In contrast, hoverflies do not have any nest and show, in general, a higher mobility in the landscape as compared to aculeate Hymenoptera, especially those living in the open agricultural landscape (Speight, 2016; Talašová et al., 2018).

Flower strips AECS targeted at the support of pollinator populations in the Czech Republic are conceived as rather simple biennial to triennial 'pollen & nectar mixes' that are mowed only once in summer every year (Czech Republic, 2017). As our study was carried out in the year of their establishment, they were unlikely to host any source populations of target insects. In contrast, selected, open, herbaceous semi-natural habitats with a relatively high diversity of dicots and occasional shrubs or trees were supposed to offer both various floral resources and nesting sites. On the other hand, strictly weed-free, intensively managed wheat fields represented a rather non-viable habitat from both perspectives.

In this study, we examined abundance, species richness and composition of communities of aculeate Hymenoptera and Syrphiae in three habitats (sown flower strips, semi-natural habitats and wheat fields). We focused on several questions that could give answers on the benefit of the Czech AECS 'Nectar rich flower strips' for local pollinator communities. To what extent do flower strips attract aculeate Hymenoptera and Syrphidae species occurring on the studied sites? What is the distribution of pollinator species in the habitats? Does the population of aculeate Hymenoptera in flower strips significantly differ from that of nearby source semi-natural habitats in terms of ecological and morphological traits prevailing among the species?

Materials and methods

Study site and design

In the spring of 2016, *flower strips* of a single seed mixture corresponding to the Czech, Agri-Environment Climate Scheme (AECS) 'Nectar-rich flower strips' were sown at 7 localities in the Czech Republic (50.0360, 14.6192; 50.0878, 14.2990; 50.1187, 14.2311; 49.5496, 14.9579; 49.6029, 14.2545; 49.5478, 14.3584; 50.0086, 14.8779). They were established on arable land alongside crop fields. On four localities, the whole flower strip was cut once between July 15 and 31 (n=2) or between August 15 and September 15 (n=2), while on the three remaining localities, half of the flower strip was cut in the first and half the strip in the second mowing period (mixed mowing).

For each sown flower strip, we chose two nearby control sites representing two control habitats common in agricultural landscapes, but offering crucially different reproduction and foraging opportunities for aculeate Hymenoptera and Syrphidae: *semi-natural habitats* (i.e., not regularly mown or managed grasslands with a relatively high richness of dicotyledons); and, *wheat fields* (i.e., intensive crop fields, with highly limited richness of weeds and thus, virtually no feeding or nesting opportunities for the focal insect groups). At each locality, both control habitats were situated over 600 m from the flower strips, and were placed at least 350 m from each other to minimize interference among the studied habitats. Such distances reflect ecology of aculeates: while most solitary bees forage 300 m from their nests, 600 m is considered as the maximum foraging distance for most of them (Gathmann& Tscharntke 2002; Zurbuchen et al. 2010,), or even far beyond their foraging possibilities for smaller bee species (Wright et al. 2015).

Insect sampling

The focal insect groups were sampled three times (approximately monthly intervals) from the peak flowering of strips at the end of June till the end of the flight period for most species of the studied groups, in the beginning of September. The sampling was carried out under suitable weather conditions (min. 18 °C, low wind, no rain, and dry vegetation).

In all studied habitats, the focal insects were collected using yellow pan traps (22 cm in diameter) that are considered as an efficient sampling method for both insect groups (Bowie 1999; Laubertie et al. 2006; Westphal et al. 2008).

In the flower strips, the traps were placed at least 1 m far from their edges, whereas in the wheat fields, they were set 90–130 m far from any field edge in order to minimize the effect of the surrounding vegetation on sampling. In the semi-natural habitats, we always focused on spots with the highest plant diversity providing most floral resources.

In each sampling site, the yellow pan traps were placed 3 m apart, with eventual higher distance in semi-natural habitats. Eight pan traps were exposed in all sampled habitats except the flower strips under mixed mowing with 16 pan traps per site (8 in early mowed part and 8 in late mowed part). Each pan trap was fixed on a plastic pole and placed at the vegetation height, filled with water and a drop of detergent, and left exposed for 48 hours during each sampling term. Consequently, all specimens sampled by each pan trap were stored separately in 70% ethanol for later identification. All collected specimens were identified into species, except for individuals from *Syrphus* spp., which were pooled and treated as a single taxon ('morphospecies') for all consecutive analyses.

During each insect sampling interval, all plant species in-flower within each study site was recorded.

Data analyses

Species richness and abundances

All analyses of relationship of species richness and abundances (i.e. number of recorded individuals) to the habitat type were run separately for three datasets: (1) all aculeate Hymenoptera; (2) wild species only (i.e. all aculeate species except honeybee (*Apis mellifera*) as its local abundance could reflect position of the beehives rather than the real habitat quality); and, (3) Syrphidae.

Differences in species richness and abundances were tested by general linear models (GLM) in R v. 3.3.3 (R Core Team, 2017). Due to the unbalanced number of pan traps among the habitat types, we used average species richness and abundance per pan trap rather than the cumulative numbers per habitat. Because of the skewed distribution of species richness and abundances of all studied groups, log-transformed data were used. Effects of habitat type, sampling term, and locality were compared by ANOVA (F-test).

Composition of insect communities

Differences of species composition among the studied habitats were analyzed separately for aculeate Hymenoptera and hoverflies. Recorded abundances of individual species were pooled for all traps and sampling terms to minimize non-target variability, which could exceed the tested effect of habitat types, especially because of the phenological turnover. This response variable was log-transformed. Based on the length of gradients, constrained unimodal Canonical Correspondence Analyses (CCA) was run to test effect of habitat type as an explanatory variable, with locality set as a covariate and treated as blocks in the permutation design. All CCA models were tested by the Monte Carlo permutation test with 999 permutations (Smilauer and Leps, 2014). In the ordination diagrams, species of both insect groups were distinguished according to their status in the national red lists. Red list categories for aculeate Hymenoptera were searched in Hejda et al. (2017), while for Syrphidae, the latest red list was published by Farkač et al. (2005).

A distance-based linear constrained Redundancy Analysis (RDA) tested a difference of in-flowering plant communities between the flower strips and semi-natural habitats (there were no flowering plants in the studied wheat fields). Presence/absence of individual species, per sampling site, per entire sampling period, were used as response variable, studied habitats were used as a second-level explanatory variable. The Bray-Curtis distance was applied to calculate the sample distances, all axes with positive Eigen values were used for a Principal Coordinate Analysis (PCO). The model was by the Monte Carlo permutation test with 999 permutations (Smilauer and Leps, 2014).

All ordination analyses were run in Canoco 5 (Ter Braak and Smilauer, 2012).

Differences in species' traits of aculeate Hymenoptera

To determine what is was specific for the species pool of aculeate Hymenoptera visiting flower strips compared to their pool occurring in nearby semi-natural habitats, a database of morphological and ecological traits of all species recorded within this study was created. More specifically, based on literature and measurements of specific body characteristics, selected traits and their value were listed. The traits cover the following: habitat preference number of generations per year, feeding strategies in adults and larvae, life histories, body length, fore wing length (Supplements: Table 1). Classification of habitat preference was inspired by Beneš and Konvička (2002). Values for traits were searched in Balthasar (1954), May (1959), Kocourek (1966), Pulawski (1971), Wolf (1971), Tyrner (1980), Westrich (1989), Bitsch & Leclerq (1993), Linsenmaier (1997), Blösch (2000), Bitsch et al. (2007), Bitsch (2010), Wisniowski (2009), Macek et al. (2010).

Only bee species with 3 or more records were used for the following analysis. For each species, normalized Shannon entropy of its distribution in two types of habitats (semi-natural habitat and flower strip) was calculated. Thus, the obtained scores evaluate how informative each species is for inter-habitat differentiation (0 means no signal of inter-habitat differences, 1 means that the species occurs in one habitat only). For species with more records in semi-natural habitat than in flower strip, this score was multiplied by -1. Then, linear regression was used to find which species traits were likely responsible for a particular species' affinity for a particular habitat. The numbers of individuals recorded were used as weights of species in linear regression.

The analysis was done in software R, version 3.3.3 (R core team, 2017).

Results

Effect of habitat type on pollinator populations

In this study, 7272 and 2674 individuals of aculeate Hymenoptera and Syrphidae, respectively, were recorded in seven localities comprising three different habitats each (Supplements: Table 3 and 4). Aculeate Hymenoptera included 1831 records of *Apis mellifera*. Numbers of individuals captured in the different habitats and then determined to species were the following: 4096 and 923 individuals in flower strips; 2138 and 713 in semi-natural habitats; and, 1038 and 1038 in wheat fields, for aculeate Hymenoptera and Syrphidae, respectively.

Effect on species richness

In total, 165 species of aculeate Hymenoptera and 31 species of Syrphidae were recorded (Supplements: Table 3 and 4). Both insect groups significantly varied in their species numbers among localities (Table 3) while this pattern was particularly important in semi-natural habitats, mainly in aculeate Hymenoptera, where it ranged from 24 to 63 species recorded, in total, in one locality, compared to 24 – 46 species in flower strips and 12 – 21 in wheat fields (Supplements: Table 2 and Fig. 10). Correspondingly, only aculeate Hymenoptera showed considerable differences in the number of species among habitats while in Syrphidae, no such difference was detected (Table 3).

When species richness between flower strips and each of the control habitats was compared, a similar pattern for both insect groups was found. Although semi-natural habitats tended to be richer in aculeate Hymenoptera as well as in hoverfly species numbers than flower strips (Supplements: Fig. 10), ANOVA test did not show any significant difference for either insect group (Table 2). However, species richness in wheat fields was significantly lower than that in flower strips with a stronger pattern shown again in aculeate Hymenoptera (***) than in Syrphidae (**) (Table 4).

For both insect groups, the proportion of the species numbers found in flower strips out of the total number of species detected on each locality (comprising flower strip, semi-natural habitat and wheat field) was calculated. In aculeate Hymenoptera, flower strips attracted from 40 to 71% species (median 56%) out of the total pool within one locality. In Syrphidae, this proportion varied from 60 to 91% (median 67%) (data not shown).

In aculeate Hymenoptera as well as in Syrphidae, species richness was decreasing throughout the sampling season from early- to late-summer (Table 3, Supplements: Table 3 and 4).

Effect on abundances

For abundance, we also present the results for the group of aculeate Hymenoptera without *Apis mellifera* (for the reason explained in Data analyses).

A comparison of abundances between flower strips and each of the control habitats showed that both semi-natural habitats and wheat fields hosted a significantly lower abundances of all aculeate Hymenoptera than flower strips (Table 4). After excluding *Apis mellifera* from the analysis, the significant difference appeared only between flower strips and wheat fields.

Abundance in all three groups was dropping towards the end of the sampling season and they differed significantly among localities likewise, in case of species richness (Table 3, Supplements: Table 3 and 4).

Table 3. Effects of three predictors (sampling term, locality and habitat type) on diversities and abundances in aculeate Hymenoptera and Syrphidae in an average pan trap. Results of Analysis of variance.

SPECIES RICHNESS		Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Aculeate Hymenoptera	**Term**	1	43,23	43,23	193,4	<2e-16	***
	Locality	6	44,65	7,44	33,3	<2e-16	***
	Habitat	2	34,88	17,44	78,02	<2e-16	***
	Residuals	526	117,57	0,22			
Syrphidae	**Term**	1	45,24	45,24	219,7	<2e-16	***
	Locality	6	24,89	4,15	20,145	<2e-16	***
	Habitat	2	1,74	0,87	4,217	0,0152	*
	Residuals	526	108,32	0,21			

ABUNDANCE		Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Aculeate Hymenoptera	**Term**	1	225,3	225,34	470,23	<2e-16	***
	Locality	6	127,3	21,21	44,27	<2e-16	***
	Habitat	2	89,5	44,75	93,39	<2e-16	***
	Residuals	526	252,1	0,48			
Aculeate Hymenoptera without *Apis mellifera*	**Term**	1	173,17	173,17	354,77	<2e-16	***
	Locality	6	121,96	20,33	41,64	<2e-16	***
	Habitat	2	55,23	27,61	56,57	<2e-16	***
	Residuals	526	256,76	0,49			
Syrphidae	**Term**	1	176,58	176,58	377,496	<2e-16	***
	Locality	6	78,65	13,11	28,021	<2e-16	***
	Habitat	2	0,91	0,45	0,972	0,379	
	Residuals	526	246,05	0,47			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 4. Differences between species richness and abundances in aculeate Hymenoptera and Syrphidae recorded in flower strips and each of the control habitats: semi-natural habitats (N) and wheat fields (W).

	SPECIES RICHNESS	**Estimate**	**Std. Error**	**t value**	**Pr (>ItI)**	
Aculeate Hymenoptera	**N**	0,049813	0,049657	1,003	0,316247	
	W	-0,52592	0,049657	-10,591	< 2e-16	***
Syrphidae	**N**	-0,07903	0,047664	-1,658	0,09791	.
	W	-0,13728	0,047664	-2,88	0,00414	**
	ABUNDANCE	**Estimate**	**Std. Error**	**t value**	**Pr (>ItI)**	
Aculeate Hymenoptera	**N**	-0,27001	0,072707	-3,714	0,000226	***
	W	-0,97319	0,072707	-13,385	< 2e-16	***
Aculeate Hymenoptera without *A. m.*	**N**	-0,11677	0,073381	-1,591	0,11215	
	W	-0,73884	0,073381	-10,068	< 2e-16	***
Syrphidae	**N**	-0,06392	0,071835	-0,89	0,373986	
	W	0,039051	0,071835	0,544	0,586937	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Composition of insect communities

Composition of communities of both aculeate Hymenoptera species (pseudo-F=1.5, P=0.001, adjusted explained variation 6.2%) and hoverflies (pseudo-F=1.5, P=0.019, adjusted explained variation 7.1%) significantly depended on the studied habitat types. Whilst for aculeate Hymenopterans the flower strips were closer to wheat fields on the first (i.e. main) axis, for hoverflies wheat differed from the two other habitats on the main ordination axis (Fig. 4).

