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Influence of temperate agroforestry systems on the diversity of insect pollinators

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Declaration

I, Priyabrata Kirtania, hereby declare that I have done this thesis entitled: *Influence of temperate agroforestry systems on the diversity of insect pollinators* independently, only with the expert guidance of my thesis tutor prof. Ing. Bohdan Lojka, PhD., and professional entomologist. All texts in this thesis are original. All the sources have been quoted and acknowledged with complete references according to the Citation rules of the FTA.

In Prague, August 6TH, 2021

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Priyabrata Kirtania

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Abstract

Agroforestry offers ecosystem benefits and services such as controlling soil erosion, modifying the microclimate to enhance yield, economic diversification, livestock well-being and production, and water quality protection. Also, agroforestry practices can affect ecosystem services offered by insect pollinators through increased functional and structural diversity in agricultural landscapes. This thesis aimed to assess the effect of modern agroforestry systems in the Czech Republic on the species richness and diversity of insect pollinators. This study was conducted in experimental station Central Bohemia. Insect pollinators were captured in four habitats (Agroforestry tree line, Agroforestry crop line, Open field, and Natural habitat) from May to September 2019. In total, 1,795 insect individuals belonging to 15 families were captured. The families with the highest number of species and number of individuals were: Halictidae, Colletidae, Crabronidae, Pompillidae, and Andrenidae. The highest abundance across all habitats was recorded in mid-July. Species richness and diversity were different in each of the habitats. The agroforestry tree line is a central area of all habitats. The highest species abundance and richness were found in the agroforestry tree line, followed by the agroforestry crop line, the natural close habitat and the open field. The agroforestry crop line was merged with the agroforestry tree line. The agroforestry tree line and the agroforestry crop line being the most similar of all habitats. The lowest values were observed in open field habitats. A well-managed agroforestry system has the potential to sustain a wide variety of native pollinator species Průhonice-Michovky,

Keywords: Alley cropping, Czech Republic, Ecosystem services, Insect abundance, Species diversity, Species richness.

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1. Introduction

For thousands of years, agroforestry techniques have been used by humans in the tropics as well as in temperate zone. A variety of fruit trees, beeches for mast, oaks for acorns, and ash trees for fodder, for example, have been preserved in woodland clearance and are at the forefront of early European agroforestry schemes (Abbas et al. 2017). According to Bentrup et al. (2019), agroforestry systems that combine wood and farm crops may achieve a technological compromise between high productivity and ecosystem services such as pollination. Pollination is a global biodiversity tool that helps raise crop yields, maintain output stability, and preserve wild plant populations. More productive as well as sustainable farming methods are needed to balance the increased demand for crop production with the growing human population while maintaining habitat diversity (Abdulai et al. 2018). Agroforestry systems, a deliberate combination of growing trees with agricultural crops or/and animals, are believed to conserve biodiversity, including insect pollinators.

Insect pollination is among the most valuable ecosystem services of the environment and is common in natural and agricultural ecosystems. For example, approximately 85% of flowering plants worldwide are pollinated by insects (Bentrup et al. 2019). In addition, the pollination of insects is vital to food safety, and about 35% of world crop output depends on insect pollination (Bentrup et al. 2019). Pollinators are a central community of plant reproductive and wildlife websites in most terrestrial environments. The pollinators are mainly bees, wasps, flies, beets, butterflies, and moths, although certain birds and bats can also pollinate. Although any pollinator plays a vital role, bees are essential for pollination for crops. However, insect pollinators are declining, with some projections that 40% of the invertebrate pollinator populations have declined globally. Main threats, including habitat destruction, erosion or depletion, viruses, and pests, all lead to the decline in pollinators (Bentrup et al. 2019).

Compared to conventional agriculture, agroforestry systems may establish pollinator habitats and promote pollinator abundance and diversity through their more complex vegetation structure. Although agroforestry is not always planned to be a refuge for pollinators or provide crop pollination services, these services may be expected with the proper design of the system (Ali & Mattsson, 2017a, 2017b). However, scientific information on the influence of temperate agroforestry systems on insect pollinators on abundance and diversity are relatively scarce in scientific literature especially from the Czech Republic.

This thesis aimed to assess the effect of modern agroforestry systems in the Czech Republic on the species richness and diversity of insect pollinators. The main goal was to show how tree vegetation structure affects insect pollinators in alley cropping system.

2. Literature Review

2.1 Biodiversity

Biodiversity means variability among living organism from all sources, such as terrestrial, marine, and other aquatic ecosystems and the ecological intricacies they are a part of; it comprises diversities within species, between species and of ecosystems (Arvind at el.2010). Biological diversity or biodiversity is the variety of life," and collectively, it refers to all levels of biological organization (Erisman et al. 2016). More specifically, the term "biodiversity" refers to the diversity of life on the Earth, from the genetic level, trough species level to ecosystems, and it may comprise evolutionary, ecological, and cultural life-supporting processes. Biodiversity comprises not only uncommon, vulnerable, or endangered species but every living thing from man to the organism of microorganisms, fungus, and invertebrates (Vellend et al. 2017).

Biodiversity includes various living forms, including genes, species, ecosystems, and ecological processes (Adom et al. 2019). Sustainable development relies on effective conservation as an essential ecological and environmental preservation (Rockstrom et al. 2020). At the United Nations Environment and Development Conference (UNCED), Biological Diversity was defined as a variable amongst living things from all sources, such as, among other things, terrestrial, marine, and different aquatic ecosystems and the environmental developments to which they belong (Munson, 2019). For most elements of our existence, biodiversity is vital. We value biodiversity for its contribution to the diversity and richness of the environment. In addition, ecosystems offer critical functions such as pollination, seed dispersion, temperature regulation, water purification, nutrient cycling, and agricultural pest management (Luke et al. 2020). Biodiversity also has worth for unrecognized prospective advantages such as discovering new drugs and other possibly undiscovered services. Biodiversity also has cultural importance for human beings, such as spiritual or religious reasons (Cicinelli et al. 2018). The intrinsic value of biodiversity is its inherent value, regardless of its importance to anybody else. Moreover, this is a philosophical idea that might be considered the inalienable right to exist.

Biodiversity also plays a vital role in the protection of water resources. The natural vegetation cover in water catchment helps maintain hydrological cycles, regulate and stabilize water runoff, and act as a barrier from natural calamities such as floods and drought. Vegetation enables water percolation into the ground, hence assisting in maintaining the groundwater table. Deforestation has been the primary cause of the lowering of the groundwater table. Also, forests that comprise diverse groups of plant species are the significant sinks of carbon dioxide serving as a greenhouse gas that causes global warming. Therefore, biologically diverse forest ecosystems help in curbing global warming (Singh & Gupta, 2018).

Finally, the significance of biodiversity may also be interpreted through the lens of our ties with one other and with the rest of nature. Biodiversity may be valued because of its shaping who we are, our connections, and our societal standards. These related values are part of the individual or community feeling of well-being, responsibility, and environmental connectedness of individuals. The many biodiversity values are significant because they may impact the choices that individuals take on conservation each day (Ross & Adkins, 2018).

2.1.1 Decline of biodiversity

Over the last century, the increase in the Earth's population has resulted in a fast change in the environment and a catastrophic biodiversity loss. Some people refer to the epoch in which we currently live as an "Anthropocene" (Vellend et al. 2017). This phenomenon has led to the Earth's changes and extinction. Habitat loss and fragmentation, wasteful use of resources, invasive species, pollution, and global climate change are the most direct threats to biodiversity. In addition, the ever-increasing demand for energy, food, water, and land has come at a significant threat to biodiversity (Tilman et al. 2017). The underlying causes are typically complicated, stemming from numerous interconnected reasons for biodiversity loss, such as an increasing human population and overconsumption.

Continuous human development has boosted per capita intake and changed food habits of increased wealth, leading to inefficient use of the Earth's biodiversity. Further declines of plants and wildlife are caused by climate change, acidification of the oceans, others driven by human activity, and environmental impacts. Farming practices and deforestation are the main contributors to biodiversity degradation, habitat functions, and natural resource dependency (Dang et al. 2019). Unsustainable farming practices, urban sprawl, and pollution are the leading causes of the dramatic reduction in Europe's biodiversity and threaten thousands of animal habitats and species (Aksoy et al. 2017). Biodiversity loss occurs in many places of the world, often quickly. The loss of individual species, groupings of species, or declines in the number of individual organisms may be monitored. However, the loss frequently reflects the reduction or destruction of a complete ecosystem in a specific place. Habitat loss is the most significant and most crucial danger to biodiversity, according to the Subsidiary Body of Scientific, Technical and Technological Advisory (Weikmans et al. 2016).

A significant danger to biodiversity is the introduction of non-native species and genetic stocks. Thousands of new and alien genes are introduced each year with trees, shrubs, herbs, and microorganisms (Sukopp & Sukopp, 1993). Most of the new species survive and become invasive after several years of adoption. Due to the introduction of new commercial species, genetic diversity across crops also decreased dramatically. There have been reported worldwide crop losses of more than eighty percent of apples, maize, tomato, wheat, and corn (Starfinger et al. 1998).

Agriculture and other developmental activities resulted in a total reduction of around two percent between 1980 and 1990 in forests around the globe. Natural forest cover in emerging areas decreased by eight percent (Marques et al. 2019). Agricultural activities also impact land and marine biodiversity in and around agricultural areas (Dudley & Alexander, 2017). The biodiversity of agricultural environments is affected by fertilizers, pest management agents, laying, and even crop rotation (Marques et al. 2019). For example, the biodiversity of Europe is continuously eroded, consequently resulting in the degradation of the ecosystem. Recent research has revealed that 60% of the assessments of species and 77% of habitat evaluations are continually in an unfavourable conservation status (Grizzetti et al. 2019). These threats to biodiversity are continuously exerting pressure and resulting in loss of habitats and species, degradation of the ecosystem, and weakening the resilience of the ecosystem.

Studies on population trends for various species groups reveal both negative and positive results. There has been a drastic decline in grassland butterflies by approximately 50% between 1990 and 2011, with no indication of ever recovering (Dieler et al. 2017). The common bird populations in Europe have reduced by 12% since 1990, and common farmland birds have decreased by 30%. Nevertheless, some populations of large carnivores and European bats seem to have recovered to a certain point from previous declines, signifying positive outcomes of conservation action and unexpected changes, for example, land abandonment (Dieler et al. 2017).

2.1.2 Biodiversity in temperate regions

Temperate regions, such as Europe, are most extensively altered by human activities. Developments and settlements of these hospitable and productive areas have a long history and significantly impact biological diversity (Titley et al. 2017). As a result, many organisms and ecosystems are highly modified and fragmented. Intense human activities, such as agricultural development and environmental pollutants, are sources of continuous threats to biota. Therefore, the preservation of biotic diversity in temperate zones represents a significant challenge. Restoration of some of the lost biodiversity is a factor of this challenge, preserving what is remaining. Positive elements in conservation include the general flexibility of temperate forests, the moderately high level of relevant knowledge, and temperate zone inhabitants and nations (Fardila et al. 2017). In addition, a recovery of temperate forests on abandoned cutover forests and agricultural lands, such as in the north-eastern United States, contributes to the possible restoration of biodiversity.

There are vital needs in enhancing and preserving biotic diversity in temperate regions. The requirements are maintaining, or, if absent, creating a complete collection of agricultural successional stages, such as old-growth agricultural condition; for maintaining functional and structural diversity in the entire agricultural landscape, e.g., through retaining fallen logs and standing dead trees; to protecting aquatic diversity in lakes, streams and rivers associated with temperate regions; and developing effective stewardship programs for maintaining, and when necessary, creating, natural area preserves within intensely utilized landscapes (Titley et al. 2017). It is also critical to integrate biodiversity objectives into managing all landscapes because preservation of selected land tracts cannot attain the desired goal of maintaining the Earth's biodiversity even at the most significant possible scale.

2.1.3 Monitoring of European biodiversity

Europe is renowned internationally as the "biodiversity hotspot" for great species richness, such as in the Mediterranean basin (Hajek et al. 2016). Around 2-6% of the world's species, varies by species group, is a significant summer home for many migratory bird species in Europe. Despite the relatively small number of species, the variety of rural and forest landscapes in Europe is noteworthy. Forests include boreal and near-arctic environments, lush beech and oak forests, alpine pines and spruces, and landscapes with cork, cypress, chestnut, and olive trees (Hajek et al. 2016).

