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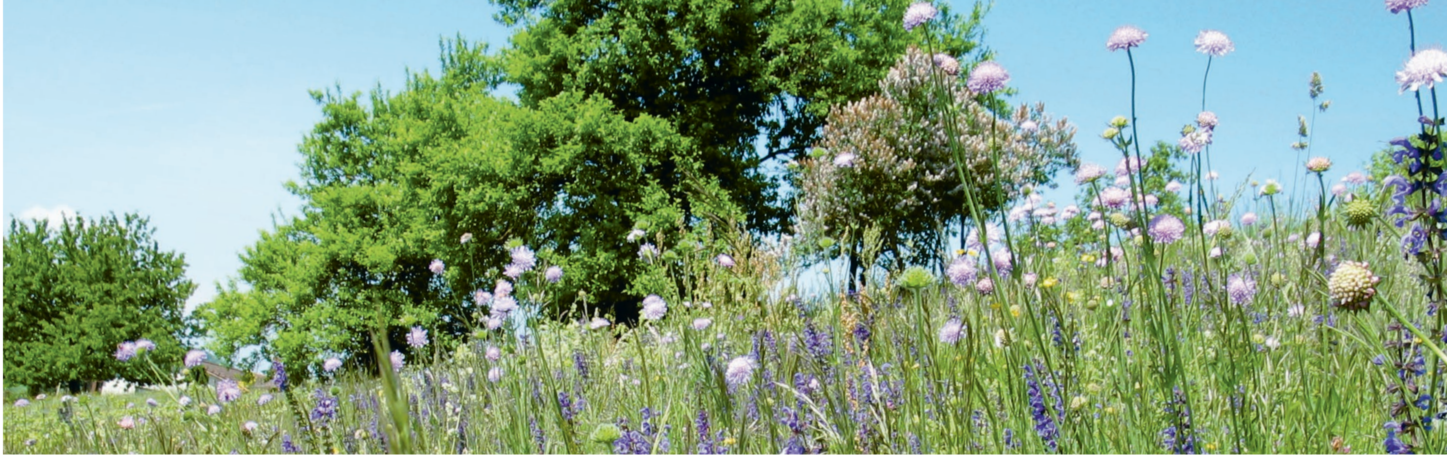

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EXCELLENCE FOR SUSTAINABILITY

Wild bees and pollination

Recent studies have shown that wild bees and other insects have a crucial role to play in the pollination of both wild plants and crop plants. Over the past few decades there has been a dramatic decline in the abundance and diversity of pollinators, resulting from a loss of food sources and nest sites. This has also impacted on the farming sector. Sustainable cropping systems geared towards agroecology demonstrably contribute to maintaining wild bee populations. Nonetheless, the potential for encouraging wild bees is far from exhausted.

Pollinators are key to maintaining biodiversity. Their activities enable reproduction of the majority of wild plants and crop plants. Pollinator decline not only results in decreasing biodiversity and the loss of a range of ecosystem services but also entails a significant decline in crop yields.

Insects such as bees, wasps, flies and beetles are the most significant pollinators of wild plants and crop plants and thus provide enormously valuable ecological and economic services for man and nature. In the temperate zone, 78 % of all species of flowering plants are dependent on insect pollination [1]. Of the 109 most important crop plants, no fewer than 87 species (or 80 %!) are entirely dependent on pollination by animals [2]. These crop species include economically important crops such as apples, strawberries, almonds, tomatoes and melons. The economic benefit of pollination to the farming sector is valued at an estimated EUR 153 billion annually [3].

Bees, the most important pollinators in the insect world, are a diverse group with more than 20,000 species worldwide and 750 species in central Europe [4] [5]. Their key role is owed to their need to gather large quantities of pollen and nectar not only to feed themselves but also in order to feed their larvae. They therefore need to visit flowers very frequently compared to other flower-feeding taxa.

Wild bees' role as pollinators underestimated

Natural pollinators such as wild bees (these include solitary bees and bumblebees) and hoverflies are responsible for the majority of pollination services. A British study has shown that the UK honeybee population only provides at most one third of pollination services, with the remainder being supplied by wild pollinators [6]. Another study showed that flower-visiting wild bees and hoverflies enhance fruit set of crops even where honeybees are frequent [7]. The fact that pollination by managed honeybees supplements, rather than substitutes for, pollination by wild insects was also demonstrated in a global study which compared the pollination services provided by honeybees and other wildflower visitors in 41 crop systems worldwide [8].

The honeybee is one of approximately 750 bee species in central Europe.