Most aculeate Hymenoptera species from red-list of endangered species of the Czech Republic were associated with natural vegetation and only few species were associated with flower strips, or wheat. However, two species ranked as endangered were associated with wheat and flower strips. Most collected species can be called decreasing species of common landscape (e.g. *Andrena agilissima*, *A. congruens*, *A. curvungula*, *A. labialis*, *Osmia parietina*, *Polistes biglumis*), but also wetland species has been recorded (*Hylaeus moricei*). The three most interesting species *Osmia parietina*, *A. semilaevis* and *T. minuta* are rather continental and/or cold tolerant species.

In Syrphidae, two red list species were found in wheat fields and two were found in semi-natural habitats. *Parhelophilus frutetorum*, *Anasimyia lineata* which where found in wheat fields and *Parhelophilus versicolor* recorded in semi-natural habitats are rather hygrophilous species, while *Didea intermedia* detected in semi-natural habitats is a xerothermophilous forest species.

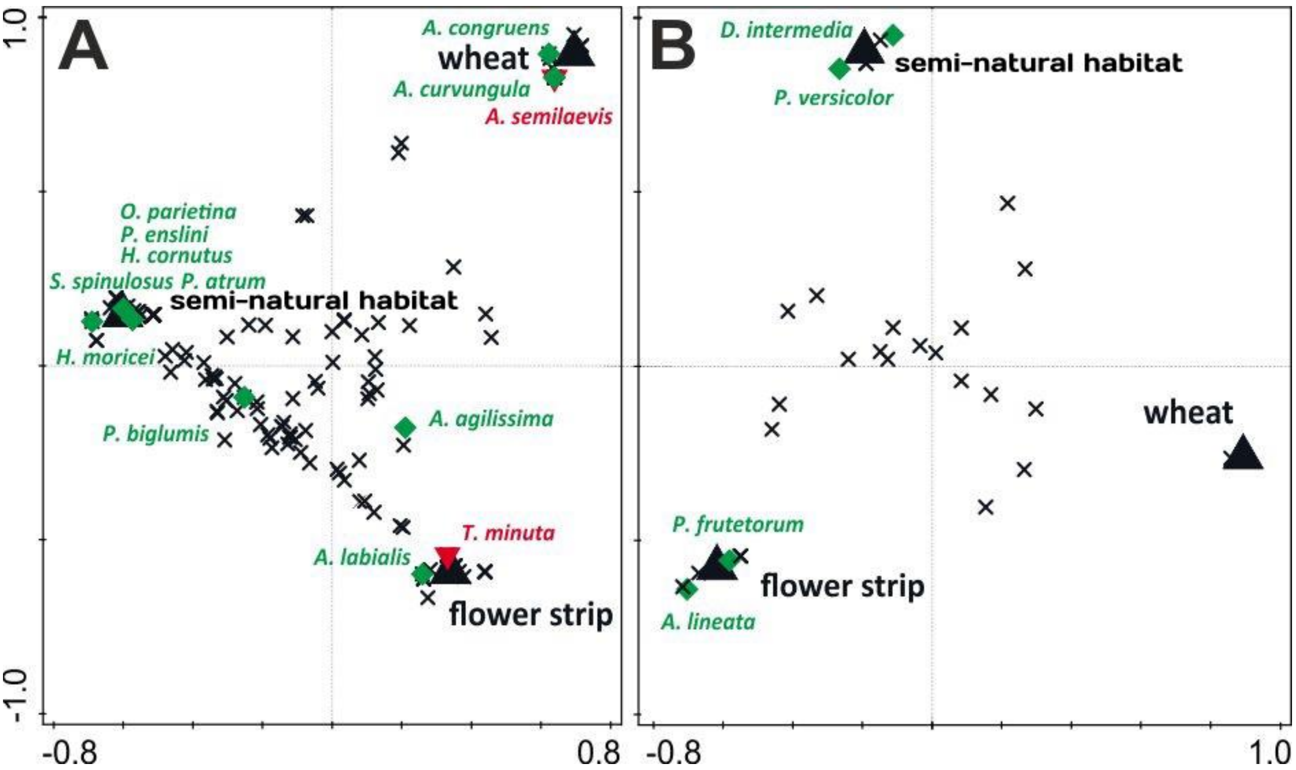


Fig.4. CCA ordination diagrams visualizing affiliations of (A) aculeate Hymenopterans and (B) hoverflies to the studied habitats. The symbols distinguish red-listed species (red triangles for endangered species and green squares for vulnerable species, together with abbreviations of their names), and non-endangered (black crosses) species. The full names of individual red-listed species are in Supplements: Table 3 and 4.

Differences in species' traits

Based on the analysis of morphological and ecological traits in aculeate Hymenoptera, there were significantly more adult food specialists in the nearby semi-natural habitats compared to flower strips. Secondly, the pool of individuals in the semi-natural habitats contained more forest xerothermophilous individuals (species living in xerophilous forests) than that in flower strips (Table 5).

Table 5. Differences in traits of aculeate Hymenoptera between the pool in flower strips and the pool in nearby semi-natural-habitats. All tested traits and their value in the semi-natural habitats compared to flower strips are listed.

	Estimate	Std. Error	t value	Pr (>ItI)	
Intercept	0,264948	0,368668	0,719	0,4753	
Mesophilous 1	0,045178	0,070178	0,644	0,5223	
Mesophilous 2	-0,059898	0,059280	-1,010	0,3166	
Mesophilous 3	-0,167342	0,166305	-1,006	0,3186	
Xerothermophilous 1	-0,027596	0,141749	-0,195	0,8463	
Xerothermophilous 2	-0,219646	0,143408	-1,532	0,1312	
Xerothermophilous 3	**-0,210212**	**0,089325**	**-2,353**	**0,0221**	*
Hygrophilous 1	-0,777068	0,419078	-1,854	0,0689	.
Hygrophilous 2	0,892161	0,448615	1,989	0,0515	.
Hygrothermophilous	0,289773	0,274455	1,056	0,2955	
Number of generations per year	0,036945	0,059307	0,623	0,5358	
Adult_specialist	**-0,459039**	**0,182684**	**-2,513**	**0,0148**	*
Larva_herbivore	0,069413	0,147576	0,470	0,6399	
Larva__parasitoid	-0,109863	0,220047	-0,499	0,6195	
Larva__specialist	0,088769	0,098037	0,905	0,3690	
Mass provisionner	-0,215280	0,234986	-0,916	0,3635	
Body length	0,001601	0,036552	0,044	0,9652	
Fore wing length	-0,021037	0,040425	-0,520	0,6048	
Degree of sociality	0,043936	0,029377	1,496	0,1403	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Composition of plant communities

The semi-natural habitats and flower strips also significantly differed in composition of in-flower plant communities (pseudo-F=8.6, P=0.001, adjusted explained variability 36.9%). In total, 67 dicotyledonous flowering plant species belonging to 24 families were registered in semi-natural habitats and the number of species per locality varied from 13 to 28

(Supplements: Table 5). Species belonging to Asteraceae and Fabaceae families prevailed in this habitat type and represented 27% and 19 % species, respectively. Each of the other families was represented by 7% or less and of twelve families by only one plant species. In flower strips, ten sown and eleven naturally occurring species were found and the number of species detected on one locality varied from three to 14 species. Species recorded in this habitat type belonged to ten families, while five of them were almost entirely represented by sown species. Fabaceae species were the most numerous and represented 60% of all species detected in this temporary habitat. Five out of six recorded Fabaceae species were cultivars sown with the mixture for the AECS. *Trifolium hybridum* and *T. pratense* were found flowering on most localities. Two other sown cultivars, *Phacelia tanacetifolia* (Boraginaceae) and *Fagopyrum esculentum* (Polygonaceae) were recorded on seven and on six out of seven localities, respectively. From the naturally occurring species, *Tripleurospermum inodorum* (Asteraceae) was detected on most localities.

Discussion

Our data pointed to significant differences in plant communities among habitats that were strongly reflected mainly by aculeate Hymenoptera with philopatric traits and a considerably lower mobility as compared to hoverflies occurring in open agricultural landscape (Talašová et al., 2018). Surprisingly, significant differences in both species richness and abundances of wild bees and wasps were found only between flower strips and wheat fields. Also, hoverflies species numbers differed only between these same two contrasting cultural habitats. In contrast to aculeates, their abundance did not differ among habitat types.

The fact that no significant difference in species richness was found between sown flower strips and semi-natural habitats and such difference existed only between flower strips and wheat fields (in ANOVA comparing flower strips to each of the control habitats) indicates that flower strips attract most species from the source populations living in semi-natural habitats. The proportion of species that the temporary flower-rich habitat attracted form its surroundings was surprisingly high (varying from 40 to 71% in aculeate Hymenoptera and from 60 to 91% in Syrphidae), if we consider that the plant species richness in flower strips was up to seven times smaller as compared to the semi-natural habitat on the same locality. However, previous studies revealed that species numbers of these insect groups occurring in flower strips were more associated with flower abundance than their diversity (Sutherland et al., 2001; Carvell et al., 2004). Also, similar abundances of wild, aculeate Hymenopteran were recorded in flower strips and semi-natural habitats within one locality. This demonstrates that most individuals from the source habitats were attracted by the flower strips.

However, our results also showed that flower strips excluded aculeate Hymenopteran food specialists to a significantly important degree as compared to semi-natural habitats. This finding may imply that floral resources in flower strips do not correspond to the foraging needs of aculeate Hymenopterans with narrow food preferences. Although these species show the greatest decreasing trends (Biesmeijer et al., 2006) and thus, would need to by taken into account by mitigating schemes. Even though there is no other study showing this based on an analysis of ecological traits of the recorded pool of wild bees and wasps, similar conclusions for so called solitary bees as a whole were published by Wood et al. (2017) and Gresty et al. (2018). Our analysis comparing the pool of aculeate Hymenoptera in flower strip to that in the nearby semi-natural habitat also reflected a poorer vegetation structure of the temporary habitat as xerophilous forest species occurred in more important numbers in the herbaceous, uncultivated habitats around the fields containing occasional shrubs or trees.

Indeed, plant communities in the studied habitat types differed significantly as the habitat type explained 36.9% of their variability. High diversity of floral resources in semi-natural habitats within this study, both in terms of the number of plant species and botanical families recorded (implicating various characteristics of flower structure), and a heterogeneity of its vegetation comprising many microhabitats with different properties and thus, a wide range of nesting opportunities for bees and wasps, can be considered as two main traits of this habitat type, which distinguish it from sown flower strips. Moreover, semi-natural habitats showed a considerable inter-site heterogeneity that was reflected by a high variability in species richness across localities for both insect groups. Naturally evolving mutualistic relationship between dicotyledonous plant species in these uncultivated habitats and their pollinators creates a balance between plant and pollinator communities where foraging needs are sustained by a continuity of food supply.

In contrast, flower strips in case of the Czech AECS are conceived as a temporary food supply for flower-visiting insects (they are ploughed after 2 or 3 years) providing discontinuous high abundance of a limited species diversity of flowers, mainly during summer. Moreover, as the composition of the seed mix is uniform for the whole territory of the Czech Republic, their vegetation was also more or less identical across different localities. Such design of an AESC can potentially sustain or boost the populations of generalist bees and wasps in terms of their abundance, rather than enhance overall species richness of pollinators. Moreover, as the food supply that they provide is massive and short-term, they can even represent a threat to the target insect groups (Nowakowski & Pywell, 2016).

To improve the efficacy of flower strips to enhance pollinator diversity on farmland, it could be useful to follow the properties of semi-natural habitats. To prevent flower strips AECS from being an ecological trap, it is necessary to ensure their continuous flowering throughout the season. As it is hardly possible to sustain this by a single flowering mixture, Nowakowski and Pywell (2016) suggest sowing at least two mixes showing complementarity in flowering: one mix flowering in spring and one in mid- to late-summer. The same effect can by delivered by perennial flowering mixes maintained by mixed mowing (Ouvrard, 2018). The choice of flowering plant species should derive from the foraging preferences of the target insect groups. However, this approach seems to be of a limited success as sown species cannot reflect foraging needs of the local pollinator community as completely as semi-natural habitats, especially in case of solitary bees (Gresty et al., 2018) or wild bee food specialists, which is shown by our study. Moreover, foraging behavior is also influenced by the structure of the vegetation, such as its height (Klečka et al., 2018), that is more heterogeneous in semi-natural habitats. Nevertheless, all initiatives focused on mitigating pollinator losses must pay attention not only to provide food supply but also to conserve or restore reproduction habitats. Even in flower strips AECS that are conceived mainly as food resources, it is supposed that species nesting in soil or in tussocky grass (in case of wildflower strips containing tussocky grass species), i.e. some bumblebee or wild bee species would build their nest there. Therefore, the design or management of the AECS should avoid possible destruction of the nests. This could be ensured by (1) prolonging the life of the flower strip to the most possible extent by sowing a perennial mixture suitable for the very site such as native wildflower mixes, which can last up to 20 years and by (2) cultivating the soil only up to 12 cm deep, if necessary. Leaving bare ground at the field corners may enhance nesting of mining solitary bees (Nowakowski & Pywell, 2016). What seems to be crucial for supporting populations of wild bees in agricultural landscape is to establish flower strips on sites within the foraging range of most individuals from the nesting habitats (Westrich, 1996) that are likely to occur mostly in semi-natural habitats around farmland (Jauker et al., 2009; Ekroos et al., 2013). The distance must respect the foraging distance of most individuals within solitary bee populations and thus, should be shorter than 300 m (Zurbuchen et al., 2010; Nowakowski & Pywell, 2016). In non-nesting insect groups such as in hoverflies, the position of flower strip may be of a lesser importance, especially, in most species living in open agricultural landscape as they are more mobile and less dependent on a particular habitat within the agricultural matrix (Jauker et al., 2009; Ekroos et al., 2013; Talašová et al., 2018).