Roughly less than half (47%) of the 463-bird species in the EU have excellent status, 5% below the previous reporting period of 2008-2012. However, during the last six years, the percentage of birds with insufficient or inadequate status climbed by 7% to a total of 39% (Morelli et al. 2017). At the national level, roughly 50% of the population trends improve, mainly including wetland and marine birds, for which Natura 2000 areas such as Ruddy Shelduck or Black Guillemot have been identified (Morelli et al. 2017). Furthermore, the most significant proportion of bird breeders, such as the Crane and the Red Kite, shows improved population trends. This is because habitat conservation or restoration is implemented, and knowledge advances, improved monitoring, and awareness are achieved.

The conservation status of just 15 % of habitat evaluations is excellent, with 81 % of the low or low conservation status at the EU level. Grasslands, dunes, moorings, mire, and fen ecosystems show significantly decreasing trends, whereas forests improve. The proportion of habitats with poor conservation status grew by 6 % over the preceding reporting period. Marine areas have several uncertain conservation status evaluations, reflecting the overall shortage of species data. Around a quarter of species have high EU-level conservation status, a 4% increase compared to the preceding reporting period (Knudsen et al. 2017). Reptiles and vascular plants, such as the Italian Wall Lizard, the Horseshoe Whip Snake, the Hairy Agrimony, and the Great Yellow gentian, are the most well-preserved (35 %) (Knudsen et al. 2017).

Biodiversity in agroecosystems depends on landscape heterogeneity and farm management (Krebs et al. 1999). Landscape context has the ability to modify the impact of organic farming on plants (Roschewitz et al. 2005a), or it could even be more vital for the diversity of butterflies, bees, spiders, and carabids than the local farming system (Schmidt et al. 2005). The contrasting results between conventional and organic fields could be larger when the fields are isolated in homogenous landscapes and the species pool could be too small to allow a response based on biodiversity to organic farming

(Tscharntke et al. 2005). The landscape context of an agricultural field could make a difference in compensating agricultural practices or field isolation which reduces diversity. Field hedges, boundaries, and fallows are satisfactory to a set of requirements for wildlife such as, breeding sites, food and habitat, which promote species persistence in agricultural landscapes (Benton et al. 2003), to facilitate both maintenance and re-colonization of populations in agricultural landscapes (Duelli & Obrist, 2003). The lack of effectiveness of AES is due to the simplification of agricultural landscapes.

2.1.4 Measurement of biodiversity

Scientists have not yet achieved an agreement on biodiversity definition, and a range of reasons have consequently been suggested. For instance, in a different biodiversity definition, scales and Biodiversity have described alteration of ecosystems and their constituents, typically considering the variety of alpha, beta, and gamma. Variety of alpha, beta, and gamma denotes diversity in habitats, between habitats and landscapes accordingly (Heydari et al. 2017)). Hence, alpha and beta diversity were included in most biodiversity studies (Heydari et al. 2017). Furthermore, ecologists defined three significant categories of biodiversity: genetic diversity, variety of species, and various ecosystems. Genetic variety refers to all the genes in all animals, plants, fungi, and microbes and enables them to adapt throughout time to environmental changes (Bhandari et al. 2017). Species diversity, on the other hand, defines variations within and between species populations and between various species, or the mathematical representation of the variant which uses the three components of the community structure, i.e. (Gilbert & Levine, 2017):

- Species richness (number of species in the community)
- Abundance (number of individuals of each species)
- Equality/heterogeneity (a proportional lot of each species to the total number of individuals).

However, intra-species differences generally include genetic variety, while inter-species differences typically have species variety. Finally, ecosystems cover all diverse habitats, biological populations, and ecological processes, including changes within distinct ecosystems (Li et al. 2020).

There are about 1.8 million different and scientifically classified species on Earth. Out of all the identified species, approximately one million are insects. Every year, new species are being discovered. Scientists have estimated that there could be around 5 to 30 million species living on Earth. Every year, about 13,000 more species increase in this growing list of known species (Lewin et al. 2018). Species diversity is essential. Every species plays a significant role in the ecosystem. An example is bees which are primary pollinators. If bees were to become extinct, fruits and vegetables would also become extinct, and consequently, the animals feeding off them and the chains ultimately affect humans. In addition, several species provide humans with food and contribute to clean air, clean water, fertile soil, climate stability, absorption of pollutants, construction materials for homes, and preventing diseases, medicinal resources, and others (Methorst et al. 2021).

2.1.5 Pollinators

Insect-mediated pollination is significantly essential to the economy. Pollinators result in a net £690 million worth of crops per annum in the United Kingdom (UK) (Hass et al. 2018). In the United Kingdom, both domesticated bees (buff-tailed bumblebees and honeybees) and the over 250 species of wild bees (bumblebees and solitary bees) including other insect pollinators play instrumental commercial roles because they are essential for efficient pollination of major crops, for example, tomatoes, oilseed rape, apples, and strawberries (Bartual et al. 2019). Insect pollination improves crop yields and marketability, such as by improving product quality and increasing shelf life. Insect pollinated crops comprise up to 20% of the cultivated land in Britain, and the expenditure of pollinating them without insect pollination is approximately not less than £1.8 billion per annum (Bartual et al. 2019). Probably, honeybees pollinate approximately between 5 and 15% of crops. The rest of the pollination is done by wild pollinators, and in some crops, they are much more effective pollinators and cannot be replaced by honeybees (Hass et al. 2018). A wide range of pollinators is crucial for flexibility in future changes, and it is also essential for crop yield.

Maintenance of the native flora, for example, wildflowers such as cornflowers, poppies and bluebells, and hedges and trees, also depends on healthy populations of pollinators. The close association between plants and pollinators is apparent in the parallel declines observed across Europe (Powney et al. 2019). For example, 76% of plants preferred by bumblebees have declined in recent decades, and 71% undergoing range restrictions. The reduction of pollinators is detrimental to the already falling wildflowers, which are mainly insect-pollinated, and a quarter of them are at risk. Consequently, other wildlife relies on both the pollinated plants and the pollinating insects for shelter and food. For example, insect-pollinated hedgerows and ivy offer birds with fruits during the winter months and habitat and protection. Meanwhile, the insects provide a strong association in the food chain as prey for other insects, bats, insect-eating birds, among other animals (Powney et al. 2019)

2.2 Agroforestry

2.2.1 Definition, concept, and classification

Agroforestry is the deliberate integration of woody vegetation (shrubs or trees), with animal or crop systems, to benefit from the resulting economic and ecological interactions (Mosquera-Losada et al. 2018). It is associated with deliberately growing shrubs and trees with animals and crops in interacting combinations for diverse aims. These kinds of farming practices have been used worldwide for an extended period. The scientific emphasis was on these farming practices, and, thus, they procured greatness as a land-use practice just beginning from the late 1970s. Significant advancements have been made in the practice and science of agroforestry (Nair, 1993). Currently, agroforestry acts as the interface between forestry and agriculture. Agroforestry is considered to be a sustainable and promising tactic for sustainable land use (Nair, 1993).

In agroforestry, trees are joined with farming and the interdisciplinary field of study that accepts land-use systems, at a scope of scales from that of the planet to the field, including relationships among individuals, agriculture and trees. Agroforestry is the phenomenon in which trees interrelate with agriculture. In most parts of the world, there is a long tradition of agroforestry practice. Still, it has reached scientific eminence and arose as the main aim in worldwide development only during the past quarter-century (Leakey, 1996). The terminology 'agroforestry' is derived from joining two subject areas, forestry, and agriculture. These two subject areas have institutionally separated the world for a long period based on research, education, implementation, and policy development

(Leakey, 1996). Therefore, agroforestry has been at the front of the most current inventions in farming and forestry. The primary forces driving these inventions have been the introduction of more human perception from the agricultural tradition into forestry while also stressing a more ecological rather than an agronomic viewpoint to agriculture, in addition to the larger spatial scales and longer time horizons that forestry has always incorporated (Leakey, 1996).

Agroforestry involves the deliberate admixture of shrubs and trees-collectively referred to as a woody tree or woody perennials-on a similar piece of land as agricultural animals or crops, either in the form of a temporal sequence or spatial arrangement (Nair & Dagar, 1991). In the resultant system, there are substantial economic and ecological interactions between the non-woody and woody constituents. Consequently, an agroforestry system comprises more than one output, and its economics and ecology would be more complex than in a monoculture system of forestry or agriculture (Schroth et al. 2002). In temperate agroforestry systems, crop species are usually cultivated between parallel tree rows in strips (Torquebiau 2000). The alley cropping agroforestry system (Figure 1) has become increasingly popular in Europe as it has the capacity to optimize nutrient and water cycles and provide multiple ecosystem services (Quinkenstein et al. 2009)

Figure 1. Experimental plot of alley cropping agroforestry system in Michovky – Průhonice, Czech Republic

Also, it is commonly stressed that all agroforestry systems are characterized by three basic qualities: adaptability (acceptance of the practice by the farming communities or other targeted clientele), sustainability (conservation of the production potential of the resource base), and productivity (producing ideal commodities and productivity of the resources of the land) (Torquebiau, 2000). These different notions are covered in ICRAF's characterization of agroforestry as "a dynamic, ecologically rigorous system of natural resource management; through integrating trees on farms in the agricultural landscapes. It is useful in diversifying and sustaining production for enhanced social, economic, and environmental advantages". Other than agroforestry, other terminologies ending with "forestry" gained prominence during the late 1970s and 1980s due to increasing worldwide interests in tree planting practices (MacDicken, 1997). They comprise farm forestry, social forestry, and community forestry. These terminologies have also not been accurately defined, but they stress the participation of people in tree planting practices. The main difference between agroforestry and the other terminologies is that agroforestry focuses on the interactive relationship between woody perennials and crops and animals for various services and products; the other terminologies refer to planting trees, mostly as woodlots (MacDicken, 1997). In addition, other initiatives and terms such as agroecology, permaculture, and farming systems encompassing the notion of integrated land use (with or without trees) also gained prominence from the 1970s (MacDicken, 1997). Practically, nevertheless, all the practices and activities, including trees, indirectly or directly refer to growing and using trees to provide fuelwood, food, fodder, cash income, medicines, and construction materials. These activities have some variations in them, and they all encompass agroforestry technologies and concepts.

According to the current agroforestry (Table 1) typology in Europe (Dupraz et al. 2018), considering the structure, agroforestry systems can be classified as agrisilvocultural/silvoarable (crops and trees), silvopastoral (pasture/animals and trees), or agrosilvopastoral (crops and pasture/animals and trees) systems (Nair, 1985).

Table 1. Agroforestry typology in Europe (Dupraz et al. 2018).

Tree location	Agroforestry system	Agroforestry practice - according to EU land use classification (e.g., LPIS)	
			Forest land
Trees inside parcels	Silvopastoral AF	Wood pasture	Forest grazing
	Silvoarable AF	Tree alley cropping	Forest farming
		Coppice alley cropping	
		Multi-layer tree-gardens	
	Permanent crop AF	Orchard intercropping	
		Orchard grazing	
	Agrosilvopastoral AF	Alternating cropping and grazing	
Trees between parcels	Field boundary AF (Tree Landscape Features)	Wooded hedges	
		Windbreaks and shelterbelts	
		Trees in line	
		Riparian tree strips	
Trees in settlements	Urban AF	Home gardens, allotments, etc.	

2.2.2 The role of agroforestry

Agroforestry has the potential to address forest degradation and issues concerning food security. Agroforestry has a great potential in meeting the food and dietary needs of the most vulnerable sectors in society. Also, agroforestry systems assist in enhancing the ecosystem services of landscapes, for example, carbon-storage potential and water flows. Agroforestry, mainly multi-strata agroforestry systems, is beneficial to natural resource management and river basins' nutrition and food security. Some of the benefits are the prevention of flooding and soil erosion, groundwater recharging, and supporting Biodiversity by providing habitat and corridors between fragmented ecosystems (Shibu et al. 2009). At the community level, agroforestry and tree farming generates high income for the community members. Thus, agroforestry brings significant advantages to the people and, in the long run, generates impacts transcending the social, environmental, and economic scales (Jose et al. 2009).

Cropping systems diversification and efficient use of natural resources assist in restoring and enhancing environmental quality. Agroforestry has the potential of contributing to both adaptation and climate change mitigation by carbon sequestration, reduction of greenhouse emissions, enhancement of resiliency, and minimizing threats while facilitating migration to more favourable conditions in the highly fragmented agricultural landscapes (Nair, 2011). Soil carbon stocks are larger in agroforestry systems in comparison to conventional cropping systems (Yakov et al. 2018).