The mason bee Osmia cornuta *is a much more efficient pollinator of fruit crops than the honeybee.*

Indispensable pollinators

Due to the high diversity of species, differing in their forage preferences, flight times and dependence on weather conditions, wild bees are often more efficient pollinators or are even the sole pollinators of certain flowering plants. The pollination service they provide also differs with geographic region, landscape type, specific weather conditions and flower morphology. Several wild bee species continue to actively forage at low solar radiation and low ambient temperatures. They are therefore of major significance for pollinating various types of fruit, for instance, especially during prolonged periods of inclement weather[9][10]. Flowers that are difficult for honeybees to work, such as red clover, alfalfa or tomato, are pollinated by specialized wild bee species[5].

Wild bees generally are very effective pollinators: Only a few hundred females of the mason bee *Osmia cornuta* are needed to pollinate a hectare of apple or almond trees, whereas tens of thousands of honeybee workers would be needed[11][12]. Similarly, wild bees have proved to be superior to honeybees in pollinating cherry trees and rapeseed plants in pollination trials[13][14].

Fruit set and seed set of crop plants appear to improve in tandem with increased diversity of flower-visiting bee species. In studies on sunflowers and almond trees, interactions between honeybees and a range of wild bees species have been found to result in enhanced pollination services[15][16]. For coffee, fruit set increased with bee species diversity but not with the number of bee individuals[17].

Therefore, the most important prerequisite for assured pollination of wild plants and crop plants is the presence of a healthy honeybee population in combination with high abundance and species richness in wild bee communities and other wild pollinators such as hoverflies[18]. However, the hoverflies' pollination efficiency is only a fifth of that of wild bees[20] and hoverflies utilize a smaller part of the spectrum of flowers compared to wild bees. Consequently, habitat conservation efforts targeted at wild pollinators, and wild bees in particular, are not only warranted for nature conservation reasons but also for the benefit of the farming sector.

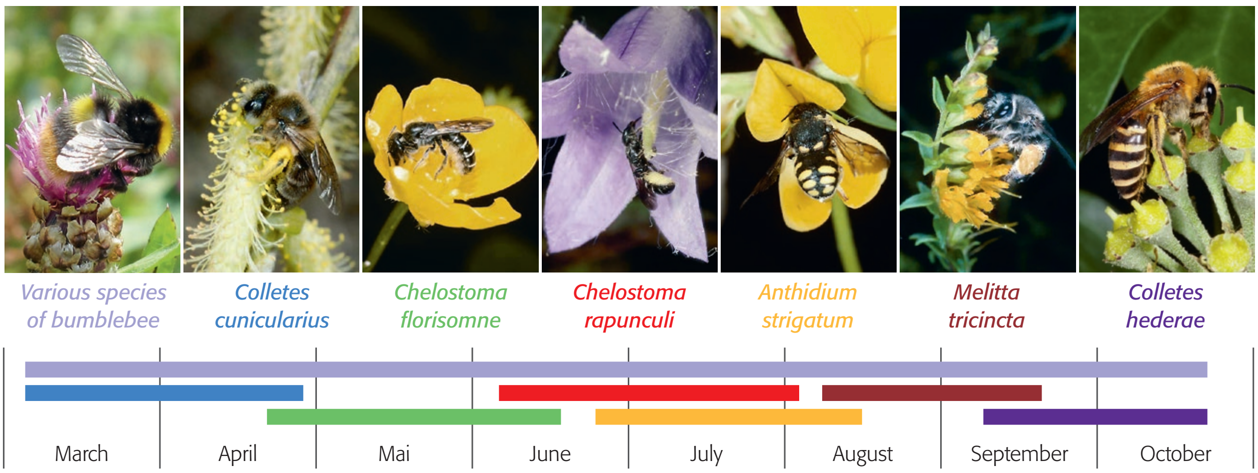

Fig. 1: *Wild bees need a continuous succession of floral resources throughout the entire vegetation period in order to ensure their survival as most of the species have differing flight periods of only one to two months duration. Colony forming species such as bumblebees require a continuous succession of floral resources from March to October.*

Alfalfa is exclusively pollinated by wild bees, for example by Melitta leporina.

The rare mason bee species Megachile parietina *needs the pollen produced by more than a thousand inflorescences of Sanfoin to produce a single offspring.*

Species with specific requirements

Flower diversity significantly impacts on the species diversity of wild bees, as almost half of the central European species collect pollen exclusively from a single plant genus or family[20]. No less than 28 different plant genera and 22 different plant families serve as these specialized species' exclusive sources of pollen[20].