Even though attracting high abundances of pollinators is not the main conservation focus of mitigating schemes such as flower strips, this quality represents an undoubted benefit to managed honeybee colonies. A significantly higher abundance of aculeate Hymenoptera comprising *Apis mellifera* (coming mostly from managed hives in the Czech Republic) in flower strips as compared to semi-natural habitats shown by our data indicates that this measure can be locally of high importance for beekeepers as it increases the supply of good pollen and nectar to the colonies in summer that is poor in floral resources, mainly in agricultural lowlands with low proportion of semi-natural habitats. However, high abundances of honeybees in flowering patches can suppress foraging of other pollinators (Herbertsson et al., 2016) and thus, decrease the conservation effect of the AECS. This implies that massive flowering of plant species that are attractive for honeybees may be in conflict with conservation targets of this measure. Therefore, defining the focus of an AECS seems to be a necessary prerequisite of its success. If its purpose is to enhance pollinator diversity, the design of flower strips should adjust their structure in a way to reduce their attractiveness to honeybees alongside other generalists and simultaneously increase their benefit to smaller and more specialized bee species. On the other hand, our study demonstrated that flower strips cannot compete with uncultivated areas around farmland in terms of their attractiveness to more specialized pollinators. As shown by Gresty et al. (2018), even rich native wildflower strips, exceeding several times the number of plant species in simple 'pollen & nectar' flower mixes as in the Czech AECS, are overlooked by specialized wild bee species as compared to nearby semi-natural habitats.

To conclude, our study demonstrated that flower strips are a good tool to boost populations of pollinator generalists on farmland what is in line with studies revealing that these flowering patches are mostly visited by common species (Pywell et al., 2005). But to enhance species richness of wild bees including the most threatened food specialists (Biesmeijer et al., 2006), promoting conservation and restoration of semi-natural habitats is more likely to be an effective approach.

Conclusion

Our data showed that Czech AECS 'nectar-rich flower strips' supports species richness of aculeate Hymenoptera and Syrphidae as their species numbers did not differ between flower strips and nearby semi-natural habitats where source populations live most likely, especially in case of aculeate Hymenoptera. In both pollinator groups, flower strips attracted most species living at the studied sites. However, based on analysis of aculeate Hymenopteran pool in semi-natural habitats as compared to that in flower strips, bee food specialists were found in significantly higher numbers in semi-natural habitats, showing significantly higher plant species diversity and including a variety of potential nesting sites. Sown flower strips attracted significantly higher abundances of all aculeate Hymenoptera comprising *Apis mellifera*, coming mostly from managed beehives, as compared to the control habitats. Although this can be locally important for beekeepers, it may be in conflict with conservation focus of the AECS as honeybees tend to suppress foraging of other bee pollinators in flowering patches (Herbertsson et al., 2010).

To conclude, Czech AECS 'nectar-rich flower strips' is a good tool to boost populations of pollinator generalists on farmland what is in line with studies revealing that sown flower strips are mostly visited by common species (Pywell et al., 2005). However, to enhance species richness of wild bees including the most threatened food specialists (Biesmeijer et al., 2006), promoting conservation and restoration of semi-natural habitats is more likely to be an effective approach.

THE EFFECT OF CUTTING MANAGEMENT OF SOWN FLOWER STRIPS ON THEIR BOTANICAL DEVELOPMENT AND POLLINATOR VISITATION RATE

Introduction

Sown flower strips have been financially supported within agri-environment schemes (AES), recently called agri-environment climate schemes (AECS) across Europe to enhance landscape diversity mainly in intensively farmed lowlands. The aim of this measure has been the support of various components of wildlife with a particular emphasis on pollinators (Haaland et al., 2011) which ensure reproduction of 90% of wild flowering plant species (Buchmann and Nabhan, 1996) and 40% of global crop production (Klein et al., 2007). Among groups of pollinating insects, bees (Hymenoptera: Apiformes) are considered as the most effective (Wilmer, 2011) and hoverflies (Diptera: Syrphidae) are likewise important pollinators of particular crops (Klein et al., 2007) as well as of wild plants (Janovský et al., 2013). Both pollinator groups have suffered from a great decline in Europe in the last decades: their species numbers have dropped by around 30% compared to pre-1980 levels with drops in food specialists being the most concerning (Biesmeijer et al., 2006). Habitat loss and reduction of floral resources are considered as major reasons of their decline (Westrich, 1989; Goulson et al., 2008). Sown flower strips represent a supply of floral resources and eventually also of nesting or reproduction sites that are scarce in many portions of European lowlands as a consequence of agricultural intensification. In Europe, different approaches exist in design and management of sown flower strips (AECS), varying from annual strips sown with flowering crops to perennial flower strips similar to enriched permanent grasslands (Haaland et al., 2011). In flower strips that are grown for more than one year, their management is essential for their subsequent development. Alongside several factors affecting the success of the establishment, e.g. sowing date or precipitations, cutting date is key for the proportion of different sown species in the flower strip and is usually the only means of an effective weed control (Westbury et al., 2008). Therefore, the cutting date in the establishment year could determine, to an important extent, presence of food resources later in the season for its target species, flower-visiting insects. Nevertheless, there are possibly other factors impacting the cover of different plant species and pollinator visitation rate of the flower strip that are at least as important as the establishment and mowing practices, e.g. conditions of the locality comprising soil and climatic conditions, local pollinator pool and availability of other competitive floral resources. Many surveys have already been done that focused on the relationships between plant species cover or flower abundance and the occurrence of insect flower visitors (Feber et al., 1996; Carvell et al., 2007; Ouvrard et al., 2018) and, some studies on the effect of management on the botanical composition as well (De Cauwer et al., 2007; Uyttenbroeck, 2017a). However, to our knowledge, the link between management of flower strips and the resulting benefit for target species has not been investigated, so far.

Within the conditions of the Czech AECS ´Nectar-rich flower strips´ specified by the Ministry of Agriculture of the Czech Republic, a single cutting with subsequent removal of excess biomass is required during the summer between July 1 and September 15. However, it is not known what the effects are of different cutting dates within this range (especially on the extremities of the range) even though the timing can be crucial for the shape of the flower strip and affect it, either in a positive or a negative, way. Therefore, a recommendation on the optimal cutting date of biennial to perennial sown flower strips is needed for effective weed control and promoting pollinator visits.

The aim of our study is to determine to what extent the cutting date in the establishment year impacts both on, the development of the flower strip (species cover and flower abundance) and, flower visits by honeybees, bumblebees, other wild bees and hoverflies over two years.

Materials and methods

Study sites and design

In the spring of 2016, flower strips corresponding to the Czech, Agri-Environment Climate Scheme (AECS) ´Nectar-rich flower strips´ were established at 7 sites in the Czech Republic. Their description is shown in Table 6. A single seeding mixture was sown at all sites (Table 7). Flower strips were cut in summer following two different approaches that are both permissible within the conditions of the AECS. These commit farmers to cut the strips once in summer from July 1st to September 15 which implies either: (i) early summer cut (July) following the main flowering period of the flower strip, serving as a weed control practice and enhancing reflowering of the flower strip within 4 to 6 weeks due to leguminous species in the period when pollinators are still active; or, (ii) late summer cut allowing the flower strip bloom sparsely until it becomes dry. In our design, the following management was adopted: (1) 2 strips were cut at the end of the main flowering between July 15 and July 31; (2) 2 strips were cut after the end of the flowering between August 15 and September 15; and (3) in 3 flower strips, half the strip was cut in the first term and half the strip in the second term following mosaic cut design where each cut term was done in two quarters placed diagonally. In the strips of option 3, two quarters managed uniformly were considered as a single strip for the monitoring. As a result, 5 flower strips in total were cut early and 5 strips were cut late in the establishment year. In 2017, all of the flower strips were mown at once.

Botanical monitoring

Counting of open flowers in the strips has been realized in three summer periods each year. Timing of the count was adapted to the developmental stage of the individual flower strip which differed slightly among localities. In 2016, the first monitoring was done at the flowering peak of the flower strips at the end of June, the second period took place in mid-summer (end of July/beginning of August) when half of the strips had already been mowed, and the last evaluation was done in late summer (end of August/beginning of September) when flower strips cut early had already been regenerated. In 2017, the first two sampling sessions took place at a two-week interval from the end of May to June when all flower strips were at their peak bloom and the last monitoring was done in mid-August.

The visual estimation of plant species cover was done together with flower counting only in the first and the last period each year. Both assessment methods were applied in four, 1x1m quadrats placed approximately, 20 m apart, representing the character of the vegetation in each locality. In flower strips with the split cutting management, four quadrats were monitored within each treatment. Percentage cover of all plant species and bare ground was recorded with total cover equal to 100%. Open flowers of all plant species per 1 m^2 were counted in the same quadrats as the cover estimation. For *Trifolium* and *Apiaceae* species, average number of flowers per inflorescence based on 10 inflorescences was counted and then multiplied by the total number of inflorescences per each quadrat.

Entomological monitoring

Standardized transects for the monitoring of pollinators were done in the same periods as flower counting, three times each year. They took place in a corridor of 100 m x 1 m and only individuals belonging to hoverflies (Diptera: Syrphidae) and bees (Hymenoptera: Apiformes) in contact with flowers were registered together with the plant species visited. In bees, three categories were distinguished: honeybees (*Apis mellifera*), bumblebees (*Bombus* spp.) and solitary bees that included all non-Apis bees except bumblebees. This group is called 'wild bees' in this article. For hoverflies and bees, transect walk is a commonly used method because of the possibility to detect plant-pollinator interactions (Dicks et al., 2002; Jauker et al., 2009). All transect walks were done by one surveyor in order to have uniform collector bias throughout the study.

Statistical analyses

For analysis of plant species cover, sown species were considered as one functional group and weed species were divided into two groups depending on their attractiveness for pollinators during the experiment: pollinator-friendly weeds and, other weeds. A three-way repeated measurement analysis of variance (ANOVA) was used to investigate differences in cover and number of flowers of plant functional groups, as well as, visitation rate of insect groups between sampling period (time), locality, cutting management, and interaction between management and time. The effect of locality was treated as a random factor and time, together with cutting management, were considered as fixed factors. Significant differences between means were reported using the Tukey HSD test at $\alpha = 0.05$. All these analyses were carried out using the STATISTICA software (StatSoft, 2012).

Effect of locality, time and cutting management on plant species cover was analysed by redundancy analysis (RDA). Due to significant interactions of management and time, effect of management x time interaction on the species coverage, number of flowers, occurrence of insect visitors on particular plant species were further tested by RDA. The option of centre and standardization by dependent variables was used. The statistical significance of the first and of all the other constrained canonical axes was determined by the Monte Carlo permutation test (499 permutations). All ordination analyses were performed in the CANOCO 4.5 software (ter Braak and Šmilauer, 2002). The ordination biplots of RDA were created in CanoDraw (Microcomputer Power, Ithaca, NY).

Results

Effect of the cutting management in the establishment year on the cover and flowering of plant species

The effect of both locality and time on the proportion of plant categories (sown species, pollinator-friendly weeds and other weeds) and bare ground was significant for all variables except the category of other weeds where only the effect of locality was significant (Table 8). Significant interactions with time for bare ground, sown species and pollinator-friendly weeds are presented in Figure 5. Late cutting management option significantly reduced total plant cover in the final sampling interval of 2016. More importantly, in flower strips under early cutting management in the year of sowing, there was a visible trend for higher sown species and lower pollinator-friendly weeds proportion in the following year.

Regarding number of flowers, a significant effect of locality and time was observed (Table 9). The effect of cutting management on the intensity of flowering was significant only for pollinator-friendly weeds in interaction with time. In this plant category, a higher number of flowers in flower strips cut in late summer compared to those cut early in summer was detected in the mid-summer sampling of 2016 (figure not shown).

Locality, time and management explained 57% of plant species cover. We used management x time interaction as an explanatory variable in following RDA analyses while the effect of locality was excluded as a covariate (Table 10). Management x time interaction explained the variability of species cover being twice as high as compared to the number of flowers.

Development of particular plant species cover is presented in Figure 6. Horizontal axis clearly separates annual species in first date of sampling (right) from perennial species in the following year 2017 (left). Among sown species, PhaTan (for abbreviations of plant species, see Table 7) and SinAlb were dominant in all monitored squares in the first date of sampling. In contrast, MalSyl was the rarest of all sown species and AchMil was not recorded at all (even later in the seeding year). The group of pollinator-friendly weeds was mostly represented by CheAlb whereas *Thlaspi arvense* was the most common within the other weeds group. In terms of the intensity of flowering (data not shown), the highest number of flowers was recorded in FagEsc and PhaTan in the first date of sampling in 2016 (228 and 513 on average per square meter). Nevertheless, SinAlb also bloomed intensely in some localities in this period.

After cutting, annual species almost disappeared on all localities with the exception of Kněževes and Ruzyně where weed species CheAlb expanded again in late summer of 2016 (monitoring term 3/16). Among legumes, only TriPra cover increased then at some sites. The flowering of sown species was generally low after cutting and even no flowers were recorded in some localities. Pollinator-friendly weeds also provided few flowers except CheAlb, which intensively bloomed in Kněževes and Ruzyně. In general, plant cover was reduced in late summer of the seeding year, however, this effect was more visible in the flower strips under late cutting management. Corresponding values of bare ground cover are shown in Figure 5 and vertical axis in Figure 6 also illustrate this effect. Across years, the proportion of the bare ground significantly ranged among localities from 1% in Kněževes to 15% in Krásná Hora.

In the spring of 2017, the strips regenerated well and the proportion of bare ground decreased to 6% as it was during the first sampling of 2016. TriPra became a dominant sown species at most sites and its cover was supported by early cutting management (see left side of Figure 6). More specifically, in flower strips under the early cutting management, cover of TriPra reached 28%, on average, as compared to the strips under late cutting management with 21% of its cover (data not shown).