2.2.3 Agroforestry and biodiversity conservation

Overcoming challenges such as depletion of resources and loss of Biodiversity, some efforts are needed in conserving and maintaining the ecosystem, species, and genes, with the sustainable management and use of biological resources. In situ protection and ex-situ conservation of genetic and biological resources can sustain genetic and biological resources (Udawatta et al. 2019).

Agroforestry plays a significant role in conserving Biodiversity within fragmented, deforested landscapes by offering resources and habitats for animal and plant species, preserving connectivity of the landscapes, making the landscape favourable for species dwelling in the forest by minimizing the intensity and frequency of fires, possibly minimizing adverse impacts on remaining forest portions and offering buffer zones to protected regions (Smith et al. 2013). In addition, home gardens are a source of a wide variety of resources and niches for supporting a high diversity of animals and plants. Still, usually, they are less than those of intact forests. Nevertheless, even agroforestry systems with low densities of trees and low species diversity may assist in maintaining biotic connectivity. Recently agroforestry systems such as alley cropping have come into focus as they integrate the production of lignocelluloses and crops (Brandt et al. 2005), thus, offering an opportunity for an energetic self-supply in rural areas and also for a diversification of the agricultural production focusing rather on the provision of biomass for energy and industry than on food.

Agroforestry systems are incapable of providing the same habitats and niches similar to the original forests. Therefore, they should not be applied as conservation tools in replacement of natural forest conservation. Nevertheless, they provide a vital complementary conservation tool. They should be put into consideration in landscape-wide conservation efforts that offer protection to remaining forest fragments and support on-farm tree cover in regions that surround the protected areas (Leakey et al. 1999). The extent to which agroforestry systems are able of serving conservation efforts is dependent on different factors, such as the origin and design of the agroforestry systems, its permanency in the landscape, its locality in relation to the remaining natural habitat, and the extent of connection within the habitat, its use and management, mainly pollarding, use of pesticides or herbicides, harvesting of non-timber and timber produce, and integration of goats, cattle, etc. (Leakey et al. 1999).

2.2.4 Temperate agroforestry system

Agroforestry is almost everywhere, but it is difficult to get reliable data on the worldwide extent of agroforestry (Zomer et al. 2009), and it is the same case in Europe. According to the European Commission (2013), agroforestry is a land-use system in which trees are grown in combination with agriculture on the same land. An accurate estimate of the geographical distribution and extent of different types of agroforestry in Europe is vital for developing supporting policies (Den Herder et al. 2017). Alley cropping is an agroforestry system that offers a promising land-use option for the temperate zone. Similarly, the sustainable production of biomass and food is possible, while simultaneously, mainly in marginal regions, the ecological function of the landscape can be improved. Hence, alley cropping corresponds with the increasing demand for renewable energy resources and for a specific adaptation to the predicted fluctuations of climatic conditions within Central Europe (Quinkenstein et al. 2009).

Long-established systems are still present in particular countries, such as 18,000 hectares of almond trees with fodder in Sicily or cereals and 10,200 hectares of fig trees with cereals in Aegean islands Crete. In North-eastern France, low-density fruit tree plantations referred to as pre-vergers are a source of grazing land, and they can be intercropped for the first five to fifteen years within a thirty-year cycle (Smith, 2010). During the pre-Roman era, rows of olive trees were intercropped with wheat in alternating years to improve the olive yield during the next year. However, olive groves still cover approximately 20,000 hectares in Italy and 650,000 hectares in Greece. The olive trees are grown as scattered trees or in rows and intercropped with fodder crops, vegetables, cereals, and systems that combine olives with grapevines are still present in Greece and Spain (46, 600 hectares) (Burgess & Rosati, 2018).

Pasturing in woodlands is among the oldest land-use practices in human history. For example, in Northern Europe, mature woodland was a source of shelter for sheep and cattle during the winter months (Burgess et al. 2018). On the other hand, in the Mediterranean regions, woodland offered shade, browse and forage during early summer drought seasons, when grazing was also reducing fire threats through controlling the understorey. In England, wood-pasture remains to characterize some of the most comprehensive and oldest trees in Europe. They provide valuable resources for various associated Biodiversity and have cultural and historical value. In southern England, the New Forest is among the largest remaining areas of wood-pasture in temperate Europe, with more than 3,000 hectares of woodland grazed by cattle, ponies, deer, and pigs (Smith et al. 2010). Recently, the New Forest was designated a National Park, and it has high cultural and biological value; hence, it must be grazed to preserve its unique nature.

Pollarding is an activity that involves cutting tree branches two to three meters above ground level to get wood for fuel or other uses and leaf fodder for feeding livestock. It has been a vital component of agriculture in Europe during the past centuries. In Europe, pollarding has a long history. Archaeological excavations have unveiled pollards that date back to the Iron Age. For example, a fossil oak pollard discovered during gravel extraction in the United Kingdom has been carbon-dated 3,400 years old (Smith et al. 2010). Fodder pollarding was practiced across Europe and was especially frequent in mountainous regions such as the Alps, Pyrenees, and high pasture regions of the Basque country and Northern Europe (Smith et al. 2010). The primary method for the collection of leaf fodder was cutting down all leaf-bearing branches during summer and drying them for livestock feed during winter. Trees could be cut on a rotation of two to three years.

Traditional hedgerows have many advantages. For example, hedges provide stock-proof hurdles, shelters, browse and forage for livestock, and medicinal plants and food for rural populations. However, in the second half of the 20th century, it started to be eliminated to create larger fields for more effective use of farm types of machinery. As a result, more than 50% of hedgerows have disappeared in the United Kingdom since 1947 (Smith et al. 2010). Notwithstanding the latest agri-environment schemes that have assisted in slowing the decline by the introduction of options that promote the management, recreation, and restoration of hedgerows. Until the previous century, nut and fruit silvoarable systems covered large regions of central Europe. *Streuobst* is fruit trees that are grown in a traditional central European system. They are tall trees with diverse varieties and types of fruits that belong to different age groups, dispersed on meadows, pastures, meadows, and croplands in a somewhat uneven association. *Streoubst* systems are subdivided into silvoarable and silvopastoral forms. Generally, the silvoarable system comprises paired rows of fruit trees intercropped closely to the tree trunks, with low branches for facilitating fruit harvest. All these declines are a result of increased mechanization and intensification (Reisner et al. 2007).

2.2.5 Influence of agroforestry on pollinators

Approximately 30% of the crops globally and 90% of all plants need cross-pollination for thriving and spreading (Shibu et al. 2009). Agroforestry is useful in promoting pollination, and bees are the most important pollinators. In addition to farm-grown vegetables and fruits, most wild plant species also rely on insect pollinators. Bees play a significant role in producing many nuts, seeds, fruits, and berries, serving as an essential food source for wild animals. Approximately 24 species of birds, such as the blackbird, starling, and ruby-throated hummingbird, prey on bees (Torralba et al. 2016). Many insects and spiders, such as praying mantises and dragonflies, also feed on bees. Among the main benefits of agroforestry for pollinator conservation is the value of floral resources that shrubs and trees provide. Shrub and tree species provide abundant nectar with relatively high sugar content such as *Aesculus* spp, *Acer* spp, *Salix* spp, *Tilia* spp, *Amelanchier* spp, *Rubus* spp, and *Prunus* spp. Pollen is a protein-rich resource used by honey bees, native bees, and some wasps for feeding their brood or to provide for their eggs. The main woody species that can offer nutritionally rich pollen *include Fraxinus* spp, *Castanea* spp, *Rubus, Prunus avium and Prunus domestica*, *Acer* spp and *Salix*.

Often, woody species in temperate regions flower early in the spring and are able to deliver some of the first nectar and pollen resources of the season, to boost early-season populations of pollinators. Spatially, agroforestry practices including a diversity of flowering species can deliver a high density of floral resources comparable to the land region occupied because of vertical layering. The main advantage of using agroforestry in supporting pollinators is that these practices are often implemented for other production and ecosystem services. Such practices often inherently offer some pollinator advantages and with additional considerations during management and design, the effectiveness of agroforestry practices for pollination services and pollinator conservation should be enhanced.

In addition, insect pollination is vital to food security, and approximately 35% of crop production globally depends on animal pollination (Priess et al. 2007). Unfortunately, insect pollinators are declining globally, with certain approximations that 40% of invertebrate species of pollinators could be threatened by extinction globally because of threats such as fragmentation and habitat loss, parasites and diseases, and pesticides (Kay et al. 2020). In addition to functional and structural diversities to agricultural lands, agroforestry may better support pollinator services and conservation. Temperate agroforestry systems significantly affect insect pollinators and their pollination services, emphasizing the role of shrubs and trees. Agroforestry activities offer three primary benefits for pollinators: they provide habitats such as egg-laying sites and foraging resources. They enhance the connectivity of the landscape and site, and they mitigate pesticide exposure. Agroforestry practices can improve crop yields and pollination (Bentrup et al. 2019). One of the main advantages of agroforestry for pollinator conservation is the value of floral resources offered by shrubs and trees. Shrubs and tree species provide profuse nectar with moderately high sugar concentrations such as horse chestnut, maple, willow, cherry and plum, brambles, and serviceberry. Pollen is a resource that is rich in proteins and is used by honey bees, native bees, and certain wasps for feeding their progeny or providing for their eggs. The main woody species for nutritionally rich pollen is maple, willow, cherry and plum, ash, and chestnut (Bentrup et al. 2019).

Woody species in temperate areas mainly flower early during the spring. Thus, they can provide some of the initial nectar and pollen resources of the season and boost early-season populations of pollinators. Spatially, agroforestry activities, including a variety of flowering species, can provide a high density of floral resources in relation to the land space occupied as a result of vertical layering (Kay et al. 2020). The main advantage of pollinators in supporting pollinators is that these activities are mostly applied for other ecosystem services and production. Thus, these activities mostly offer some pollinator advantages, and with more considerations during management and design, the efficiency of agroforestry practices for pollinator services and pollinator conservation should be improved (Kay et al. 2020).

2.2.6 Advantages of agroforestry

2.2.6.1 Ecosystem services

Agroforestry techniques can increase soil porosity, reduce water runoff, and increase soil cover, which can improve water retention and infiltration in the soil profile, hence reducing moisture stress during low rainfall years (Dollinger & Jose, 2018). Soils are under high pressure, but agroforestry improves soil fertility and nutrient cycling. Intensive farming methods are based on the principles of the economy instead of the principles of ecology. Still, it deals with living organisms interacting in complex ways that cannot be simplified and replicated uniformly. The presence of trees minimizes soil disturbance, which benefits a wide range of soil microorganisms, and allows a symbiotic formation of mycorrhizal associations between fungi and plant roots (Montagnini et al. 1999).

Agroforestry improves pollinator and wildlife habitat. However, loss of habitat due to modern developments and intensive agricultural practices with hectares of monoculture fields drives many amphibians, birds, mammals, and insects away from large areas of land. For instance, in some regions of the Czech Republic, farmers are suffering from significant crop losses because of the overpopulation of a small rodent referred to as common vole (Bentrup et al. 2019).

Through agroforestry, farmers aim to increase resource use efficiency (e.g., for light or water), reduce wind erosion (Zhu et al. 2000) and mitigate risks related to climate change (Smith et al. 2012). Agroforestry systems have strong biophysical interactions between the crops and the trees (Doufour et al. 2013). However, severe competition for water between trees and crops might only occur when the soil moisture content was low (Nambiar and sands, 1993). Shading caused by a companion tree in the agroforestry also helps maintain soil moisture (Mushagalusa et al. 2008).

Recently, the role of agroforestry in mitigation and adaptation to climate change has particularly received strong attention. Agroforestry is among the main practices used in agriculture for mitigating climate change. Agroforestry practices should be promoted because they are providing various environmental benefit (Palma et al. 2007), and increasing ecosystem services delivery (reducing soil erosion and nitrogen leaching, and increasing carbon sequestration and landscape biodiversity(Rigueiro - Rodriguez et al. 2009)

By acting as windbreaks, they slow air movement and can reduce evaporative water losses from crops (Jose et al. 2004). Similarly, although the shade cast by trees may limit the growth of crops, the consequent reduction in irradiance and hence transpiration may be beneficial in arid areas, especially when growing sensitive understorey vegetable crops; in some cases, there may be a moderate beneficial effect of shading for crop yield (Lin et al. 1999). Although competition for nutrients may occur, the deeper root systems of trees also bring up nutrients from deeper soil layers and reduce nutrient leaching from the topsoil. These nutrients are then recycled via leaf litter and turnover of roots, thereby increasing the overall resource-use efficiency of the system (van Noordwijk et al. 1996). Moreover, in the agroforestry systems, tree root distributions may be constrained both vertically and horizontally, due to competition with crop roots (Fernández et al. 2008), which could reduce the availability of water and nutrients in the soil (Schroth et al. 1995). Belowground competition of roots from different species has been described in intercropped agricultural fields with two or more herbaceous species (Ozier-Lafontaine et al. 1998) but has been seldom examined between trees and crops (Wang et al. 2014).