Flower abundance significantly affects reproductive success as the wild bees' quantitative pollen requirements for feeding their larvae are very high. The mason bee *Megachile parietina*, for example, needs all the pollen produced by 1140 inflorescences of Common sanfoin *Onobrychis viciifolia*[21] to provision a single offspring, while a population of 50 females of the mining bee *Andrena hattorfiana* must exploit the pollen produced by 920 plants of Field scabious *Knautia arvensis* to sustain themselves[22]. Many wild bees have short periods of flight activity lasting only a few weeks with different species flying in spring, early summer and late summer respectively. Therefore the provision of a succession of floral resources from early spring to late summer is essential to maintaining species diversity in a given landscape[23] (Fig. 1).

Another precondition of wild bee diversity at landscape level is the provision of small-scale habitat features exposed to the sun; these are needed for nest establishment[24]. The most important nesting sites of central European wild bees include, depending on the species concerned, bare or sparsely vegetated soil, coarse woody debris, rock and stone features as well as uncut vegetation containing plant stems and empty snail shells[20].

As wild bees must fly back and forth a lot between food plants and nesting sites in order to provision their brood cells, the spatial distance between nesting sites and suitable food plants is critical to their reproductive success. For most wild bee species the maximum flight distance between nesting and food habitats is between 100 and 1500 metres[25][26] (Fig. 2). However, long flight distances to food sources are associated with great losses: An increase of a mere 150 m in the distance between the nesting site and food plants can reduce the number of brood cells provisioned by almost 25 % [26][27] and reduce the number of viable offspring by more than 70 %[28].

Given these high demands in terms of food and nesting resources, wild bees are very sensitive to any changes in landscapes and habitats which reduce or spatially alter the provision of floral resources and small-scale habitat features.

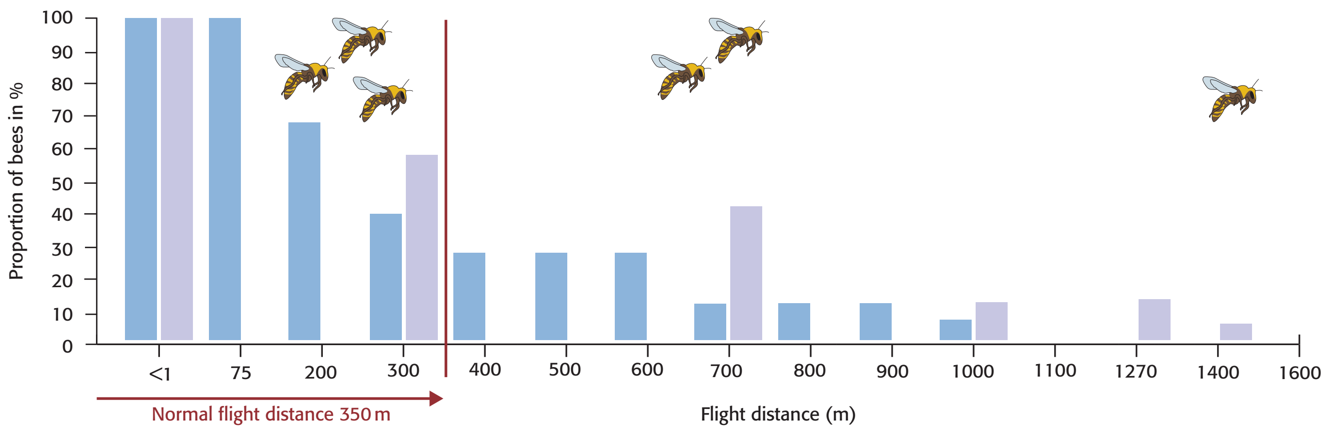

Fig. 2: *Foraging distances of* Hoplitis adunca *mason bees at two sites (coloured). Proportion of marked females observed collecting pollen from potted host plants at increasing distances to their nests. While some individual females travelled more than 1 km, half of the individuals ceased their nesting activities once the foraging distance was increased to 300 m*[26].

Beetle boreholes in sun-exposed coarse woody debris are important nesting sites for numerous wild bee species.

Roughly half of the central European wild bee species are miners and nesting by burrowing in the ground in bare vegetated soil exposed to the sun.

Alarming decline of wild bees over the past few decades

Landscapes and land uses have changed dramatically since the 1960s [29]. Many nutrient-poor, extensively farmed habitats rich in flowers and small-scale features were destroyed in the course of farmers adopting intensified or industrial-style farming practices. At the same time many valuable marginal lands were left fallow or were re-colonized by woodland as a result of land abandonment. The intensification of grassland use in particular, with the attendant applications of mineral fertilizers and herbicides, as well as the shift from hay to silage production have resulted in landscapes devoid of natural structures and floral resources. The much reduced provision of food and nesting resources as well as the increasing fragmentation of sites rich in floral resources and habitat features have led to a strong decline in both the abundance and diversity of wild bee species (Table 1).