Regarding flowering of sown species in the first sampling of 2017, the highest number of flowers was recorded in CarCar (960), PhaTan (100), TriPra (540), and TriHyb (160 flowers per square meter). Later, leguminous species TriPra and TriHyb became the main flowering species yet MelAlb was also important in some localities. TriPra had the flowering peak in the last term of 2017 when this species reached on average nearly 1,000 flowers per square meter in contrast to other species, which were generally poor in blooming (data not shown).

Effect of the cutting management on the pollinator visitation rate in relation to plant flowering

In total, 1326 and 3672 individuals of hoverflies and bees, respectively, were recorded during transect walks on various plant species in the flower strips.

A significant difference in total pollinator visitation rate between the flower strips cut early and late in the seeding year was found only for the group of flowering dicotyledonous plants that spontaneously appeared in the flower strip ('pollinator-friendly weeds'), not for sown species (Table 11). In the establishment year, both wild bees and hoverflies pointed to a difference in the attractiveness of the flower strips cut early and late, in relation to the mid-summer flowering of 'pollinator-friendly weeds' in strips that were left unmown until then. However, in the following year, bees indicated only small differences in the attractiveness of the two cutting management options. Moreover, RDA based on the occurrence of hoverflies that year was non-significant as they were almost absent in the flower strips regardless of the cutting management (only 12 records in total in 2017 compared to 1314 records in 2016; data not shown).

Over two years, management x time interaction explained 33 and 46% of occurrence variability for bees and hoverflies on particular plant species, respectively. These relationships are illustrated by ordination biplots for bees (Figure 7) and hoverflies (Figure 8) separately, where chronology of interactions between pollinators and plant species in the two types of management can be seen.

In the first sampling period that occurred before cutting in the early summer of the seeding year, all bees and hoverflies were found mainly on PhaTan (Fig. 7, Fig. 8) and, additionally, honeybees were also numerous on SinAlb and FagEsc while bumblebees preferred VicSat (Fig. 7). In the second monitoring period in mid-summer when half of the flower strips had already been mown, visitation rate of both pollinator groups differed considerably in the two types of management of the strips (Fig. 7 and 8). In hoverflies, this contrast was more important. Flowering weeds were responsible for the difference in visitation rate during this period as they were significantly more visited by wild bees and hoverflies in the flower strips that were left unmown until then (Table 11). More specifically, CheAlb attracted both hoverflies and wild bees and the latter group also visited TriIno. In late summer when strips that were cut early had already been regenerated, almost no difference in insect visitation of the strips was found (Fig. 7 and 8).

In the spring/early summer sampling period of the following year, there was no real difference in the visitation rate of bees between the two cutting management types. Bees in general were numerous on TriPra. The same trend was also recorded in next sampling period when other *Trifolium* species attracted bees in addition to TriPra. Later in summer, all bees were present mainly on TriPra which was shown to be more dominant in flower strips cut early in the previous year. Honeybees also preferred MelAlb.

Table 6. List of experimental sites and their characteristics.

Locality	GPS	Altitude (m)	Region		Soil type	Cutting management
			Temperature (°C)	Precipitation (mm)		
Kněževes	50.118752, 14.231156	348	8-9	500-600	Luvisol	E*, L**
Lukavec	49.555119, 14.979040	627	5-6	700-800	Cambisol	E
Krásná Hora nad Vltavou	49.602991, 14.254553	391	7-8	550-700	Cambisol	E
Petrovice	49.547837, 14.358497	499	7-8	550-700	Cambisol	L
Ruzyně	50.087857, 14.299001	357	8-9	500-600	Luvisol	E, L
Svatbín	50.008692, 14.877918	348	7-9	550-700	Cambisol	L
Zelená Ves	49.549666, 14.957945	578	5-6	700-800	Cambisol	E, L

*E (early cut) = strips were cut at the end of the main flowering between July 15 and July 31 2016, **L (late cut) = strips were cut after the end of the flowering between August 15 and September 15, 2017

Table 7. Plant functional groups with plant species included. The group of sown species corresponds to the uniform seed mixture sown on all sites.

Functional group	**Species (abbreviation; weight to weight % in seed mixture)**
Sown species	*Achillea millefolium* (AchMil; 0.04%), *Carum carvi* (CarCar; 10.60%), *Fagopyrum esculentum* (FagEsc; 10.60%), *Lotus corniculatus* (LotCor; 0.80%), *Malva sylvestris* (MalSyl; 0.20%), *Melilotus albus* (MelAlb; 4.20%), *Onobrychis viciifolia* (OnoVic; 21.20%), *Phacelia tanacetifolia* (PhaTan; 4.20%), *Sinapis alba* (SinAlb; 6.40%), *Trifolium pratense* (TriPra; 17.00%), *T. hybridum* (TriHyb; 1.70%), *T. repens* (TriRep; 1.70%), *Vicia sativa* (VicSat; 21.20%)
Pollinator-friendly weeds	*Capsella bursa-pastoris* (CapB-P), *Centaurea cyanus* (CenCya), *Chenopodium album* (CheAlb), *Cirsium arvense* (CirArv), *Daucus carota* (DauCar), *Galeopsis tetrahit* (GalTet), *Lamium purpureum* (LamPur), *Myosotis* sp. (MyoSp.), *Tripleurospermum inodorum* (TriIno), *Viola arvensis* (VioArv)
Other weeds - monocotyledonous	*Avena fatua*, *Echinochloa crus-galli*, *Elytrigia repens*, *Poa annua*, Other *Poaceae*
Other weeds - dicotyledonous	*Amaranthus retroflexus, Arctium tomentosum, Artemisia vulgaris, Atriplex sagittata, Anthyllis vulneraria, Brassica oleracea, Cerastium holosteoides, Cirsium vulgare*, *Convolvulus arvensis*, *Crepis biennis, Descurainia sophia*, *Equisetophyta*, *Euphorbia helioscopia*, *Fallopia convolvulus*, *Galium aparine*, *G. mollugo*, *Geranium pusillum*, *Lactuca serriola*, *Lathyrus tuberosus*, *Matricaria chamomilla*, *Matricaria discoidea*, *Medicago lupulina*, *M. sativa*, *Melilotus*

officinalis, *Mercurialis annua*, *Persicaria lapathifolia*, *Plantago lanceolata*, *P. media*, *P. major*, *Polygonum aviculare*, *Rumex* sp., *Securigera varia*, *Silene latifolia*, *Sonchus arvensis*, *Stellaria media*, *Taraxacum* sp., *Thlaspi arvense*, Unsown *Apiaceae*, *Urtica dioica*, *Veronica* sp., *Vicia pannonica*

Table 8. Effect of locality, time and cutting management on estimated cover of plant functional groups (%) averaged over two-year period. Significant values are boldfaced.

Factor	Cover of functional groups (%)			
	Bare ground	Sown species	Pollinator-friendly weeds	Other weeds
Locality (D.F. = 6, 144)				
P	<0.001	<0.001	<0.001	<0.001
Time (D.F. = 4, 144)				
P	<0.001	<0.001	<0.001	0.267
Management (D.F. = 1, 144)				
Early cut	**11.1^a**	**70.6^b**	**8.0**	10.4
Late cut	**15.1^b**	**61.7^a**	**14.1**	9.2
P	**0.004**	**0.032**	0.575	0.349
Management x Time	**0.002**	**0.023**	**<0.001**	0.270

n = 160; D.F.: degrees of freedom (numerator, denominator); *P*: probability; different letters indicate statistical differences between cutting management for Tukey HSD, α = 0.05

Table 9. Effect of locality, time and cutting management within each plant functional group on the number of flowers per m^2 over two-year period. Significant values are boldfaced.

Factor		Sown species	Pollinator-friendly weeds	Other weeds
Locality (D.F. = 6, 222)				
	P	0.001	0.068	0.065
Time (D.F. = 5, 222)				
	P	<0.001	0.001	0.017
Management (D.F. = 1, 222)				
	Early cut	941	**17** ^{a}	5
	Late cut	889	**107**^{b}	13
	P	0.413	**0.005**	0.162
	Management x time	0.377	<**0.001**	0.484

n = 48; D.F.: degrees of freedom (numerator, denominator); *P*: probability; different letters indicate statistical differences between two cutting managements for Tukey HSD, α = 0.05

Table 10. Results of redundancy analyses investigating effects of three explanatory variables or interactions between management and time on variability of plant species cover (%), number of flowers (per m^2) and pollinator visitation rate (individuals per 100 m^2) in the flower strips under different cutting management regimes over two-year period.

Variables	Explanatory variables	Covariate	% ax. 1 (all)	F 1 (all)	*P* 1 (all)
Plant species cover	Locality, Time, Management	-	23.5 (56.8)	45.5 (19.6)	0.002 (0.002)
Plant species cover	Management x Time	Locality	19.7 (35.7)	50.8 (18.4)	0.002 (0.002)
Number of flowers	Management x Time	Locality	6.6 (15.5)	16.8 (4.0)	0.002 (0.002)
Bumblebee, Honey bee, Wild bee,	Management x Time	Locality	12.3 (32.9)	4.1 (1.6)	0.004 (0.002)
Hoverfly	Management x Time	Locality	17.8 (46.2)	2.2 (1.0)	0.698 (0.536)

% ax. 1 (all) – variability explained by canonical axis 1 or by all axes in brackets; F 1 (all) – F statistics for the test of axis 1 or all axes in brackets; *P* 1 (all) – corresponding probability value obtained by the Monte Carlo permutation test (499 permutations) for the test of axis 1 or all axes in brackets.

Table 11. Effect of locality, time, management and interaction between management and time (M x T) on bumblebee (BB), honeybee (HB), wild bee (WB), hoverfly (HF) and total pollinator (TP) visitation rate (number of individuals per 100 m^2) on sown species (SS) or pollinator-friendly weed species (PFW) over two-year period. Significant values are boldfaced.

	BB	HB	WB		HF		TP	
Factor	SS	SS	SS	PFW	SS	PFW	SS	PFW
Locality								
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Time								
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Management								
Early cut	9.4	39.5	1.8	**0.4**	24.0	**0.5**	74.7	**0.9**
Late cut	8.3	30.0	2.2	**0.9**	18.6	**1.0**	59.1	**1.9**
P	0.530	0.090	0.489	**0.015**	0.988	**0.039**	0.255	**0.018**
M x T	0.156	0.239	0.758	**<0.001**	0.862	**<0.001**	0.174	**<0.001**

Figure 5. Effect of cutting management (early *vs*. late) and time interaction on plant functional groups cover over two-year period. Roman numbers mark the number of the sampling period in the row – plant cover was estimated in the first and in the third sampling period of each year. Stars indicate significant differences within one sampling period for Tukey HSD, α = 0.05.

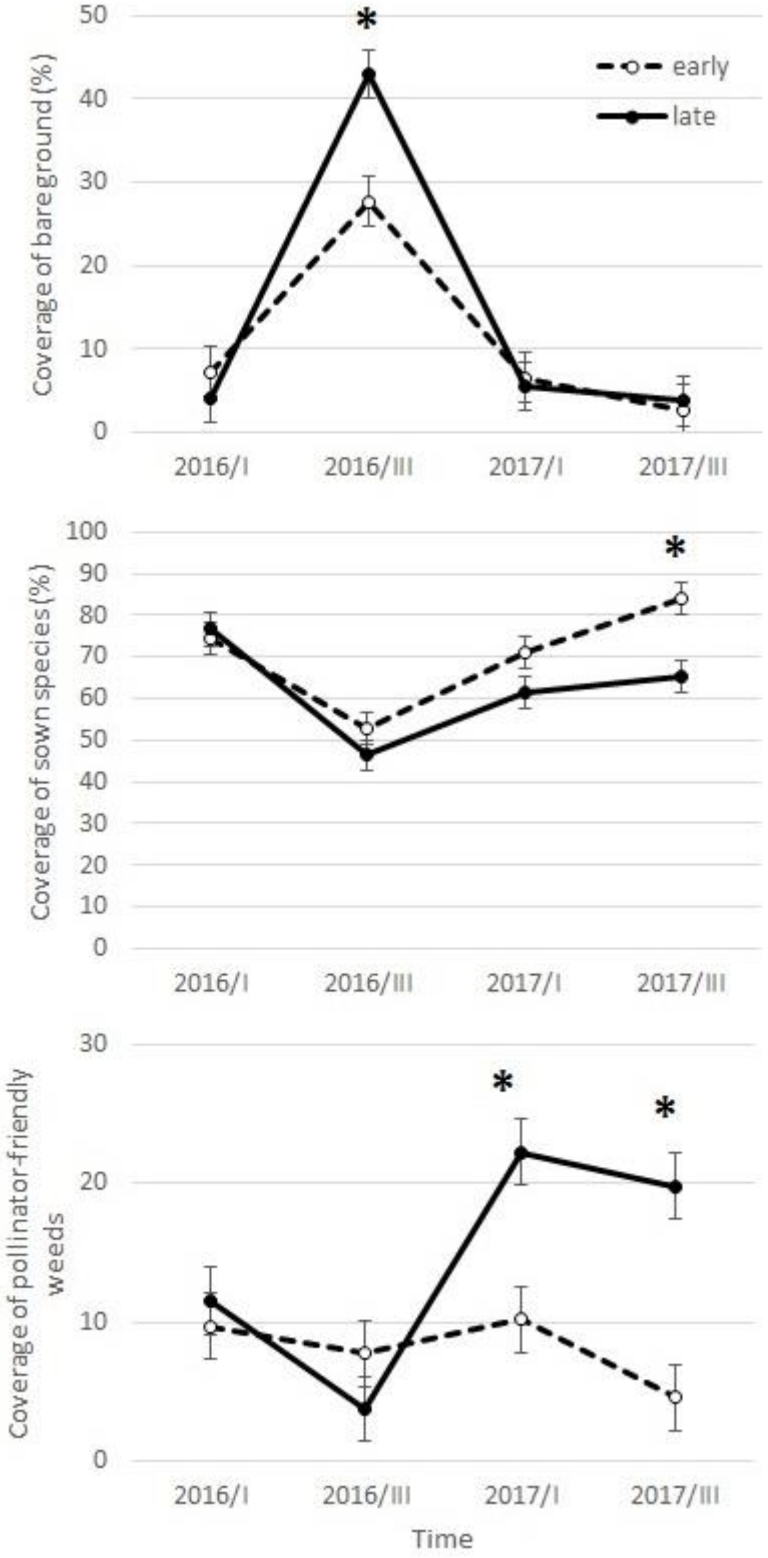


Figure 6. Ordination biplot of plant species cover explained by interaction of cutting management (early – E or late – L summer cut in the seeding year) and sampling period (1 = spring/early summer, 3 = late summer) over two-year period. Sown species are bold.