Agroforestry stabilizes soils and microclimate. Trees are among the most stabilizing elements in the landscape because they stand strong and tall in the landscape; they are well-rooted in the ground, with branches swinging in the wind. People and wildlife are instinctively driven to trees for safety. Trees planted as windbreaks can reduce wind speed by approximately 50%. Trees planted as windbreaks protect crops from falling or breaking down, mainly during the ripening stage when they are heaviest. By reducing the velocity of wind, trees also protect agricultural lands from wind erosion (Mosquera-Losada et al. 2018).

2.2.6.2 Production advantages

Agroforestry landscapes currently occupy 15.4 million hectares across the European Union (EU) – 3.6% of its total territorial area (den Herder et al. 2017). It has highlighted multiple benefits of agroforestry in Europe in terms of environmental benefits e.g., ecological values and biodiversity, social benefits e.g., rural employment and cultural practices and economic benefits e.g., diversified source of income (Plieninger et al. 2015).

The agroforestry landscapes combine woody vegetation with crops and/or animal grazing and production through a set of diverse and partially simultaneous land-management activities, resulting in multiple tangible and intangible benefits for human societies (Fagerholm et al. 2016). Trees have traditionally served three main purposes in the agrarian economy – the production of fruits, fodder and wood for fuel, litter or timber. Agroforestry is beneficial in providing various products and poverty reduction. Farmers advocate for monoculture, but properly managed agroforestry systems diversify the production of farms and can produce larger quantities from land. When favourable tree species are chosen, they do not compete for resources with crops. Instead, they offer more benefits than support higher yields of crops (Leakey et al. 2005). Most notably in the *dehesa* system, the trees provide an important source of fodder. Trees being managed exclusively for their leaves as a valuable food source for livestock during seasons when ground vegetation for grazing is sparse (Lachaux et al. 1988).

2.2.7 Disadvantages of agroforestry

Despite the multitude of positive benefits, many traditional European agroforestry systems (in particular silvoarable practices and systems such as meadow orchards) disappeared throughout the 20th century, due to agricultural intensification, mechanization and consolidation of agricultural land. As a result, bushes, hedgerows, and trees were removed and traditional land-use practices became abolished. Agriculture, forestry, and husbandry were seen and understood as three very separate land-use activities with few chemicals, material, and energetic relationships (Dupraz et al. 2005)

Agroforestry is a labour-intensive system that requires adequate planning, knowledge, and maintenance of trees periodically. When shrubs and trees are among crops, they do not allow complete mechanization of the farm's production, which can be irritating to farmers. The growth of healthy trees for profit needs regular maintenance work which takes years of commitment and is highly specialized. Spaces between trees should be maintained individually to control weeds' growth and ensure that all trees have enough room for development based on their purpose (Dix et al. 1999).

The main disadvantage of agroforestry is that agroforestry is not a quick-fix strategy. Unlike crops, trees take longer to mature before they can fulfill their role in the system. However, agroforestry is worth investing and effort if farmers plant trees with a broader vision for future generations. The price for agroforestry products might be high, but because it requires several years of waiting time, farmers are unsure whether the prices might not reduce when they need to sell their products, rendering their hard work futile (Wetzel et al. 2006).

Agroforestry creates limited possibilities for selling products. Farmers are reluctant about switching to agroforestry because of the poorly structured markets for most tree commodities. It is partly because most agroforestry products are not regularly traded. Such products are uncommon, and marketing them is challenging for farmers. Also, farmers experience fluctuations in prices, their products rejected, and an inability to get a new buyer. More challenges are due to the diverse nature of agroforestry commodities (Fischer et al. 2002).

Also, agroforestry farmers lack support. After the Second World War, intensified agriculture substituted other farming methods quickly. Monocultures were conquered because they were perceived as the most productive systems and allowed for efficiency and mechanization of farming processes. That is when agricultural incentives and policies started favouring such farming methods. It also signified when most trees on farms were eliminated to create room for subsidized cash crops. Regardless of the studies on the various advantages of agroforestry for sustainable agricultural production, supportive policies for this farming method are still inadequate (Beer et al. 1987).

Agroforestry can be miserably unsuccessful when applied in the wrong situation. Therefore, farmers should seek expert advice or conduct thorough research to consider local conditions, government regulations for land management, and market situations. (Cole 2010). The choice of the correct tree species determines the success of the entire system. Trees impact their surrounding environment, and the effect does not have to be always beneficial. In certain situations, trees host pests of crops or offer nesting habitats to rodents and birds that destroy crops. In some cases, introduced trees become invasive species resulting in more disadvantages than advantages (Budowski 1981).

3. Aims of the thesis

The general aim of the thesis was to assess the influence of temperate agroforestry (AF) systems on species richness and diversity of insect pollinators in the Czech Republic. The specific objectives were following:

- Influence of alley cropping agroforestry system on pollinators abundance, species richness and diversity compared to open field monocropping and nature close habitat.
- Assessment of pollinators similarity among the various habitats.
- Identification of pollinator groups in each habitat.

We expected that alley cropping AF will increase the abundance, species richness and diversity compared to open field monocropping and can provide two main benefits for insect pollinators in a temperate climate:

A) supplies habitat for them to forage, nest, and lay their eggs, and

B) serves as enhancing the site and landscape connectivity.

Through this knowledge, we can then design a better agroforestry system that will provide benefits to pollinators in addition to other desired ecosystem services.

4. Materials and methods

4.1 Study site

This study was conducted in Průhonice-Michovky in the Czech Republic (Figure 2). Průhonice is a village and municipality in Prague-West District in the Central Bohemian Region of the Czech Republic located on latitude 49°59′N and longitude 14°34′E and on an elevation of 303 m above sea level.

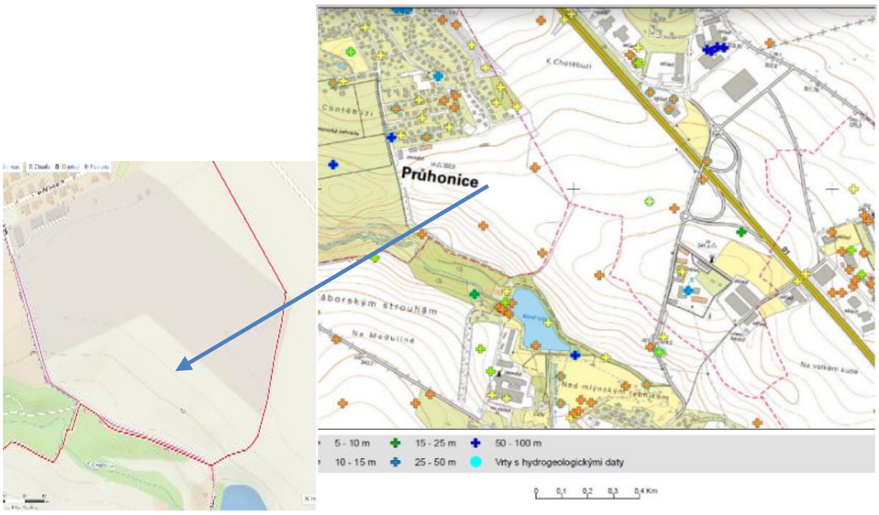

Figure 2. Map of the study area Michovky – Průhonice, Central Bohemia

According to the Czech Republic climate evaluation (kolektiv 1990), the site belongs to a warm and moderately dry climatic region. The mean annual temperature is 9.4 °C and the average annual precipitation is 687 mm (measured by a meteorological station at the locality).

Precipitation is the lowest in February, with an average of 37 mm. The highest precipitation falls in July, averaging 85 mm. At an average temperature of 19.3 °C, July is the hottest month of the year. January is the coldest month, with temperatures averaging -0.6 °C (Figure 3).

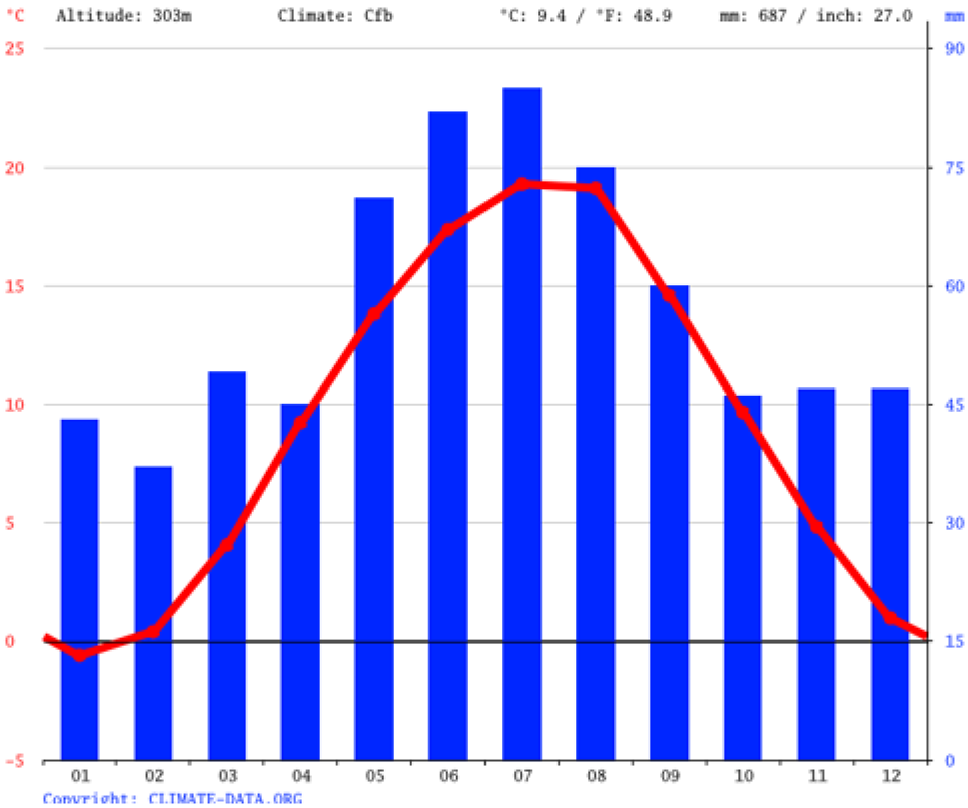

Figure 3. Climate diagram of Pruhonice (Source: Climate-Data 2021)

The Michovky experimental site was arable land used for agriculture and food production in the past. In 1991, agriculture production stopped on this site and it was converted into grassland.

The alley cropping (Table 2) system at Michovky (0.6 ha) was established for experimental purposes in 2018-2019. Distances between tree lines are 7, 10, and 15 meters. The soil of the AFS has been farmed by an agro co-operative. The distance between the Open field and AFSs is about 50 meters and the nature close to the habitat is about 15 meters respectively. The natural habitat was filled by the *Coniferae*, *silver fir*, *Pinus sylvestris* and various wild grasses. The open field was the fallow area and the land preparing for the next crops.

Table 2. Tree species in alley cropping agroforestry system in the experimental area

Row	Tree species	Mean distance in tree line (m)
1	*Tilia platyphyllos*	3.5
2	*Acer campestre, Fraxinus spp.*	1.0
3	*Acer campestre.,Sorbus aucuparia*	1.5
4	*Acer campestre.,Sorbus domestica*	2.0
5	*Tilia platyphyllos*	3.5
6	*Sorbus torminalis,Corylus colurna,Fraxinus excelsior*	2.5

During the selection of different habitats for pollinators monitoring (Table 3), we focused on differences in their characteristics. We paid attention to choose areas with different levels of canopy shade cover and tree diversity, different intensity of management and consequent various coverage of soil and amount of organic matter.

Table 3. General characteristics of the various vegetation habitats at the study site

Vegetation Habitat	Shade cover	Tree diversity	Size(ha)	Slope	Level of soil organic matter (%)
Alley cropping AF	High	High	0.6	Flat land	1
Open field	Low	None	2.2	Flat land	0.5
Natural habitat	High	High	0.2	Flat land	1.4

4.2 Data collection

Data were collected in the vegetation period during the months of May to September 2019. The insect pollinators were trapped with yellow pots (0.5.l, Figure 4) filled with a mixture of water, detergent and salt (1 teaspoon detergent, 500g salt in 5 litres water). Five traps were installed in open field monocropping (OF) and nature close habitat (NH) and 10 in alley cropping agroforestry, five in tree line (AF-TL) and five in crop line (AF-CL). The distance between the traps was at least 5 m (Figure 5).

Figure 4. Yellow container used in trapping insects

The insects trapped were collected for each trap separately every two weeks during the whole vegetation period and stored in ethanol. All insects were then sorted out, only the individuals of Hymenoptera order were selected and later identified to the species by an experienced entomologist.

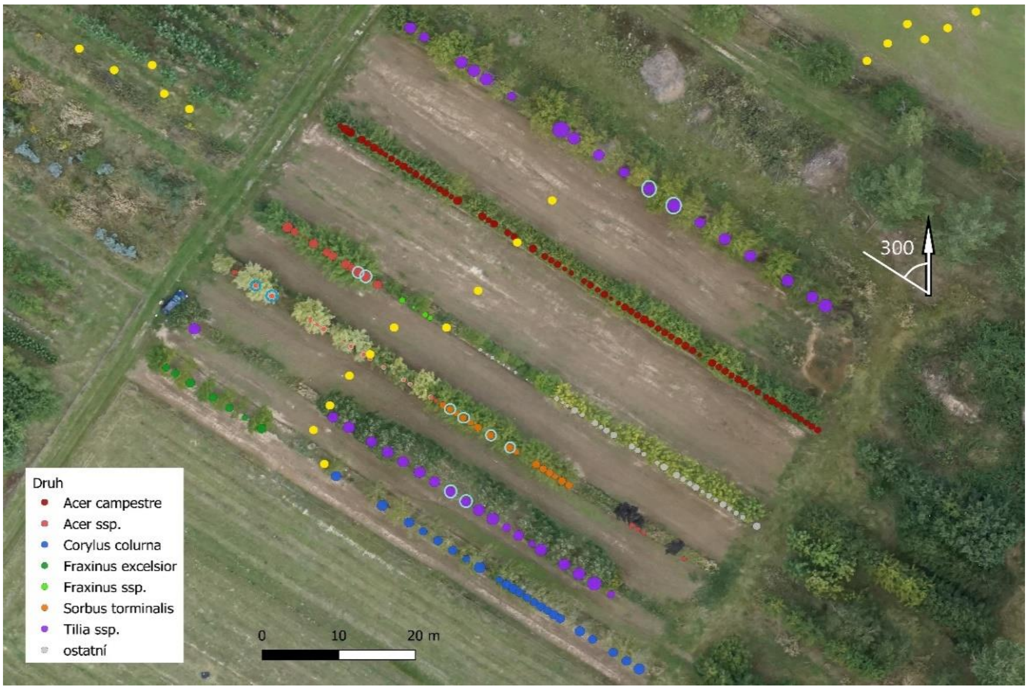

Figure 5. Design of experimental alley cropping agroforestry plot (yellow dots are the insect traps)

4.3 Data evaluation

We use an excel spreadsheet to firstly evaluate the fluctuation of the abundance of the pollinators during the vegetation period in each habitat. The insects captured during the entire sampling period were then pooled together to assess the abundance of pollinators according to families in each habitat.

For evaluation of insect species richness, we calculated the observed number of species in each habitat. For estimation of total species richness was used Jackknife species estimator. To evaluate insect diversity, the Shannon-Weiner and Simpson indices were calculated for each habitat. The Sorensen index and Venn diagram were used to estimate the similarity between different habitats.

The calculation of the indices is based on the following equations:

Jackknife estimate of species richness

Jackknife species richness estimator □ = □ + (□−1 □) □

Where Ŝ is Jackknife estimate of species richness, s is observed total number of species present in n quadrats, n is total number of quadrat samples and k is number of unique species (the species that occur only in one quadrate).

Shannon–Wiener of species diversity index

Shannon index H = - $\sum_{pi} \ln_{(pi)}$ S i =1

where s is the total number of species and p is the relative abundance of the i species. In contrast to direct measures of species richness (number of species), this index takes into account the relative abundances of species. The average value ranges from 1.5 - 3.5(Legendre and Legendre, 1998).

Simpson index of species diversity

$D = 1 - \Sigma(ni(ni - 1)) / (N (N - 1))$

D = 1 - Σ (n-1) where n is the number of individuals displaying one trait (e.g., the number of N(N-1) individuals of one species)

N = the total number of all individuals

The first nonparametric measure of diversity was proposed by Simpson (1949). Simpson suggested that diversity was inversely related to the probability that two individuals picked at random belong to the same species (Krebs 1998). The index measures the probability that two randomly selected individuals from a sample will be the same.

Sørensen index

$S_S = 2a/ (2a + b + c)$,

where:

A = total number of species of the first sample compared;

B = total number of species of the second sample compared;

C = number of species in common between the two samples compared.

The Sørensen index is a statistic used for comparing the similarity of two samples. It was developed by the botanist Thorvald Sørensen and published in 1948 (Sørensen, 1948).

Venn diagram

$n(A \cup B) = n(A) + n(B) - n(A \cap B)$

$n(A \cup B)$ represents the number of elements present in either one of the sets A or B

$n(A \cap B)$ represents the number of elements present essentially in both sets A and B

Named after John Venn (1834–1923), who used diagrams of overlapping circles to represent propositions, Venn diagrams are commonly used in set theory to visualize the relationships between different sets (Khalegh Mamakani et al.2012).

5. Results

5.1 Abundance of insect pollinators

In total, we captured and identified 1,795 individuals belonging to 15 families of Hymenoptera order (Table 4). The families with the highest number of species and number of individuals were: Halictidae, Colletidae, Crabronidae, Pompillidae and Andrenidae. The most abundant species were *Lasioglossum pauxillum*, *Trypoxylon attenuatum*, *Trypoxylon minus*, and *Apis mellifera* (Appendix A).

The family Halictidae were the most abundant group found in agroforestry tree lines and natural habitat. The pollinator species of *Lasioglossum pauxillum* (Halictidae) and *Hylaeus confusus* (Colletidae) were the most abundant in natural habitat and agroforestry tree lines.

In terms of percentage (Table 4), we observed that out of the total 15 families, three families composed around 60 % of all pollinator abundance. The highest percentage of insect pollinators were found in the family of the Halictidae 30.8 %, Colletidae 16.8 % and Crabronidae 16% (Figure 6).

The highest number of individuals were found in agroforestry tree lines (38.9 %) while the lowest number of individuals were found in open field (5.79 %).

Table 4. Insect pollinators abundance, percentage share and number species of each family in various habitats (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field)

	Number of individuals					Abundance Families (%)					No. of Species			
Family	**NH**	**AF-TL**	**AF-CL**	**OF**	**Sum**	**NH**	**AF-TL**	**AF-CL**	**OF**	**Total**	**NH**	**AF-TL**	**AF-CL**	**OF**
Ampulicidae	0	5	1	0	6	0.00%	0.70%	0.20%	0.00%	0.30%	0	1	1	0
Andrenidae	26	66	87	8	187	5.10%	9.40%	18.20%	7.70%	10.40%	11	13	11	4
Apidae	30	33	19	3	85	5.80%	4.70%	4.00%	2.90%	4.70%	13	13	12	2
Bethylidae	1	2	8	0	11	0.20%	0.30%	1.70%	0.00%	0.60%	1	1	1	0
Colletidae	116	88	94	4	302	22.60%	12.60%	19.60%	3.80%	16.80%	7	6	7	3
Crabronidae	69	124	75	23	291	13.50%	17.70%	15.70%	22.10%	16.20%	10	18	20	6
Halictidae	177	186	140	49	552	34.50%	26.60%	29.20%	47.10%	30.80%	15	21	22	12
Chrysididae	10	14	4	6	34	1.90%	2.00%	0.80%	5.80%	1.90%	5	5	4	1
Megachilida	13	8	4	0	25	2.50%	1.10%	0.80%	0.00%	1.40%	7	6	4	0
Mutillidae	1	4	0	0	5	0.20%	0.60%	0.00%	0.00%	0.30%	1	1	0	0
Pompilidae	48	141	33	6	228	9.40%	20.20%	6.90%	5.80%	12.70%	13	17	11	6
Sapygidae	0	0	1	0	1	0.00%	0.00%	0.20%	0.00%	0.10%	0	0	1	0
Sphecidae	11	24	6	0	41	2.10%	3.40%	1.30%	0.00%	2.30%	1	1	1	0
Tiphiidae	0	0	2	0	2	0.00%	0.00%	0.40%	0.00%	0.10%	0	0	1	0
Vespidae	11	4	5	5	25	2.10%	0.60%	1.00%	4.80%	1.40%	4	2	2	3
Sum	513	699	479	104	1795	100%	100.00%	100.00%	100.00%	100.00%	88	105	98	37

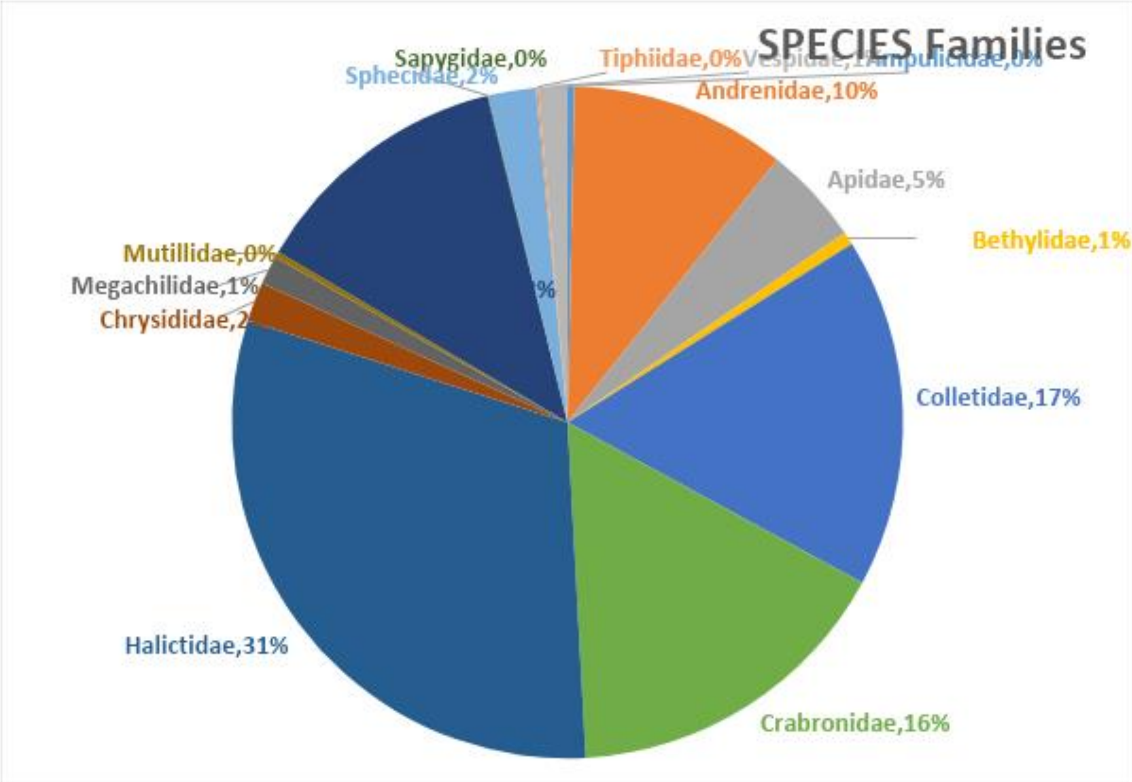

Figure 6. Percentage the number of individuals found in the study area (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field)

5.2 Seasonal fluctuations of insect pollinators' abundance

There was a strong fluctuation of insect pollinators' abundance during the vegetation period in all habitats (Figure 7). The highest abundance was recorded in mid-July in the agroforestry tree line. The lowest abundance in the open field was found in May and the beginning of September. The highest number of insect pollinators was found in agroforestry crop lines in the spring, but towards the autumn, it had the lowest abundance. The peak time for the number of insect pollinators was in the middle of July. An effective difference in the species abundance was found between agroforestry crop lines and the open field in the month of May.