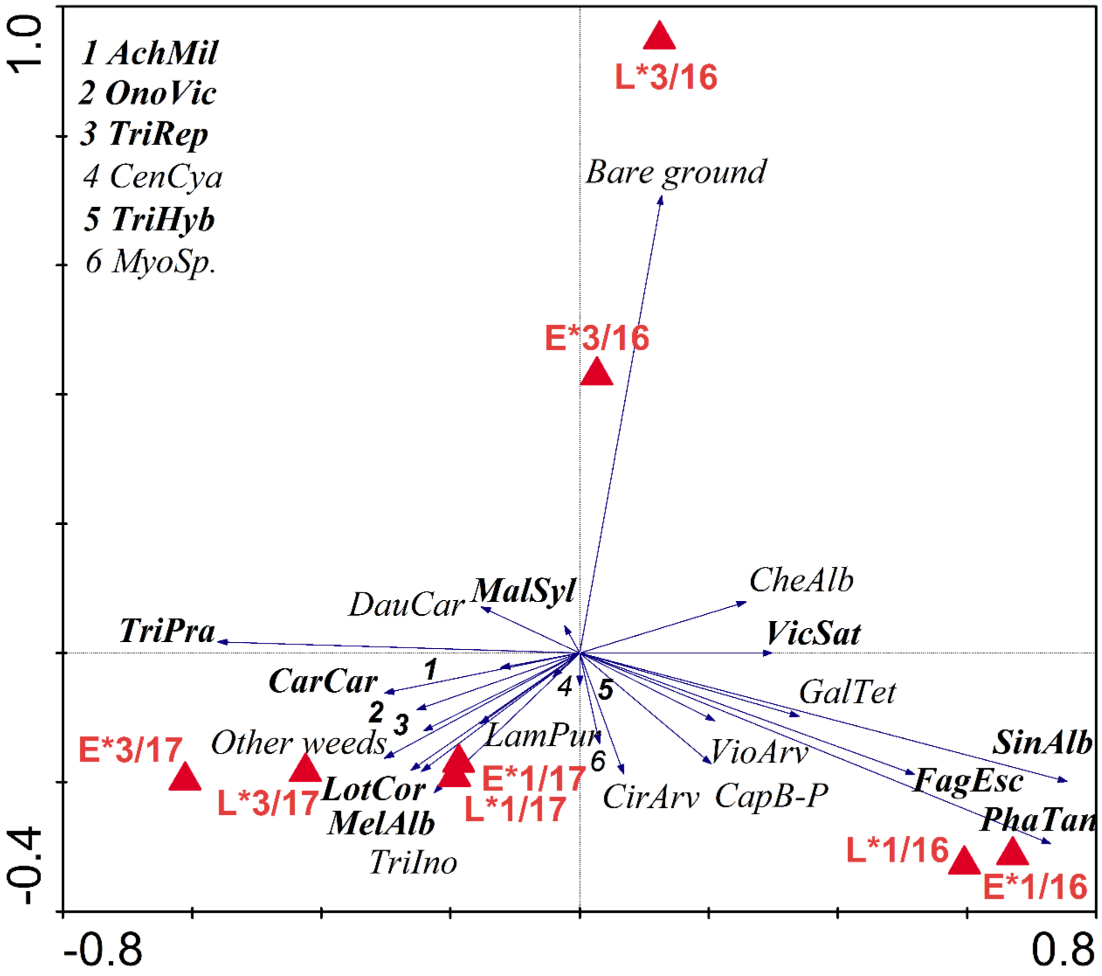


Figure 7. Ordination biplot of bumblebee (BB), honeybee (HB) and wild bee (WB) visitation rate on particular plant species explained by interaction of cutting management (early - E or late - L summer cut in the seeding year) and sampling period (1 = early summer, 2 = mid-summer, 3 = late summer) over two-year period. Sown species are in bold.

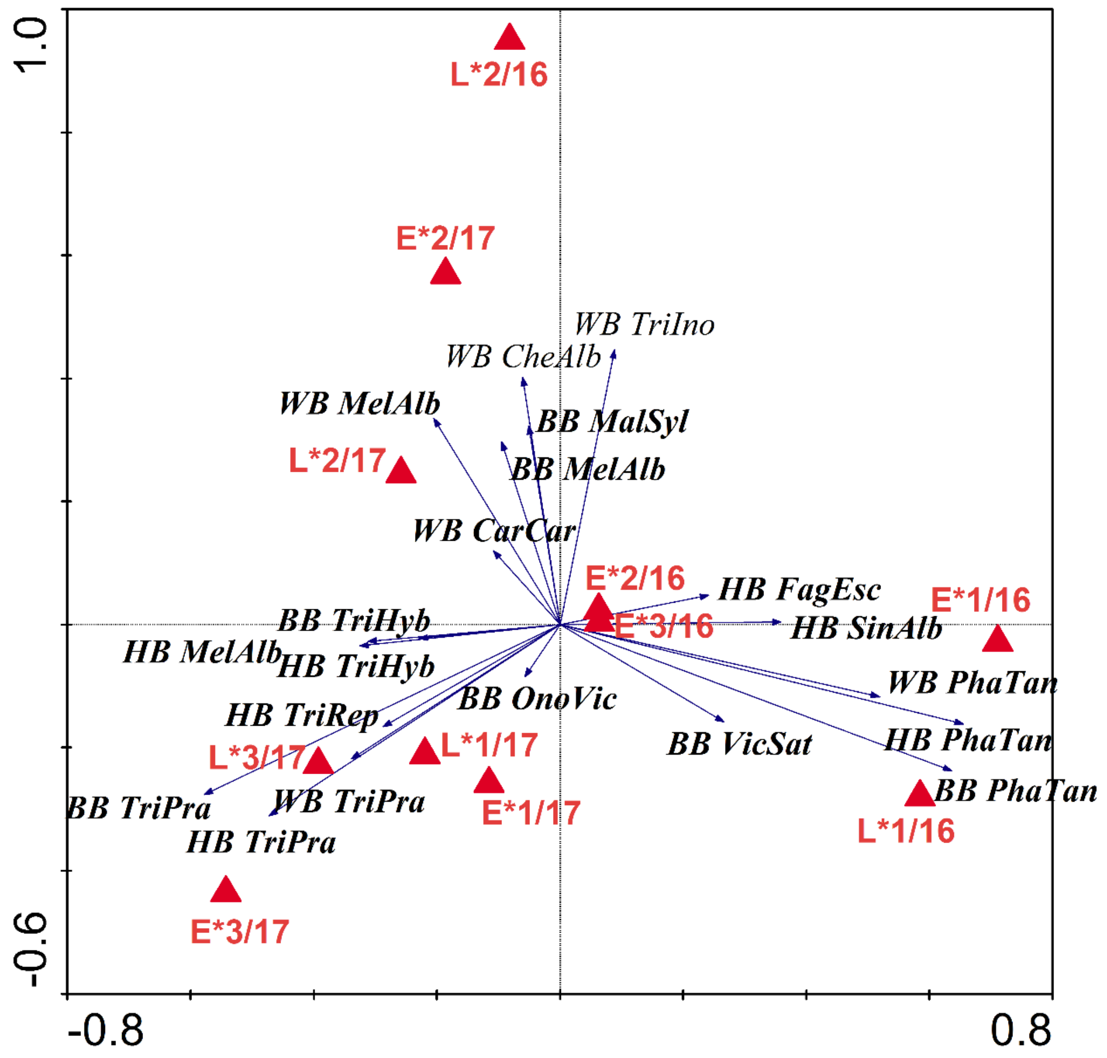
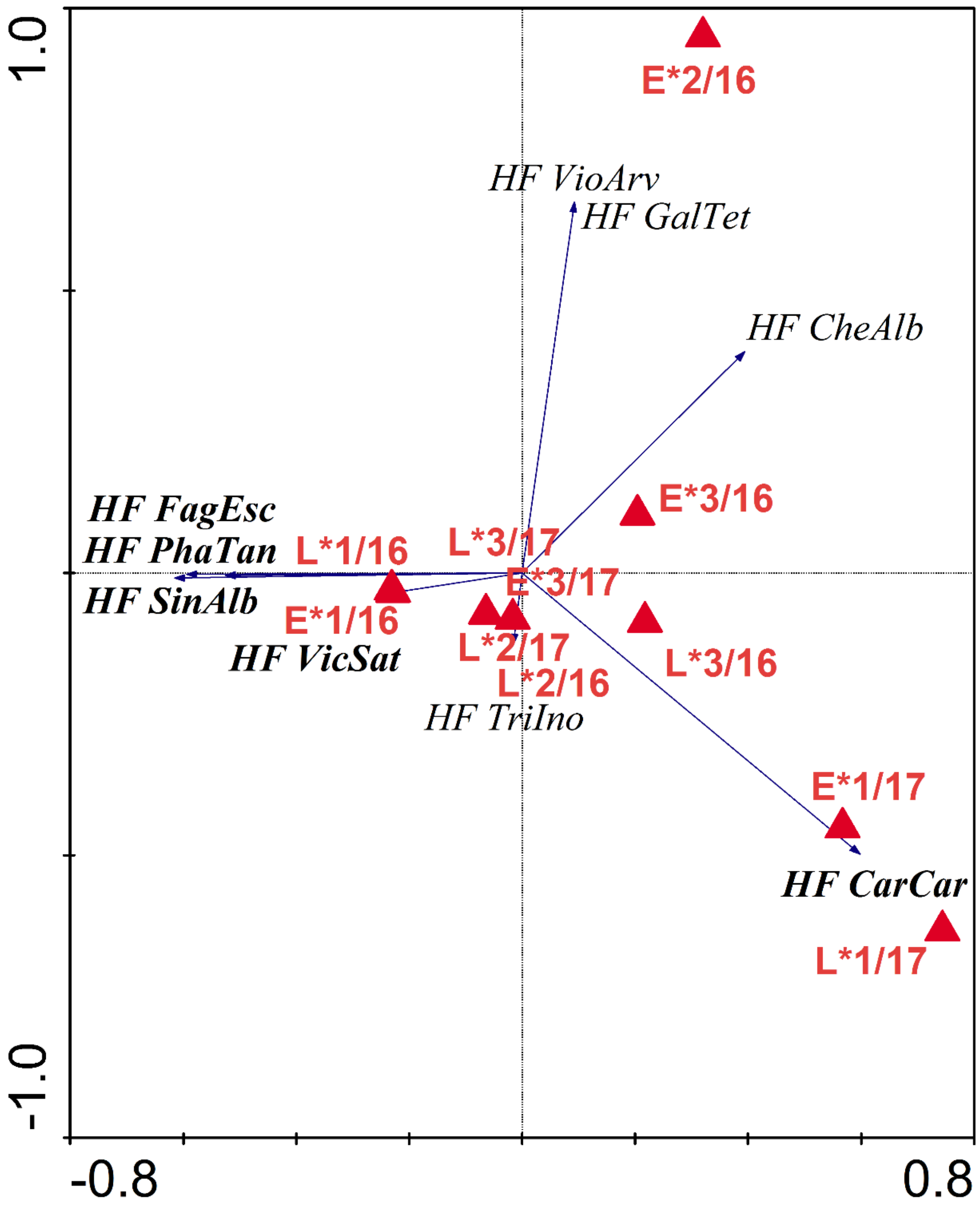


Figure 8. Ordination biplot of hoverfly (HF) visitation rate on particular plant species explained by interaction of cutting management (early - E or late - L summer cut in the seeding year) and sampling period (1 = early summer, 2 = mid-summer, 3 = late summer) over two-year period. Sown species are in bold.



Discussion

In search of a suitable management recommendation of perennial flower strips, it is necessary to consider both the conservation aspect highlighting the efficacy of this measure for target pollinator species, and, the agronomical aspect requiring as weed-free flower strips as possible (which is understandable as flower strips are often practiced as a temporary measure).

Early summer cutting of flower strips supports significantly sown species and suppresses simultaneously development of species from the soil seedbank. More precisely, it reduces flowering of spontaneously appeared dicotyledonous plants in the year of sowing as well as in the following year, which is beneficial from the farmer's point of view. On the other hand, flowering of those 'pollinator-friendly weeds', which is enhanced by delayed mowing (late summer cutting), increases the attractiveness of the flower strips for flower-visiting insects, as it covers the gap in flowering of sown species that usually occurs in summer. In this study, flowering of 'pollinator-friendly weeds' in summer was the only characteristic of the flower strips responsible for the differences in attractiveness between the two cutting management regimes. However, flowering species from the soil seedbank significantly increased the attractiveness of the strips, which is in line with Warzecha et al. (2018), it is hardly acceptable from the farmer's point of view as it may increase the probability of their spreading within the flower strip as well as into the neighboring crop.

Even though mowing helps to reduce weeds in the flower strips (Benvenuti and Bretzel, 2017) and according to Tarmi et al. (2011) and some perennial weed species probably need cutting even more frequently than once per year in order to be suppressed, only a reasonable attitude towards cutting ensures acceptable flowering of the strip, as a compromise.

From the agronomical perspective, one cutting per year, done before maturing of weed seeds usually occurring at the end of the main flowering period of annual species in mid-July (if strips were sown in April, which is a common practice) should be enough for acceptable weed control in the strip.