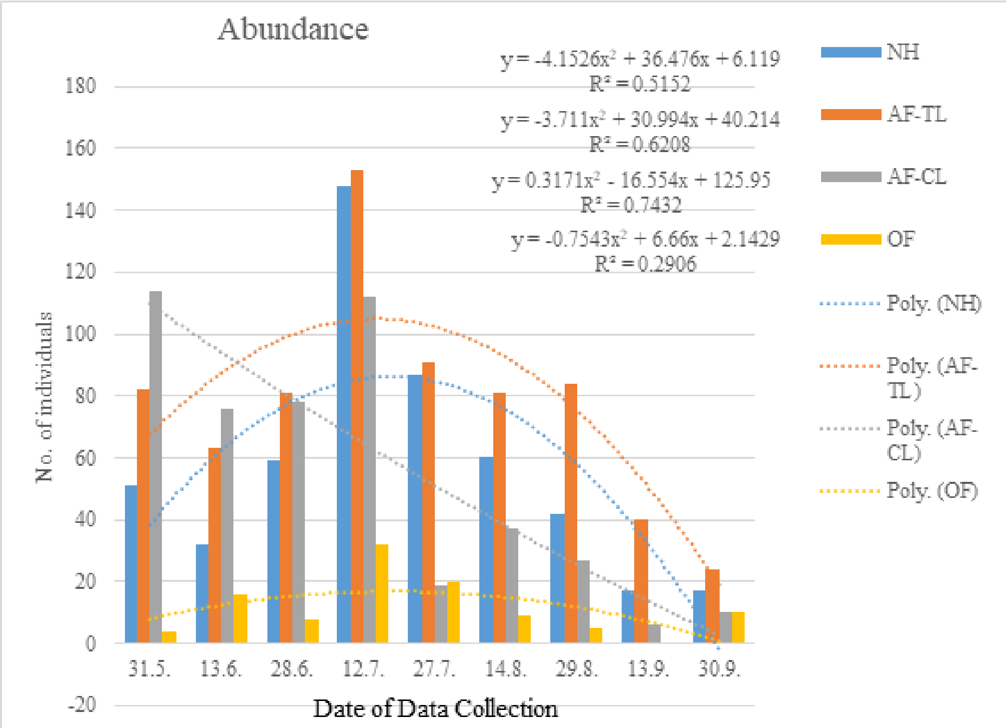

Figure 7. Seasonal fluctuations of the pollinator's abundance in different habitat (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field)

5.3 Species richness and diversity of insect pollinators

The highest observed species richness was found in the agroforestry tree lines and agroforestry crop lines in the middle of July (Figure 8). We also found that the species *Hylaeus confusus*, *Lasioglossum morio* and *Trypoxylon minus* were the most abundant in the agroforestry tree line while in the agroforestry crop line most abundant species were the *Hylaeus brevicornis*, *Lasioglossum pauxillum* and *Andrena flavipes*. We observed an important difference that the highest number of individuals (*Lasioglossum pauxillum*) species was found in the natural habitat compared to all other habitats. The lowest species richness was recorded in the month of September in the open field. The highest richness in species was found in the Halictidae family in the agroforestry crop line followed by the agroforestry tree line, the nature close habitat and the open field.

To study different habitats, we classified the number of highest species richness on the agroforestry tree line, the natural habitat, the agroforestry crop line and the open field individually in the AFSs.

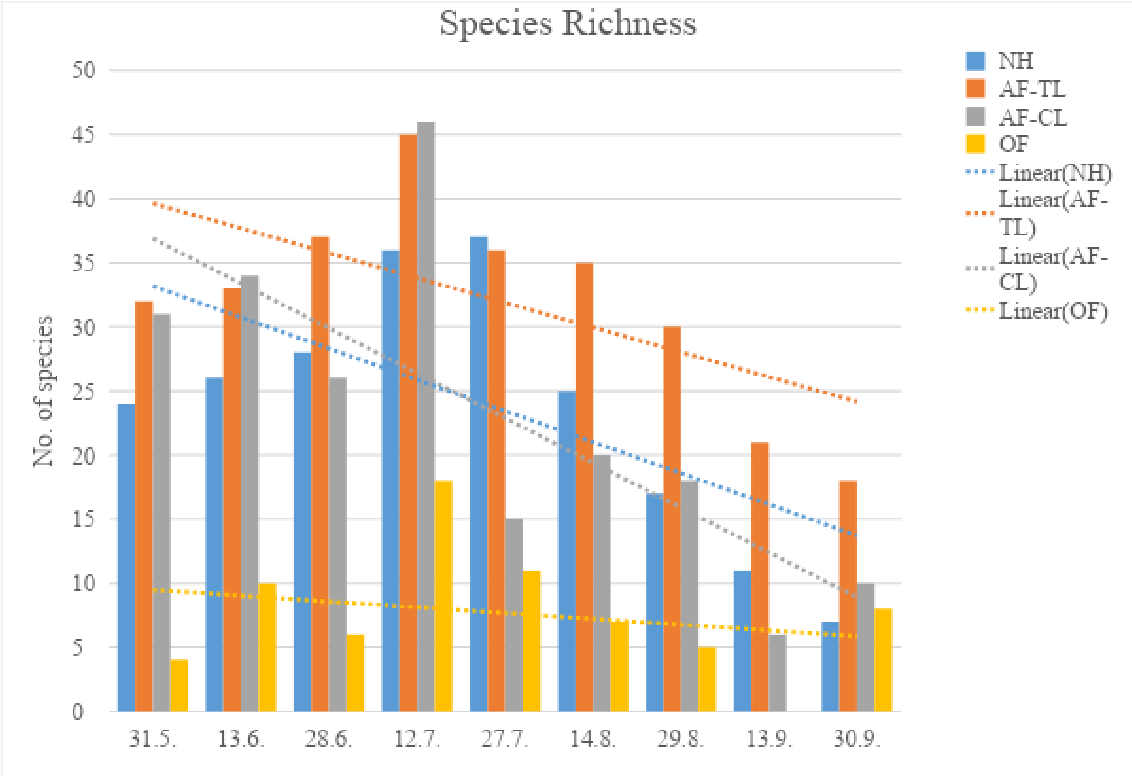

Figure 8. Seasonal fluctuations of the pollinator's species richness in different habitat (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field)

According to the Jackknife estimator, the highest estimated species richness was found in the agroforestry tree line, followed by the agroforestry crop line, natural habitat and the lowest in the open field (Table 5). Based on the Shannon-Wiener index of species diversity, the agroforestry tree line had the highest species diversity and the open field had the lowest species diversity. The highest number of effective species was observed in the agroforestry tree line.

According to the Simpson's Diversity Index, higher values (near 1) indicate a high diversity in the agroforestry system. The agroforestry tree line had the highest diversity index (0.973) and the lowest diversity index (0.942) was recorded in nature close to the habitat.

Table 5. Abundance, species richness and various diversity indices of insect pollinators found in various habitats

Habitat	**No of individuals**	**No of species**	**No of unique sp.**	**Jackknife Estimator of Sp. Richness**	**Shannon-Wiener index of sp. diversity**	**Effective number of species**	**Simpson index of sp. diversity**
Natural habitat	513	88	20	108	3.563	35.3	0.942
AF-Tree line	699	105	20	125	3.974	53.2	0.973
AF-Crop line	479	98	18	116	3.859	47.4	0.965
Open field	104	37	2	39	3.346	28.4	0.954
Total	1795	153					

5.4 Similarity among habitats

Using the Sorensen similarity index (Table 6), the highest similarity was observed between the agroforestry tree line and the agroforestry crop line. We observed the moderate similarity index between the nature close to habitat and the agroforestry tree line. Based on the result, the similarity index between the open field and the nature close to the habitat.

Table 6. Species similarity Sorensen index of insect pollinators (lower left half of the table) and number of shared species (upper right half of the table), (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field)

Habitats	**NH**	**AF-TL**	**AF-CL**	**OF**
Natural habitat	x	61	55	28
AF-Tree line	0.632	x	74	31
AF-Crop line	0.591	0.729	x	32
Open field	0.448	0.437	0.474	x

Venn diagrams (Figure 9) help to visually illustrate the similarities and differences between different agroforestry systems. This is an illustration where overlapping circles are used to show the number of shared species among the different habitats. Similar pollinator (24 sp.) species were observed in all four habitats. In addition, there were many common species found in different habitats such as *Lasioglossum pauxillum*, *Lasioglossum morio*, *Andrena flavipes*, *Bombus terrestris*, *Hylaeus communis*, *Halictus* *tumulorum*, *Cryptocheilus versicolor*, *Trypoxylon minus*, *Hylaeus hyalinatus*, *Sphecodes crassus*, *Hedychridium coriaceum*, *Lasioglossum morio*, *Apis mellifera*, *Halictus subauratus*, *Priocnemis hyalinata*, *Andrena flavipes* etc.

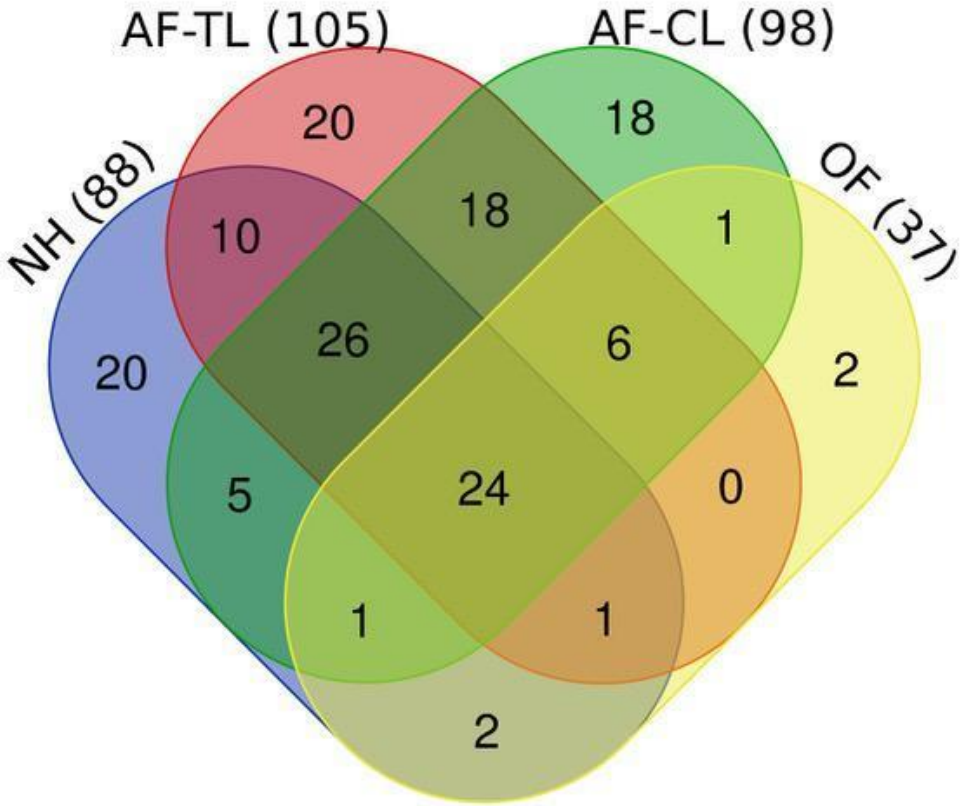

Figure 9. Venn diagram of similarity of pollinators species found in various habitats (NH – natural habitat, AF-TL – agroforestry tree line, AF-CL – agroforestry crop line, OF – open field). Number in parenthesis is the species richness in corresponding habitat.

The data show that out of 153 species, 24 species were found in all habitats (Appendix B). The largest number of similar species was found in three habitats (The agroforestry tree line, agroforestry crop line and natural habitat). The similar species were found in the above three habitats such as *Oplitis leucomelana*, *Anoplius nigerrimus*, *Arachnospila anceps*, *Nomada flavoguttata*, *Hedychrum gerstaeckeri*, *Passaloecus singularis*, *Halictus simplex*, *Caliadurgus fasciatellus*, *Pseudomicrodynerus parvulus* and *Crossocerus exiguus* etc. The minimal (1 sp.) similar species were found (*Trypoxylon beaumonti,* family of Crabronidae) in the agroforestry crop line and the open filed habitat.

6. Discussion

6.1 Abundance of insect pollinators

The highest abundance of insect pollinators was found in the agroforestry tree line. Our results are consistent with other studies showing that agroforestry systems increase the number of insect pollinators in agroecosystems and provide ecosystem services (Martin et al. 2019).

In the present study, most of the *Lasioglossum pauxillum, Lasioglossum morio, Halictus subauratus, Lasioglossum lucidulum* (family Halictidae), *Diodontus luperus*, Crossocerus *exiguous* (family Crabronidae), *Hylaeus dilatatu*s, *Hylaeus confuses* (family Colletidae), *Cryptocheilus versicolor* and *Arachnospila anceps* (family Pompilidae) were found in the agroforestry tree line. This habitat was the most suitable for the bees as they collect nectar from flowers there. The presence of flowering trees (*Acer campestre* from the family Sapindaceae, *Fraxinus excelsior* from the family Oleaceae, *Sorbus aucuparia* from the family Rosaceae) and herbaceous flowering plants in the experimental plot were probably the most important reason why the highest number of insect pollinators was found in the agroforestry tree line. The observed increase in insect pollinator numbers is likely due to the AF treatments providing more floral, nesting, and larval resources, more undisturbed areas, and more diverse vegetation structure (Scheper et al. 2015).

The nature close to habitat was also an important habitat for insect pollinators, as the second highest number of pollinator occurrences (*Lasioglossum pauxillum, Hylaeus confusus, Priocnemis agilis* family of helictidae, Colletidae and Pompilidae respectively) were observed there. The natural habitat serves as a home and breeding ground for insects. Roubik at el. (1989) reported that bees use natural habitats for their nests to protect adults and developing larvae from predators, parasites and extreme environmental conditions. Most species lived in the natural habitats with a potentially unlimited supply of mud, leaves, resin, dead wood and large protected chambers.

Natural habitats have abundant and diverse floral and nesting resources that allow them to support a wide range of pollinator species (Potts et al. 2005). We examined our experimental area, specifically the natural habitat that supports several species of flowering plants (*Coniferae, silver fir, Pinus sylvestris) and* wild grasses. In many studies, it was found that natural habitats at landscape level, flowering plants within agricultural fields can also support higher diversity and performance of pollinators (Carvalheiro et al. 2011). In addition, nature near habitat also provides sufficient floral resources for foraging and suitable conditions for nesting (Roulston and Goodell, 2011).

According to our data, the agroforestry crop line had the third highest number of abundances. In this habitat, we found almost 80% of occurrence in only three families such as Halictidae (Lasioglossum pauxillum), Colletidae (Hylaeus brevicornis), Andrenidae (Andrena minutula, Andrena flavipes), Crabronidae (Trypoxylon minus). The agroforestry crop line was merged with the agroforestry tree line. It is likely that many insect pollinators nest near the agroforestry tree line (in the shade of the trees) and then move around the crop line. In addition, Mcgregor at al. 1976 found that Apis mellifera and Andrena minutula were considered the most important insect pollinators in the agroforestry crop area.

We counted that the number of abundances was lower in the agroforestry crop line compared to the agroforestry tree line and the nature close habitat. We concluded that the habitat at the crop line was the most disturbing area for pollinators, as it was fallow land and land for preparing the next crop. Kevan at el. (1986) reported that land removal due to agricultural expansion disturbed habitat for local insect pollinators. We also found that the habitat at the crop line was empty due to flowering plants, which is another cause of the decline of insect pollinators compared to other habitats with high abundance. Macgregor et al. 1976 defined that the main role of pollination in agriculture is in the known food crops that depend wholly or partly on insect pollinators for pollination, including flowering crops or trees.

Compared to the other habitats, only a small number of species were found in the open field. This finding is directly related to the distribution of vegetation in the study areas, which had a high tree cover compared to the open field. We found a case that proves that the occurrence of pollinators is likely influenced by the distribution of flowering plants that serve as food sources, the amount and composition of soil available for nesting sites, and other environmental variables (Aguirre-Gutiérrez et al. 2015). The open field was a field of monocultures with no other plants, shrubs, or trees. The lower absence of pollinator species in this habitat could be related to a lack of food supply and flowers. Kremen et al. (2002) reported that agricultural intensification has a negative effect on wild bee abundance and diversity by increasing habitat fragmentation and limiting the availability of nesting sites and food resources. However, another explanation is that they are also affected by direct sunlight, rain and wind. A similar study also found that in agricultural landscapes, negative impacts on pollinator diversity caused by habitat loss and landscape simplification, however it can be offset by semi-natural habitats (Winfree et al. 2011).

6.2 Seasonal fluctuations of insect pollinators abundance

We found substantial fluctuations in insect pollinators abundance throughout the season, but the highest pollinator occurrence for all four habitats was found in July. Smart et al. (2016) reported that honey bees collect large amounts of pollen from non-native plant species during the summer between late June and September. Gill et al. (2017) confirmed that pollinator emergence and seasonal abundance are related to changes in seasonal weather, such as the accumulation of growing degree days and rising temperatures. We predict that the timing of pollinator emergence in this ecosystem is at least partially dependent on temperature.

At the beginning of our data collection (month of May), the number of pollinator species was highest (Lasioglossum pauxillum) family of Helictidae, (Andrena minutula, Andrena flavipes) family of Andrenidae in the agroforestry crop line and lowest in the open field. This may be explained by the fact that many temperate insects avoid extreme temperature stress by diapause, but that temperature fluctuations during the active season may affect insect survival (Janzen, 1967). We found that pollinator insects in all habitats gradually declined from July to late August. Scheper et al. 2014 confirmed that the scarcity of floral resources for honeybees and wild bees was most pronounced in the Northern Hemisphere summer months of July and August. September is probably the late season for some flowering plants, but then pollinators gradually decline due to food scarcity. Goulnik et al. (2021) reported that temporal stability of floral resources may also cause species pollinator densities to decline. This has particular implications for pollinators that require nectar and pollen throughout the season. In addition, our results suggest that pollinator insects probably have little survival power to withstand the cold weather.

The open field habitat was constantly changing its crops. Potts et al. (2010) reported that increasing land use changes are considered a major pressure on European bees. We found a greater number of species in AF -TL compared to other habitats. Less than 10% of abundance was recorded in the open fields. Therefore, we can assume that frequently used arable fields are not a suitable place for insect pollinators. Forrest et al. (2015) supports our assumption that the probability of occurrence of most species was greatly reduced in intensively used croplands.

6.3 Species richness and diversity of insect pollinators

We expected that the nature close to habitat in the experimental area would have the greatest richness and diversity. Schroth et al. (2004) found in an experiment that agroforestry systems are generally characterized by a canopy of shade trees under which a wide range of crops can be grown, and which provide shade for insects and animals. However, our data have shown that the highest values are found in the agroforestry tree line.

We assumed that the agroforestry tree line is a central area of all habitats. The area is mainly a transition between two habitats, the agroforestry tree line and the agroforestry crop line. This habitat contains many species of perennial flowering trees such as *Tilia platyphyllos, Acer campestre, Sorbus domestica, Tilia platyphyllos, Sorbus torminalis, Corylus colurna and Fraxinus excelsior*. Pollinator species meet their needs (e.g., nesting, food) in these habitats. This would be a good reason why this habitat has the largest number of insect pollinators. Kouki et al. (1999) collected evidence that some insect pollinators such as *Pseudomicrodynerus parvulus* and *Vespula vulgaris* (family Vespidae) are highly abundant in the tree line ecotone. Shmida et al. (1985) reported that ecotones have been shown to have particularly high species diversity across multiple tree lines (i.e., number of species in an area, species richness).

Species richness and diversity were different in each of the habitats. Jennersten et al. (1984) observed *Bombus terrestris* (family Apidae) and *Lasioglossum morio* (family Helictidae) as the most important pollinator insects in Britain and Central Europe. The most common families were Halictidae, Colletidae, Colletidae and Pompilidae, respectively. We hypothesized that greater abundance and/or diversity of pollinating insects would lead to improved pollination performance, as reported in Castle et al. (2019).

As mentioned earlier, the agroforestry tree line had the highest species diversity. Fontaine et al. (2006) found that the effects of pollinator species diversity depend mainly on available plants or vegetation in the habitats and that plants play a crucial role in AFSs. We observed that the tree line of AF was covered by different types of shade trees where pollinator species were more abundant compared to other habitats. Forsyth et al. 1982 reported that more intensive management of agroforestry systems with the production of shade trees had a positive effect on the diversity (species richness and abundance combined in the Simpson index) of *Lasioglossum morio* and *Vespula vulgaris*.

We found that the number of insect pollinators are very equivalent between the agroforestry tree line and the agroforestry crop line. We assume that the two habitats are very close to each other, and the environmental conditions are also similar. Therefore, pollinator species can migrate from one habitat to the other. We can assume that the insect life cycle is the same in both habitats, e.g., nesting, foraging, feeding, etc. The results indicate that the difference in species richness among the natural habitat, the agroforestry crop line and the open field were low, compare to the agroforestry tree line.

6.4 Similarity among habitats

The Sorensen similarity index registered that the agroforestry-tree line and the agroforestry-crop line were the most similar habitats in terms of species composition, followed by the agroforestry tree line and the nature close habitat, the nature close habitat and the agroforestry crop line. We assumed that both habitats were very close to each other and had a similar environment, which is why we found many similar species in this area. We found the second highest similarity of pollinator species in the agroforestry tree line and the nature close habitat. We assumed that the nature close habitat and the agroforestry tree line were covered with a variety of flowering trees, shrubs, and wild grasses. Both habitats were similar in terms of food base and habitat. We frequently observed insect pollinators moving through the insect colony from one habitat to the other. The open field and the agroforestry tree line were the least similar among all habitats. We have assumed that two habitats are far away compared to other habitats, so the living standard of pollinators in both habitats was different, which could be a crucial reason for the low similarity in both habitats.

7. Conclusion

we found that the alley cropping AF increases abundance, species richness, and diversity compared to the natural habitat and the open field monoculture cropping. Species abundance and richness occurred in a peak season in all habitats in month of July. The highest species richness and diversity were found in alley cropping, while the lowest in the open field was due to lack of food resources, nesting opportunities, climate, pesticides and limited food supply. Relatively high overall species richness and initial high abundance in the agroforestry tree line may indicate that the agroforestry alley cropping area provides better habitat for insect pollinators than the open field and even natural habitat. Agroforestry tree line and the nature close habitat had the highest number of pollinator species from the same families such as Halictidae, Colletidae and Crabronidae. While the agroforestry crop line was more abundant the family of Andrenidae, Halictidae, colletidae. Linear agroforestry practices such as alley cropping in temperate regions can contribute to pollinator conservation by providing habitat, including food sources and nesting or egg-laying sites, improving site and landscape connectivity, and reducing pesticide exposure. The presence of diverse pollinators provides multiple ecosystem services and functions and adds robustness and resilience to pollinator networks. Our results suggest that a well-managed agroforestry system has the potential to sustain a wide variety of native pollinator species

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Appendix A

Insect species of selected pollinators (Hymenoptera order) are found in the agroforestry tree line, agroforestry crop line, nature close to habitat, and open field.