At the same time, mowing in late summer is discouraged in perennial flower strips containing Fabaceae and other dicotyledonous species as well as an important percentage of annual species, as the biomass of annual species suppress the development of perennial species, which was also found by Benvenuti and Bretzel (2017). This results in higher cover of weeds in the following year (Fig. 6). In such a mixture composition, annual species play a role of cover crop to perennial species. And, their biomass must be removed early, so Fabaceae (mainly *Trifolium* spp.) can develop in the flower strip (Hakl et al., 2014).

However, from the perspective of pollinator conservation, early summer cut causes a gap in flowering lasting from 4 to 6 weeks during summer when pollinator species diversity and abundance is still high and thus, decreases considerably the effectiveness of the flower strip for target species. Therefore, splitting the flower strip into two longitudinal halves, which are mown in a way ensuring continuous flowering of the strip (at least a 4-week interval in between) could be a solution in case that weed control is not necessary in the whole strip. Such practice is common in a corresponding AECS in Wallonia, Belgium, where strips are divided evenly into three parts, with one third left completely unmown each year serving as a reproduction site and refuge for insects (Le Roi et al., 2010).

To sum up, there is a conflict between the conservation requirements for having as long of a flowering period in summer as possible and the support of perennial plant species in the flower strip for the ongoing years which is in line with effective weed control, particularly important from the farmer's perspective. Nevertheless, the balance of these two requirements is key for satisfying perennial quality of flower strips and their flowering in the subsequent years.

Alongside management, the seeding mixture composition can also help to ensure a good shape of perennial strips for several years, in addition to locality conditions. Marhsall and Moonen (2002) suggest that grasses are effective in suppressing plant species from the soil seed bank. In the seed mix designed for the Czech AECS studied within this survey, forb species (*Trifolium* spp. and *Melilotus albus*) also tended to suppress weeds if their development was enhanced by early summer cut. At the same time, these species provide excellent floral resources to mainly to honeybees and bumblebees (Lagerlöf et al., 1992; Carvell et al., 2007;

Goulson, 2010) and were responsible for most visitation of the strip in the post-seeding year. However, attractive floral resources for hoverflies were almost completely missing in the post-seeding year as suitable plant species e.g. *Carum carvi* (Apiaceae) or *Achillea millefolium* (Asteraceae) were very scarcely represented. Hence, if flower strips are intended as a measure supporting a wider pollinator diversity including hoverflies, a higher percentage of Asteraceae and Apiaceae species should be included (Ouvrard et al., 2018). Flowering species supporting higher pollinator diversity were insufficient even in the summer of the sowing year when flowering weed species *Tripleurospermum inodorum* (Asteraceae) and *Chenopodium album* (Amarathaceae) were responsible for the difference in visitation rate between the two types of cutting management. The only period when all the target groups (hoverflies, honeybees, bumblebees and other wild bees) found their food source in the strips was the early summer of the sowing year when *Phacelia tanacetifolia*, *Fagopyrum esculentum* and *Sinapis alba* were flowering intensively.

Given the above, the mixture composition and its suitable management should be conceived in a way that sown species can develop in the flower strips and fulfill their function. Only such design makes sense also economically, which is another important aspect when designing flower strips (William and Londsdorf, 2018).

However, Uyttenbroeck (2017b) concludes, that high plant functional diversity of the flower strips does not necessarily imply their satisfying support to pollinators. Also, even the effect of management on final visitation rate of pollinators seems to be limited.

Surprisingly, a higher cover of sown species as a consequence of early mowing did not cause any difference in the number of flowers between flower strips under the two cutting management regimes. In other words, statistical analysis showed that the effect of management x time interaction on the number of flowers represented only a half of its effect on the cover of plant species. Differences in variability of plant species cover and number of flowers can be explained by compensation mechanisms in plants. Moreover, the effect of management x time interaction on the pollinator visitation rate was twice as high than this effect on the number of flowers (Table 11). These findings may indicate that there are other factors affecting occurrence of flower-visiting insects in the flower strips (or any flowering patches), which are at least of the same importance as flowering intensity. These factors can include timing of the flowering as both abundance and species richness of insects drops towards the end of the vegetation period. Other factors may be the size of local source pollinator populations and the availability of other floral resources within their foraging range. Therefore, such placement of flower strips in the landscape ensuring source populations of target insects in proximity and low competition of other floral resources is necessary for the efficacy of the AECS. This is particularly important if we focus on supporting wild bees, attached on a daily basis to their nesting sites in semi-natural habitats and showing a limited foraging range, maximum of 300 m, for most individuals (Zurbuchen et al., 2010). In case of hoverflies that are more mobile in the agricultural landscape (at least most species of this environment), the placement of the strips is not so essential (Talašová et al., 2018). Similarly, Uyttenbroeck et al. (2017b) concluded that increasing plant functional diversity was not the key for supporting pollinators in wildflower strips.

Although the date of mowing is not decisive for the subsequent visitation of the flower strips by target pollinator groups, it can be supposed that its effect may be of higher importance under locally arid conditions or, in generally dry seasons. Drought together with late removal of annual species biomass can cause underdevelopment of perennial species and insufficient regeneration before winter. Therefore, it may decrease the capacity of the perennial sown species to form dense patches for the next years.

Conclusion

Our study clearly demonstrated that the date of mowing is not decisive for the subsequent visitation of the flower strips by target pollinator groups, but it impacts on the cover of the sown and unsown plant species in the flower strips. Based on the data analysis, there are other untested factors affecting pollinator visitation rate at least as much as flowering intensity.

Early summer cutting management of flower strips in the establishment year significantly supports sown species and reduces simultaneously the development of weed species. Late summer cutting enhanced flowering of 'pollinator-friendly weeds' in mid-summer of the sowing year. Differences in the number of flowers within the plant category of 'pollinator-friendly weeds' and their visitation by pollinators in mid-summer of the establishment year represented the only characteristic related to pollinator visits that distinguished significantly the two cutting management options. Simultaneously, it pointed to insufficient floral resources provided by sown species in this period. Hence, there is a conflict between the conservation requirements for having as long of a flowering period in summer as possible and the support of perennial plant species in the flower strip requiring early cutting. A split mowing management could be a solution in flower strips that do not suffer from high cover of weeds.

In early summer of the establishment year, all target pollinator groups were attracted by *Phacelia tanacetifolia*, *Fagopyrum esculentum* and *Sinapis alba*, whereas in the post seeding year, flower strips were attractive mainly for honeybees and bumblebees due to the flowering of *Trifolium* species. Therefore, plant species suitable for other wild bees and hoverflies (i.e. Asteraceae, Apiaceae) should be added in the seeding mix if the AECS is supposed to support wider pollinator species diversity.

CONCLUSION

Suitability test of the selected pollinator groups contrasting in their degree of philopatry, aculeate Hymenoptera and Syrphidae, sampled by yellow pan traps and transect walks, for local-scale biomonitoring showed that philopatric group represented by aculeate Hymenoptera is suitable for this purpose as it was detected in significantly different species numbers in two contrasting habitat types, regardless of sampling method used. In contrast, Syrphidae as a rather non-philopatric group within this study pointed to differences between habitats only in transect walks and thus, showed a mixed pattern. Nevertheless, affinity of Syrphidae towards non-philopatric behavior suggests that they may be a suitable indicator at a landscape scale.

Czech AECS 'nectar-rich flower strips' proved to be a good tool to support aculeate Hymenopteran and hoverfly species diversity on farmland as the number of species found in flower strips did not differ from that found in nearby semi-natural habitats where source populations live most likely (especially in case of bees and wasps) and they even attracted most species occurring at the studied sites. However, semi-natural habitats contained a significantly higher number of aculeate Hymenopteran food specialists, what is supposed to be in relation to a significantly higher plant species diversity in this habitat type as compared to flower strips. Higher abundances of all aculeate Hymenoptera (including honeybee coming mostly from managed beehives) captured in flower strips as compared to the numbers in nearby habitats suggest that 'nectar-rich flower strips' can be locally beneficial for beekeepers. However, it can decrease the effect of the AECS for pollinator species diversity as honeybees tend to suppress foraging of other bee pollinators in flowering patches. To conclude, Czech AECS 'nectar-rich flower strips' is effective mainly in promoting pollinator generalists. To enhance the most threatened bee food specialists, promoting conservation and restoration of semi-natural habitats is more likely to be a suitable approach.

Our study clearly demonstrated that the date of mowing is not decisive for the subsequent visitation of the flower strips by target pollinator groups, but it impacts on the cover of sown and unsown plant species. While early cutting significantly supports sown plant species and reduces the cover of weeds over a two-year period, late cutting enhances flowering of 'pollinator-friendly weeds' in mid-summer of the establishment year and their subsequent visitation by pollinators. Hence, there is a conflict between the conservation requirements for having as long of a flowering period in summer as possible and the support of perennial plant species in the flower strip requiring early cutting. A split mowing management could be a solution in weed-free flower strips.

In the establishment year, sown flower strips attracted all pollinator categories comprising honeybees, bumblebees, other wild bees and hoverflies, mainly thanks to *Phacelia tanacetifolia*. Later that year, floral resources provided by sown species were insufficient. In the post-seeding year, flower strips were attractive mainly for honeybees and bumblebees due to the flowering of *Trifolium* species. Therefore, plant species suitable for other wild bees and hoverflies should be added in the seeding mix if the AECS is supposed to support wider pollinator species diversity.

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SUPPLEMENTS

Tables

Table 1. List of analyzed morphological and ecological traits in aculeate Hymenoptera, with categories within traits and their definition.

Trait	Categories within trait	Definition of categories
Habitat preference	*Mesophilous 1*	Species living in opened mesic habitats, especially on meadows or on fine-grained soil
	Mesophilous 2	Species living on the edge of opened and forest habitats, forest meadows, forest clearings and bush margins of other habitat types
	Mesophilous 3	Species living in mesic forest habitats
	Xerothermophilous 1	Species living in opened xerotermophilous habitats (steppe grasslends, rocky steppe, xeric meadows)
	Xerothermophilous 2	Species living in warm bush and forest steppes
	Xerothermophilous 3	Species living in xeric (pine) steppes on sandy soil, xeric oak forests
	Hygrophilous 1	Species living in opened wetland habitats (wet meadows, moorlands, reeds, etc.)
	Hygrophilous 2	Species living in wetland forests (watterloged pine forests, willow-poplar alluvial forests, alder forest)
	Hygrothermophilous	Species living in warm wetland biotopes
Number of generations per year		
Feeding strategies in adults	*Specialist*	Feeds only on representatives of 1 plant family, 1 host pray family or a single host species (or a few closely related species) for cleptoparasites
Feeding strategies in larvae	*Herbivore*	
	Omnivore	
	Parasitoid	
	Specialist	Feeds only on representatives of 1 plant family, 1 host pray family
	Mass provisionning	Food is supplied to larvae at once
Body length		Minimal and maximal body length; average body length was counted from maximal and minimal values and it has been stated for males and females mixed [mm]
Fore wing length		Aproximated minimal and maximal wing length counted from body and wing length ratio from photographs in Macek et al. (2010) or collections and extrapolated to real size. Average wing length is counted from minimal and maximal values. Males and females are mixed [mm]
Degree of sociality	*1= solitary, 2=agregated, 3= communal, 4= eusocial*	Highest recorded degree of social structure

Table 2. Inter-habitat differences in aculeate Hymenoptera and Syrphidae species richness sampled by pan traps and transect walk in sown flower strips (F), semi-natural habitats (N) and wheat fields (W) on 7 different localities. *P* values are results of Mann-Whitney U test, significant values are boldfaced ($P < 0.05$).

Insect group		**Aculeate Hymenoptera**			**Syrphidae**		
Habitat type		**F**	**N**	**W**	**F**	**N**	**W**
Species richness on sites	1	31	63	16	10	7	7
	2	24	29	21	8	10	9
	3	24	28	14	10	8	10
	4	38	52	19	7	7	6
	5	25	24	13	9	10	10
	6	24	44	12	9	12	9
	7	46	44	14	17	13	10

Table 3. List of plant species recorded on seven localities in semi-natural habitats and sown flower strips. Plant species sown in flower strips that were recorded in flower are boldfaced.