Family	Pollinator's species	AF-TL	NH	AF-CL	OF	Season
Pompilidae	Dolichurus corniculus	2	1	3	0	6
Sphecidae	Andrena albofasciata	24	11	6	0	41
Andrenidae	Andrena carantonica	2	1	0	0	3
	Andrena dorsata	1	0	0	0	1
	Andrena flavipes	0	3	2	0	5
	Andrena floricola	24	10	27	2	63
	Andrena gravida	1	0	2	0	3
	Andrena helvola	6	0	5	3	14
	Andrena chrysosceles	1	0	1	0	2

	Andrena labialis	1	0	5	0	6
	Andrena labiata	0	0	1	0	1
	Andrena minutula	0	1	0	0	1
	Andrena minutuloides	25	3	35	0	63
	Andrena nigroaenea	1	0	6	1	8
	Andrena ovatula	1	0	2	0	3
	Andrena proxima	1	0	0	0	1
	Andrena pusilla	0	1	0	0	1
	Andrena strohmella	0	1	0	0	1
	Andrena subopaca	1	0	1	0	2
	Andrena viridescens	1	1	0	0	2
	Andrena wilkella	0	1	0	0	1
	Panurgus calcaratus	0	1	0	2	3
Pompilidae	Apis mellifera	0	1	0	0	1
	Bombus lapidarius	4	4	1	0	9

Apidae	Bombus lucorum	1	1	1	1	4
Pompilidae	Bombus pascuorum	19	7	3	0	29
	Bombus terrestris	2	0	0	0	2
	Ceratina cyanea	2	0	0	0	2
	Nomada atroscutellaris	3	2	1	0	6
Bethylidae	Nomada bifasciata	0	1	0	0	1
Apidae	Nomada castellana	1	3	0	0	4
	Nomada fabriciana	3	1	3	0	7
	Nomada flava	3	0	1	0	4
	Nomada flavoguttata	2	2	4	2	10
Pompilidae	Nomada fucata	4	1	5	0	10
Apidae	Nomada guttulata	0	1	0	0	1
Crabronidae	Nomada marshamella	1	0	0	0	1
	Nomada minuscula	0	0	1	0	1
Megachilidae	Nomada sheppardana	0	1	0	0	1

Crabronidae	Nomada succincta	10	1	15	0	26
	Bethylus cephalotes	1	0	1	0	2
Pompilidae	Pseudisobrachium subcyaneum	30	9	7	1	47
Crabronidae	Hylaeus brevicornis	3	1	0	0	4
	Hylaeus communis	30	9	15	3	57
Pompilidae	Hylaeus confusus	4	1	0	0	5
Ampulicidae	Hylaeus dilatatus	5	0	1	0	6
Crabronidae	Hylaeus gredleri	1	0	0	0	1
	Hylaeus hyalinatus	6	0	0	0	6
Pompilidae	Hylaeus paulus	0	0	1	0	1
Halictidae	Hylaeus variegatus	3	0	17	2	22
	Cerceris quinquefasciata	11	3	4	0	18
	Cerceris rybyensis	19	15	2	6	42
Halictidae	Crossocerus exiguus	16	20	5	2	43

Crabronidae	Crossocerus quadrimaculatus	0	0	1	0	1
Chrysididae	Didineis lunicornis	6	4	1	6	17
	Diodontus luperus	5	0	1	0	6
	Ectemnius lapidarius	1	1	1	0	3
Chrysididae	Entomognathus brevis	0	3	0	0	3
Megachilidae	Harpactus laevis	0	1	0	0	1
	Lindenius albilabris	1	2	1	0	4
	Lindenius pygmaeus armatus	1	3	1	0	5
Colletidae	Mimumesa dahlbomi	12	3	45	0	60
	Mimumesa unicolor	2	2	1	1	6
	Nysson dimidiatus	38	62	6	0	106
	Oxybelus trispinosus	28	35	19	2	84
	Passaloecus brevilabris	0	3	6	0	9
	Passaloecus clypearis	7	3	16	1	27
	Passaloecus singularis	0	8	0	0	8

	Pemphredon inornata	1	0	1	0	2
Chrysididae	Pemphredon lugubris	1	0	0	0	1
	Pemphredon wesmaeli	1	1	1	0	3
Halictidae	Tachysphex dimidiatus	1	0	0	0	1
	Tachysphex jokischianus	2	0	0	0	2
	Trypoxylon attenuatum	0	1	0	0	1
	Trypoxylon beaumonti	1	0	19	3	23
	Trypoxylon figulus	1	0	0	0	1
	Trypoxylon medium	7	10	4	2	23
	Trypoxylon minus	1	0	0	0	1
	Halictus scabiosae	18	6	7	4	35
	Halictus simplex	5	2	3	4	14
	Halictus subauratus	21	3	14	3	41
	Halictus tumulorum	36	24	8	6	74
	Lasioglossum calceatum	0	0	8	0	8

	Lasioglossum clypeare	33	84	34	13	164
	Lasioglossum interruptum	1	0	3	2	6
	Lasioglossum laticeps	0	1	0	0	1
	Lasioglossum lativentre	2	0	0	0	2
	Lasioglossum leucopus	1	0	1	0	2
	Lasioglossum leucozonium	4	1	2	0	7
	Lasioglossum lucidulum	0	0	1	0	1
	Lasioglossum malachurum	0	4	0	0	4
Crabronidae	Lasioglossum minutissimum	1	0	1	0	2
	Lasioglossum morio	0	0	3	0	3
Megachilidae	Lasioglossum nitidiusculum	1	2	0	0	3
	Lasioglossum pauxillum	0	1	0	0	1
	Lasioglossum politum	3	3	1	0	7
Crabronidae	Lasioglossum punctatissimum	1	0	1	0	2
	Lasioglossum pygmaeum	2	0	1	0	3

Mutillidae	Lasioglossum quadrinotatum	4	1	0	0	5
Apidae	Lasioglossum villosulum	0	1	0	0	1
	Lasioglossum xanthopus	2	0	2	0	4
	Lasioglossum zonulum	3	3	1	0	7
	Sphecodes crassus	2	10	1	0	13
	Sphecodes ephippius	2	1	0	0	3
	Sphecodes geoffrellus	3	4	1	0	8
	Sphecodes gibbus	0	1	1	0	2
	Sphecodes miniatus	0	0	1	0	1
	Sphecodes monilicornis	0	1	0	0	1
Apidae	Sphecodes niger	1	0	0	0	1
	Hedychridium coriaceum	9	1	2	0	12
	Hedychridium rossicum	1	0	1	0	2
Crabronidae	Hedychrum gerstaeckeri	1	0	0	0	1
Vespidae	Hedychrum nobile	1	1	0	0	2

Megachilidae	Chrysura cuprea	1	0	0	0	1
	Chrysura dichroa	1	0	1	0	2
Crabronidae	Pseudochrysis neglecta	0	0	2	0	2
Andrenidae	Coelioxys inermis	0	3	0	0	3
Crabronidae	Heriades truncorum	0	1	0	0	1
	Hoplitis claviventris	2	7	1	0	10
	Hoplitis leucomelana	6	10	3	0	19
Crabronidae	Megachile centuncularis	1	1	2	0	4
	Megachile circumcincta	0	0	1	0	1
	Megachile versicolor	0	0	1	0	1
Vespidae	Osmia bicornis	0	0	0	2	2
	Osmia caerulescens	0	2	0	1	3
Pompilidae	Myrmosa atra	11	12	0	0	23
	Agenioideus cinctellus	12	2	3	1	18
	Anoplius caviventris	1	0	1	1	3

	Anoplius nigerrimus	8	4	0	1	13
	Arachnospila anceps	7	3	1	1	12
	Arachnospila minutula	19	0	0	0	19
	Auplopus albifrons	10	1	7	1	19
Pompilidae	Auplopus carbonarius	3	0	0	0	3
Bethylidae	Caliadurgus fasciatellus	2	0	8	0	10
Chrysididae	Cryptocheilus versicolor	0	1	0	0	1
Vespidae	Dipogon subintermedius	3	7	1	0	11
Sapygidae	Evagetes crassicornis	0	0	1	0	1
Halictidae	Priocnemis agilis	1		1	2	5
	Priocnemis confusor	0	2	3	0	5
	Priocnemis cordivalvata	2	0	0	0	2
	Priocnemis fennica	0	0	1	0	1
	Priocnemis hyalinata	0	0	1	0	1
	Priocnemis minuta	0	0	1	0	1

	Priocnemis parvula	0	0	1	0	1
Crabronidae	Priocnemis pusilla	2	0	0	0	2
Crabronidae	Sapygina decemguttata	0	0	2	0	2
Tiphiidae	Ammophila sabulosa	0	0	2	0	2
Crabronidae	Tiphia femorata	5	11	3	6	25
	Odynerus melanocephalus	0	0	2	4	6
	Polistes dominula	0	0	0	1	1
	Polistes nimpha	23	18	8	4	53
	Pseudomicrodynerus parvulus	28	10	11	5	54
Vespidae	Vespula vulgaris	0	1	4	2	7
	Total pollinators abundance	699	513	479	104	1795
	Total number of species/ species richness	105	88	98	37	328

Appendix B

Shared species of insect pollinators (Hymenoptera order) caught in various habitats in the study site during the vegetation season of 2019 (AF-TL - agroforestry tree line, AF-CL agroforestry crop line, NH - natural habitat, and OF - open field).

Habitats	Number of similar species	Shared species
AF-CL (98) AF-TL (105) NH (88) OF (37)	24	*Bombus terrestris, Hylaeus communis, Halictus tumulorum, Cryptocheilus versicolor, Lasioglossum pauxillum, Trypoxylon minus, Hylaeus hyalinatus, Sphecodes crassus, Hedychridium coriaceum, Lasioglossum morio, Apis mellifera, Halictus subauratus, Priocnemis hyalinata, Andrena flavipes, Trypoxylon medium, Priocnemis parvula, Lasioglossum malachurum, Diodontus luperus, Lasioglossum leucopus, Hylaeus dilatatus, Trypoxylon attenuatum, Lasioglossum lucidulum, Lasioglossum minutissimum, Priocnemis confusor.*
AF-CL (98) AF-TL (105) NH (88)	26	*Hoplitis leucomelan, Anoplius nigerrimus, Arachnospila anceps, Nomada flavoguttata, Hedychrum gerstaeckeri, Passaloecus singularis, Halictus simplex, Caliadurgus fasciatellus, Pseudomicrodynerus parvulus, Crossocerus exiguous, Chrysura dichroa, Pemphredon inornate, Ammophila sabulosa, Agenioideus cinctellus, Nomada castellana, Nomada sheppardana, Hylaeus confuses, Lasioglossum villosulum, Auplopus carbonarius, Hylaeus brevicornis, Hoplitis claviventris, Bombus lucorum, Megachile versicolor, Passaloecus clypearis, Nomada fabriciana.*
AF-TL (105) NH (88) OF (37)	1	*Priocnemis fennica.*
AF-CL (98) NH (88) OF (37)	1	*Vespula vulgaris.*
AF-CL (98) AF-TL (105) OF (37)	6	*Andrena gravida, Lasioglossum politum, Halictus scabiosae, Andrena minutuloides, Lasioglossum laticeps, Priocnemis cordivalvata.*
AF-TL (105) NH (88)	10	*Andrena subopaca, Megachile centuncularis, Odynerus melanocephalus, Andrena albofasciata, Nomada flava Panzer, Priocnemis agilis, Dipogon subintermedius, Didineis lunicornis, Myrmosa atra, Bombus lapidarius*

AF-CL (98) NH (88)	5	*Andrena minutula, Sphecodes ephippius, Nomada fucata, Hylaeus gredleri, Andrena dorsata.*
NH (88) OF (37)	2	*Polistes nimpha, Andrena wilkella.*
AF-CL (98) AF-TL (105)	18	*Osmia caerulescens, Andrena helvola, Lindenius albilabris, Dolichurus corniculus, Hylaeus variegatus, Crossocerus quadrimaculatus, Nomada bifasciata, Mimumesa dahlbomi, Mimumesa unicolor, Andrena chrysosceles, Andrena nigroaenea, Nomada succincta, Pseudisobrachium subcyaneum, Bombus pascuorum, Hedychridium rossicum, Andrena floricola, Andrena strohmella, Lasioglossum quadrinotatum.*
AF-CL (98) OF (37)	1	*Trypoxylon beaumonti.*
NH (88)	20	*Passaloecus brevilabris, Andrena pusilla, Ceratina cyanea, Coelioxys inermis, Anoplius caviventris, Andrena proxima, Hylaeus Paulus, Lasioglossum interruptum, Panurgus calcaratus, Bethylus cephalotes, Andrena labiate, Nomada marshamella, Lasioglossum zonulum, Andrena viridescen, Lasioglossum punctatissimum, Megachile circumcincta, Hedychrum nobile, Nomada atroscutellaris, Heriades truncorum, Pseudochrysis neglecta.*
AF-TL (105)	20	*Lasioglossum lativentre Entomognathus brevis, Andrena carantonica, Nysson dimidiatus, Lasioglossum leucozonium, Lasioglossum clypeare, Chrysura cuprea, Auplopus albifrons, Priocnemis minuta, Andrena ovatula, Sphecodes geoffrellus, Arachnospila minutula, Nomada minuscula, Ectemnius lapidaries, Priocnemis pusilla, Tachysphex dimidiatus, Cerceris quinquefasciata, Lasioglossum pygmaeum, Lasioglossum calceatum, Osmia bicornis.*
AF-CL (98)	18	*Lindenius pygmaeus armatus, Sphecodes monilicornis, Cerceris rybyensis, Oxybelus trispinosus, Lasioglossum xanthopus, Lasioglossum nitidiusculum, Sapygina decemguttata, Sphecodes gibbus, Tachysphex jokischianus, Andrena labiali, Pemphredon lugubris, Tiphia femorata, Sphecodes niger, Evagetes crassicornis, Harpactus laevis, Sphecodes miniatus, Nomada guttulate, Pemphredon wesmaeli.*
OF (37)	2	*Polistes dominula, Trypoxylon figulus.*