	HABITAT TYPE	**Semi-natural habitats**								**Flower strip**							
	LOCALITY	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**ALL**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**ALL**
1	*Achillea millefolium*	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
2	*Anchusa officinalis*	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
3	*Anthemis arvensis*	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
4	*Apiaceae* *(species unspecified, unsown)*	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	1
5	*Arctium tomentosum*	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0
6	*Atriplex patula*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
7	*Ballota nigra*	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	1
8	*Campanula rotundifolia*	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
9	*Capsella bursa-pastoris*	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1	1
10	*Centarurea cyanus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
11	*Centaurea jacea*	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
12	*Centaurea scabiosa*	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	*Cichorium intybus*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
14	*Cirsium arvense*	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	1
15	*Cirsium palustre*	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
16	*Cirsium vulgare*	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0
17	*Chenopodium album*	0	0	0	1	0	0	0	1	1	0	0	1	0	1	0	1
18	*Convolvulus arvensis*	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
19	*Crepis biennis*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
20	*Dianthus carthusioanorum*	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0
21	*Dianthus deltoides*	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0
22	*Dipsacus fullonum*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
23	*Echium vulgare*	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
24	*Erigeron strigosus*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
25	*Euphorbia helioscopia*	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
26	*Fallopia convolvulus*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
27	***Fagopyrum esculentum***	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1
28	*Galeopsis tetrahit*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
29	*Galium mollugo*	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0
30	*Galium verum*	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
31	*Geranium pratense*	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
32	*Hypericum perforatum*	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0
33	*Impatiens parviflora*	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
34	*Knautia arvensis*	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0
35	*Lactuca serriola*	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0
36	*Lamium album*	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0
37	*Lamium purpureum*	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
38	*Lathyrus tuberosus*	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1

	HABITAT TYPE	**Semi-natural habitats**								**Flower strip**							
	LOCALITY	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**ALL**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**ALL**
39	*Lathyrus pratensis*	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
40	*Linaria vulgaris*	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	*Lotus corniculatus*	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
42	*Lysimachia punctata*	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
43	*Malva moschata*	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
44	***Malva sylvestris***	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1
45	*Matricaria chamomilla*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
46	*Medicago lupulina*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
47	*Medicago sativa*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
48	***Melilotus albus***	1	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1
49	*Melilotus officinalis*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
50	*Myosotis spp.*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1
51	*Papaver rhoeas*	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0
52	***Phacelia tanacetifolia***	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
53	*Plantago lanceolata*	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
54	*Polygonum aviculare*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
55	*Raphanus raphanistrum*	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
56	*Rubus spp.*	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
57	*Saponaria officinalis*	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0
58	*Securigera varia*	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
59	*Silene latifolia*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
60	*Silene vulgaris*	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0
61	***Sinapis alba***	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
62	*Solidago canadensis*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
63	*Tanacetum vulgare*	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0
64	*Taraxacum spp.*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
65	*Tragopogon pratensis*	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
66	*Trifolium alpestre*	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
67	*Trifolium arvense*	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
68	***Trifolium hybridum***	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	1
69	***Trifolium pratense***	1	0	1	0	1	0	1	1	1	1	1	1	0	0	1	1
70	***Trifolium repens***	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1
71	*Tripleurospermum inodorum*	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1
72	*Verbascum thapsus*	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
73	*Veronica persica*	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
74	***Vicia sativa***	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
75	*Vicia villosa*	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0
76	*Viola arvensis*	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	1
		28	**22**	**16**	**17**	**25**	**13**	**23**	**67**	**12**	**3**	**7**	**7**	**6**	**4**	**14**	**21**

Table 4. List of Syrphidae species with number of individuals caught in pan traps in three studied habitats on each sampling term (1, 2, 3) and over the sampling season in total (ALL).

	Habitat type	**Flower strip**				**Semi-natural habitat**				**Wheat**			
	Term	1	2	3	ALL	1	2	3	ALL	1	2	3	ALL
1	*Anasimyia lineata*	1	0	0	1	0	0	0	0	0	0	0	0
2	*Didea intermedia*	0	0	0	0	0	0	1	1	0	0	0	0
3	*Episyrphus balteatus*	289	11	6	306	209	13	1	223	555	11	3	569
4	*Eristalinus aeneus*	1	0	0	1	0	0	0	0	0	0	0	0
5	*Eristalinus sepulchralis*	1	0	0	1	0	0	0	0	0	0	0	0
6	*Eristalis arbustorum*	107	53	36	196	48	42	40	130	29	11	9	49
7	*Eristalis interruptus*	8	0	7	15	3	1	5	9	1	1	0	2
8	*Eristalis pertinax*	1	0	0	1	0	0	0	0	0	0	0	0
9	*Eristalis tenax*	41	38	10	89	25	48	11	84	13	26	9	48
10	*Eupeodes corollae*	34	12	1	47	16	5	7	28	59	8	11	78
11	*Helophilus hybridus*	0	0	0	0	0	0	0	0	1	0	0	1
12	*Helophilus pendulus*	1	0	6	7	0	1	0	1	0	0	0	0
13	*Helophilus trivittatus*	0	16	2	18	0	37	3	40	2	16	8	26
14	*Chrysotoxum festivum*	0	1	0	1	0	0	0	0	0	1	0	1
15	*Chrysotoxum verralli*	0	0	0	0	3	0	0	3	1	1	0	2
16	*Lapposyrphus laponicus*	0	0	0	0	1	0	0	1	0	0	0	0
17	*Melanostoma mellinum*	2	2	3	7	1	2	1	4	13	2	5	20
18	*Myathropa florea*	9	3	5	17	1	5	12	18	3	1	0	4
19	*Parhelophilus frutetorum*	6	1	0	7	0	0	0	0	0	0	0	0
20	*Parhelophilus versicolor*	0	0	0	0	0	2	0	2	0	0	0	0
21	*Rhingia campestris*	0	1	0	1	0	0	0	0	0	0	0	0
22	*Scaeva pyrastri*	7	0	0	7	1	0	0	1	13	0	0	13
23	*Sphaerophoria scripta*	57	58	10	125	116	26	13	155	135	80	7	222
24	*Syrphus ribesi*	1	0	0	1	1	0	0	1	0	0	0	0
25	*Syrphus sp.*	1	1	1	3	1	1	2	4	1	0	1	2
26	*Syrphus vitripenis*	0	0	0	0	1	0	0	1	1	0	0	1
27	*Tropidia scita*	0	0	0	0	2	0	0	2	0	0	0	0
28	*Volucella pellucens*	0	1	0	1	0	1	0	1	0	0	0	0
29	*Xantogramma pedissequum*	0	0	0	0	1	0	0	1	0	0	0	0
30	*Xylota segnis*	6	0	61	67	0	2	1	3	0	0	0	0
31	*Xylota sylvarum*	0	0	4	4	0	0	0	0	0	0	0	0
	TOTAL	573	198	152	923	430	186	97	713	827	158	53	1038

Table 5. List of aculeate Hymenoptera species with number of individuals caught in pan traps in three studied habitats on each sampling term (1, 2, 3) and over the sampling season in total (ALL).

	Habitat type	**Flower strip**				**Semi-natural habitat**				**Wheat**			
	Term	1	2	3	ALL	1	2	3	ALL	1	2	3	ALL
1	*Allodynerus delphinalis*	0	1	0	1	0	0	0	0	0	0	0	0
2	*Ancistrocerus claripennis*	0	0	0	0	0	2	1	3	0	0	0	0
3	*Ancistrocerus gazella*	0	0	0	0	0	0	1	1	0	0	0	0
4	*Ancistrocerus nigricornis*	0	0	0	0	0	0	3	3	0	0	0	0
5	*Andrena agilissima*	4	0	0	4	1	0	0	1	1	0	0	1
6	*Andrena albofasciata*	0	1	0	1	0	0	1	1	0	0	0	0
7	*Andrena barbilabris*	3	0	0	3	1	0	0	1	0	0	0	0
8	*Andrena bicolor*	1	1	0	2	0	0	0	0	0	0	0	0
9	*Andrena carantonica*	0	1	0	1	0	0	0	0	0	0	0	0
10	*Andrena cineraria*	2	0	0	2	0	0	0	0	0	0	0	0
11	*Andrena congruens*	0	0	0	0	0	0	0	0	0	1	0	1
12	*Andrena curvungula*	0	0	0	0	0	0	0	0	1	0	0	1
13	*Andrena dorsata*	4	27	0	31	1	2	0	3	0	0	0	0
14	*Andrena flavipes*	6	96	2	104	9	27	1	37	2	8	2	12
15	*Andrena fucata*	2	0	0	2	2	0	0	2	1	0	0	1
16	*Andrena fulvago*	0	0	0	0	1	0	0	1	0	0	0	0
17	*Andrena gravida*	1	0	0	1	0	0	0	0	0	0	0	0
18	*Andrena haemorrhoa*	3	0	0	3	1	0	0	1	0	0	0	0
19	*Andrena intermedia*	0	0	0	0	1	0	0	1	0	0	0	0
20	*Andrena labialis*	1	0	0	1	0	0	0	0	0	0	0	0
21	*Andrena minutula*	6	7	0	13	7	4	0	11	2	0	0	2
22	*Andrena minutuloides*	1	0	0	1	0	0	0	0	0	0	0	0
23	*Andrena nigroaenea*	6	0	0	6	2	0	0	2	4	6	0	10
24	*Andrena nitida*	1	0	0	1	0	0	0	0	1	0	0	1
25	*Andrena proxima*	1	0	0	1	0	1	0	1	0	0	0	0
26	*Andrena semilaevis*	0	0	0	0	0	0	0	0	1	0	0	1
27	*Andrena subopaca*	1	0	0	1	0	0	0	0	0	0	0	0
28	*Andrena wilkella*	2	0	0	2	0	1	0	1	0	0	0	0
29	*Anthidiellum strigatum*	0	0	0	0	0	0	1	1	0	0	0	0
30	*Anthidium manicatum*	0	0	0	0	5	19	1	25	0	0	0	0
31	*Anthidium punctatum*	0	0	0	0	0	2	0	2	0	0	0	0
32	*Apis mellifera*	1508	186	137	1831	223	130	150	503	186	19	35	240
33	*Auplopus carbonarius*	0	0	0	0	2	0	0	2	0	0	0	0
34	*Bombus bohemicus*	5	2	0	7	0	0	0	0	0	0	0	0
35	*Bombus hortorum*	9	0	5	14	6	3	1	10	3	1	0	4
36	*Bombus humilis*	0	0	2	2	0	0	0	0	0	0	0	0
37	*Bombus hypnorum*	0	0	0	0	2	0	0	2	0	0	0	0
38	*Bombus lapidarius*	54	20	1	75	9	10	3	22	8	5	2	15
39	*Bombus lucorum*	1	1	0	2	0	2	0	2	1	0	0	1
40	*Bombus pascuorum*	4	2	6	12	2	4	10	16	1	3	2	6
41	*Bombus pratorum*	20	0	0	20	6	1	0	7	0	0	0	0
42	*Bombus rupestris*	0	2	1	3	0	1	0	1	0	0	0	0
43	*Bombus sylvarum*	0	0	0	0	2	1	2	5	0	4	0	4
44	*Bombus terrestris*	416	31	5	452	52	77	11	140	42	18	2	62
45	*Bombus vestalis*	8	0	1	9	1	1	0	2	0	1	0	1
46	*Ceratina cyanea*	0	0	0	0	0	0	1	1	0	0	0	0
47	*Cerceris quinquefasciata*	0	1	0	1	1	1	0	2	0	0	0	0
48	*Cerceris rybyensis*	0	3	0	3	2	0	2	4	1	0	0	1
49	*Cleptes semiauratus*	0	0	0	0	1	0	0	1	0	0	0	0

	Habitat type	Flower strip				Semi-natural habitat				Wheat			
	Term	1	2	3	ALL	1	2	3	ALL	1	2	3	ALL
50	*Clisodon furcatum*	0	1	0	1	1	0	1	2	0	0	0	0
51	*Colletes daviesanus*	0	0	0	0	2	2	1	5	0	0	0	0
52	*Crabro cribrarius*	0	0	0	0	0	0	0	0	2	0	0	2
53	*Crossocerus ovalis*	0	0	1	1	0	0	0	0	0	0	0	0
54	*Crossocerus quadrimaculatus*	0	0	0	0	0	0	1	1	0	0	0	0
55	*Crossocerus varus*	0	0	1	1	0	0	0	0	0	0	0	0
56	*Cryptocheilus versicolor*	0	0	2	2	0	0	0	0	0	0	0	0
57	*Diodontus luperus*	0	0	0	0	0	0	2	2	0	0	0	0
58	*Dolichovespula saxonica*	1	4	1	6	0	3	0	3	0	0	0	0
59	*Dolichovespula sylvestris*	0	1	0	1	0	0	0	0	0	0	0	0
60	*Ectemnius continuus*	0	0	0	0	0	0	1	1	0	2	0	2
61	*Ectemnius rubicola*	0	1	0	1	0	1	0	1	0	0	0	0
62	*Ectemnius ruficornis*	0	0	0	0	0	0	1	1	0	0	0	0
63	*Eumenes pedunculatus*	0	0	0	0	0	0	1	1	0	0	0	0
64	*Euodynerus quadrifasciatus*	0	0	0	0	0	0	0	0	1	0	0	1
65	*Gorytes quinquecinctus*	0	0	0	0	0	0	0	0	1	0	0	1
66	*Gymnomerus laevipes*	0	0	0	0	3	0	0	3	0	0	0	0
67	*Halictus maculatus*	0	0	0	0	0	0	0	0	0	0	1	1
68	*Halictus rubicundus*	0	1	0	1	2	0	0	2	0	0	0	0
69	*Halictus scabiosae*	0	0	0	0	0	2	0	2	0	0	0	0
70	*Halictus sexcinctus*	1	0	0	1	0	1	0	1	0	0	0	0
71	*Halictus simplex*	4	6	0	10	1	3	5	9	0	0	0	0
72	*Halictus subauratus*	0	2	7	9	4	5	5	14	0	0	0	0
73	*Halictus tumulorum*	18	34	11	63	28	42	22	92	14	21	7	42
74	*Harpactus elegans*	0	0	0	0	0	0	0	0	0	2	0	2
75	*Hedychrum gerstaeckeri*	0	0	0	0	1	0	0	1	0	0	0	0
76	*Heriades truncorum*	0	0	0	0	1	3	3	7	0	0	0	0
77	*Hoplitis adunca*	0	0	0	0	3	0	0	3	0	0	0	0
78	*Hoplitis leucomelana*	1	0	0	1	1	1	0	2	0	0	0	0
79	*Hylaeus annularis*	2	8	3	13	2	6	1	9	0	0	0	0
80	*Hylaeus brevicornis*	0	1	1	2	1	2	4	7	0	0	0	0
81	*Hylaeus communis*	8	5	5	18	4	2	15	21	0	0	1	1
82	*Hylaeus confusus*	0	1	2	3	11	3	3	17	0	0	0	0
83	*Hylaeus cornutus*	0	0	0	0	2	0	0	2	0	0	0	0
84	*Hylaeus difformis*	0	1	0	1	3	3	1	7	0	0	0	0
85	*Hylaeus hyalinatus*	2	1	1	4	5	10	3	18	0	0	1	1
86	*Hylaeus moricei*	0	0	0	0	1	0	0	1	0	0	0	0
87	*Hylaeus nigritus*	0	3	0	3	4	5	0	9	0	0	0	0
88	*Hylaeus paulus*	0	0	0	0	0	0	2	2	0	0	0	0
89	*Hylaeus punctatus*	1	0	0	1	0	0	0	0	0	0	0	0
90	*Chalicodoma ericetorum*	0	0	0	0	0	2	0	2	1	0	0	1
91	*Chelostoma rapunculi*	0	1	0	1	6	1	0	7	0	0	0	0
92	*Chrysis gracillima*	2	0	0	2	0	0	0	0	0	0	0	0
93	*Lasioglossum calceatum*	3	5	1	9	9	12	3	24	6	0	0	6
94	*Lasioglossum fulvicorne*	0	0	1	1	0	0	0	0	1	0	0	1
95	*Lasioglossum laevigatum*	3	2	0	5	4	1	0	5	0	0	0	0
96	*Lasioglossum laticeps*	36	9	0	45	326	7	13	346	26	4	0	30
97	*Lasioglossum lativentre*	14	3	0	17	4	0	1	5	1	0	0	1
98	*Lasioglossum leucopus*	0	0	0	0	0	0	1	1	0	0	0	0
99	*Lasioglossum leucozonium*	3	0	0	3	6	1	3	10	1	0	1	2
100	*Lasioglossum malachurum*	174	89	56	319	26	39	14	79	91	36	7	134
101	*Lasioglossum morio*	10	8	1	19	9	6	6	21	10	2	0	12
102	*Lasioglossum nitidulum*	0	3	0	3	0	1	0	1	0	0	0	0
103	*Lasioglossum parvulum*	1	0	0	1	1	0	0	1	0	0	0	0
104	*Lasioglossum pauxillum*	536	222	68	826	310	67	17	394	357	34	19	410

	Habitat type	**Flower strip**				**Semi-natural habitat**				**Wheat**			
	Term	1	2	3	ALL	1	2	3	ALL	1	2	3	ALL
105	*Lasioglossum politum*	1	2	2	5	5	2	0	7	0	0	0	0
106	*Lasioglossum punctatissimum*	0	0	0	0	1	0	0	1	0	0	0	0
107	*Lasioglossum quadrinotatum*	0	0	0	0	0	1	0	1	0	0	0	0
108	*Lasioglossum villosulum*	0	2	0	2	11	1	0	12	2	0	0	2
109	*Lasioglossum zonulum*	0	0	0	0	1	1	0	2	2	1	0	3
110	*Lestica clypeata*	1	0	0	1	0	0	0	0	0	0	0	0
111	*Lindenius albilabris*	0	0	0	0	0	1	2	3	0	0	0	0
112	*Macropis europaea*	0	0	0	0	0	0	0	0	1	0	0	1
113	*Megachile centuncularis*	1	0	0	1	3	2	6	11	0	0	0	0
114	*Megachile pilidens*	0	0	0	0	0	0	2	2	0	0	0	0
115	*Megachile versicolor*	1	0	2	3	1	3	2	6	0	0	0	0
116	*Megachile willughbiella*	0	0	0	0	1	0	0	1	0	0	0	0
117	*Microdynerus parvulus*	0	0	0	0	0	1	0	1	0	0	0	0
118	*Nomada flavoguttata*	4	2	0	6	0	1	0	1	0	0	0	0
119	*Nomada fucata*	0	1	0	1	0	2	0	2	0	0	0	0
120	*Nysson dimidiatus*	0	0	0	0	1	0	0	1	0	0	0	0
121	*Nysson maculosus*	1	0	0	1	0	0	0	0	0	0	0	0
122	*Nysson spinosus*	0	0	0	0	2	0	0	2	0	0	0	0
123	*Odynerus melanocephalus*	1	0	0	1	6	0	0	6	0	0	0	0
124	*Odynerus spinipes*	1	0	0	1	0	0	0	0	0	0	0	0
125	*Omalus aeneus*	0	0	0	0	0	0	1	1	0	0	0	0
126	*Osmia aurulenta*	0	0	0	0	3	0	0	3	0	0	0	0
127	*Osmia caerulescens*	0	0	0	0	1	0	0	1	0	0	0	0
128	*Osmia parietina*	0	0	0	0	1	0	0	1	0	0	0	0
129	*Osmia rufa*	0	0	0	0	0	0	0	0	1	0	0	1
130	*Oxybelus trispinosus*	1	0	0	1	0	0	0	0	0	0	0	0
131	*Oxybelus uniglumis*	0	0	1	1	1	0	0	1	0	0	0	0
132	*Oxybelus variegatus*	0	1	0	1	0	0	0	0	0	0	0	0
133	*Passaloecus singularis*	0	1	0	1	1	1	2	4	0	0	0	0
134	*Pemphredon enslini*	0	0	0	0	0	1	0	1	0	0	0	0
135	*Pemphredon fabricii*	0	1	0	1	0	6	0	6	0	0	0	0
136	*Pemphredon inornata*	0	0	1	1	1	4	1	6	0	0	0	0
137	*Pemphredon lethifer*	0	0	1	1	3	2	0	5	0	0	0	0
138	*Pemphredon littoralis*	0	0	0	0	1	1	0	2	0	0	0	0
139	*Pemphredon morio*	0	0	0	0	0	0	0	0	1	0	0	1
140	*Pemphredon rugifer*	0	0	0	0	1	0	0	1	0	0	0	0
141	*Pison atrum*	0	0	0	0	0	1	0	1	0	0	0	0
142	*Polistes biglumis*	0	0	1	1	0	0	2	2	0	0	0	0
143	*Polistes dominula*	1	11	7	19	6	5	13	24	1	3	0	4
144	*Polistes nimpha*	0	0	1	1	0	2	2	4	0	0	0	0
145	*Psenulus pallipes*	0	1	0	1	0	2	0	2	0	0	0	0
146	*Rophitoides canus*	0	0	0	0	0	0	0	0	1	0	0	1
147	*Sapygina decemguttata*	0	1	0	1	0	0	0	0	0	0	0	0
148	*Sphecodes albilabris*	0	0	0	0	1	0	0	1	0	0	0	0
149	*Sphecodes crassus*	0	0	0	0	1	1	1	3	0	0	0	0
150	*Sphecodes ephippius*	5	0	0	5	3	0	0	3	0	0	0	0
151	*Sphecodes geoffrellus*	0	0	1	1	1	1	0	2	0	0	0	0
152	*Sphecodes gibbus*	0	0	0	0	0	0	1	1	0	0	0	0
153	*Sphecodes puncticeps*	0	0	0	0	1	0	0	1	0	0	0	0
154	*Sphecodes spinulosus*	0	0	0	0	1	0	0	1	0	0	0	0
155	*Stelis breviuscula*	0	0	0	0	0	2	0	2	0	0	0	0
156	*Stenodynerus steckianus*	0	0	0	0	0	1	0	1	0	0	0	0
157	*Tachysphex obscuripennis*	1	0	0	1	0	0	0	0	0	0	0	0
158	*Tiphia femorata*	0	3	8	11	0	9	0	9	0	0	0	0
159	*Tiphia minuta*	1	0	0	1	0	0	0	0	0	0	0	0

	Habitat type	**Flower strip**				**Semi-natural habitat**				**Wheat**			
	Term	1	2	3	ALL	1	2	3	ALL	1	2	3	ALL
160	*Trachusa byssina*	0	0	0	0	1	1	0	2	0	0	0	0
161	*Trypoxylon medium*	0	1	0	1	0	0	0	0	0	0	0	0
162	*Trypoxylon minus*	0	0	0	0	1	0	0	1	0	0	0	0
163	*Vespula germanica*	0	0	11	11	0	5	21	26	0	1	8	9
164	*Vespula rufa*	0	0	0	0	0	0	0	0	1	1	0	2
165	*Vespula vulgaris*	0	0	7	7	0	0	1	1	0	0	0	0
	TOTAL	2910	821	365	4096	1182	580	376	2138	777	173	88	1038

Figures

Fig. 1. Nectar-rich flower strip in the Czech Republic two months after sowing. June 2016.

Fig. 2. Nectar-rich flower strip in the Czech Republic one year after establishment. August 2017.

Fig. 3. Nectar-rich flower strip in the Czech Republic one year after establishment. July 2017.

Fig. 4. Semi-natural habitat with yellow pan traps.

Fig. 5. Transect walk in the flower strip done by the author Anna Talašová.

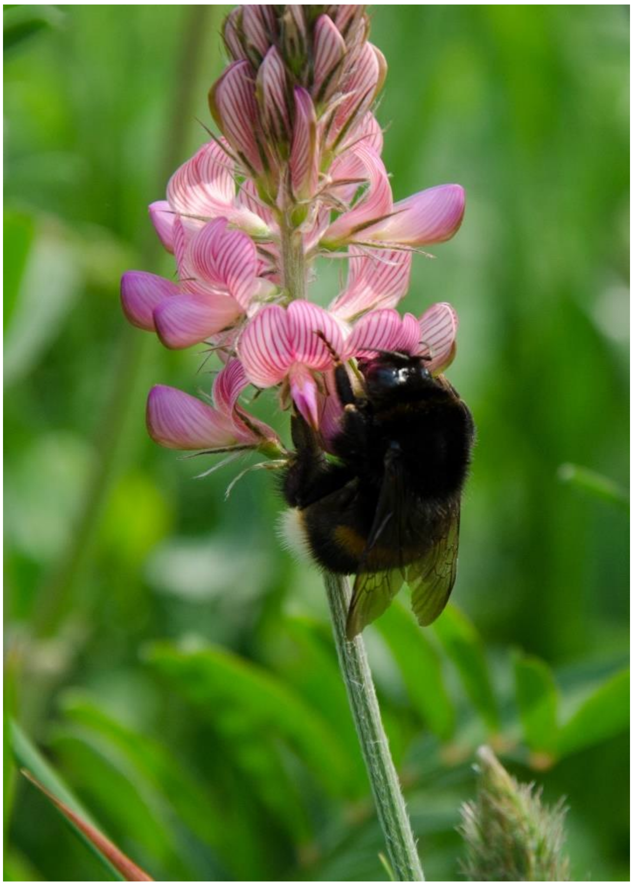

Fig. 6. *Bombus terrestris* feeds on *Onobrychis viciifolia* in the nectar-rich flower strip.

Fig. 7. Solitary bee *Andrena* sp. on clover.

Fig. 8. Sweet clover (*Melilotus albus*) in the flower strips is an excellent food source for honeybees.

Fig. 9. Hoverfly species Sphaerophoria scripta is eating pollen of Phacelia tanacetifolia.

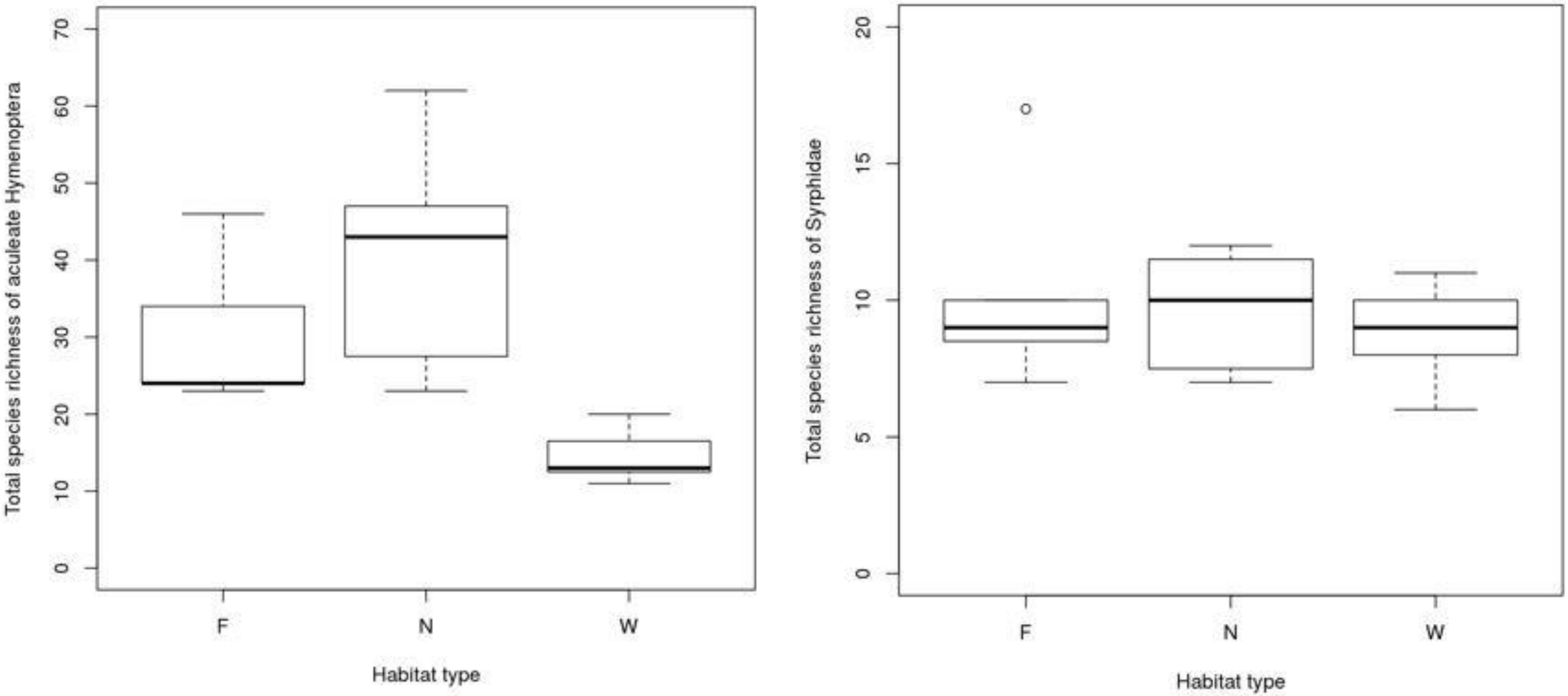

Figure 10. Total species richness of aculeate Hymenoptera and Syrphidae recorded in three habitats (F-sown flower strip, N – semi-natural habitat, W – wheat field) at the study localities over the sampling season. Cummulative species numbers found in pan traps.

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