Between 25 % and 68 % of all wild bee species in central Europe are endangered, with the percentages varying between countries and regions [20]. Wild bees are thus amongst the insect groups with the highest proportions of endangered species.

Table 1: Assessment of factors adversely affecting wild bees

A. Anthropogenic factors	
	Relevance
Destruction or damaging of suitable habitats	
Decline in diversity of flowering plants	+++
Decline in flower abundance	+++
Loss of sun-exposed small-scale habitat features	+++
Fragmentation of habitats rich in wildflowers and structural features	+++
Uniform land use over large areas (e.g. timing of cuts)	++
Agricultural inputs	
Herbicides	++
Pesticides	++
Other potential factors	
Neozoa (non-native species)	–
Global warming	– / ?
Genetically modified plants	– / ?
Neophytes	–
B. Natural factors	
Fungal infection of food stores	+
Parasites	+
Predators	–
Periods of inclement weather	+

+++ = very high; ++ = high; + = moderate; – = marginal; ? = unknown

Adverse impacts of chemical crop protection

The widespread use of systemic insecticides such as neonicotinoids [30] and pyrethroids in Europe has resulted in traces of these poisons being passed on unchecked to flower-visiting insects in the cultural landscape by way of the crop plants' pollen and nectar. Wild bees, honeybees, hoverflies, beetles and many other flower visitors are thus exposed to these toxic substances.

In addition to the immediately lethal effects of pesticides, a variety of sublethal impacts on the health and behaviour of bees have been detected [31] [32].

Neonicotinoids for example impact negatively on the behaviour, reproduction and brain development of honeybees, bumblebees and stingless bees [31-38]. Therefore it is reasonable to expect similarly damaging effects on the populations of solitary bees.

New research has shown that pesticides may weaken the bees' immune response, allowing intestinal pathogens and parasites to compromise the bees' health [39].

Chemical-synthetic pesticides are prohibited in organic farming. Instead, organic farmers use plant protection products that generally have no or only moderate side-effects on non-target organisms such as insects, other small fauna and vertebrates.

An increase in the distance to food sources by 150 m reduces the number of brood cells provisioned by the mason bee species Hoplitis adunca *by nearly 25%.*

Vertical plant stems on uncut fallows are used as nesting sites by a range of rare wild bee species.

Promotion and protection measures

Targeted measures can successfully support wild bees (Table 2). The maintenance of habitats rich in floral resources and small-scale features is of the highest priority. Any measures designed to increase the abundance, diversity and distribution of flowering plants and small-scale habitat features well exposed to the sun will foster greater species diversity and increase population sizes in wild bees. It is critical in this context that food and nesting resources are located in close proximity and that there is continuous provision of floral resources from early spring to late summer.

Positive effects of organic management

Organic agriculture as a whole-systems approach is of benefit to the conservation of and support for wild bees. This is due in part to the following practices:

1. No applications of chemical-synthetic pesticides.
2. No applications of chemical fertilizers.
3. More frequent inclusion of grass-clover leys in arable crop rotations. Legumes such as alfalfa, red clover and white clover support a range of bumblebee and other wild bee species, offering them ample food.
4. Non-chemical weed control measures. These result in a flower-rich arable flora including important sources of pollen and nectar[40].
5. Extensive grassland management results in more flower-rich, less grass-dominated swards and ultimately in more insect-pollinated plants[41].
6. Depending on their altitude, Swiss organic farms host on average between 46% and 72% more ecological compensation areas than non-organic farms[42] and therefore potentially provide floral resources as well as small-scale habitat features including nesting sites in greater quantities than non-organic farms.

Table 2: Recommended measures for the protection and enhancement of wild bees on farm holdings

	Relevance
Maintaining habitats rich in floral resources and small-scale features	+++
Species-rich meadows and pastures	
Embankments, fallows, gravel pits, pioneer vegetation	
Increasing the diversity and abundance of floral resources	+++
Extensification of grassland management	
Establishing wildflower strips alongside fields, hedgerows, woodland margins, watercourses and paths	
Maintenance and establishment of sun-exposed small-scale habitat features	+++
Exposed ground (sloped or vertical bare soil patches, cliff faces, paths with unsealed surfaces, path margins) and stone structures (rocks, dry-stone walls, boulders)	
Coarse woody debris (dead standing or fallen logs, strong branches, stubs)	
Uncut areas providing plant stems, empty snail shells for over-wintering bees	
Establishing a network of habitats rich in floral resources and small-scale features	+++
Distances between species used for nesting and as food sources at most 100 to 300 m	
Cutting and grazing of grassland staggered in time	++
Reductions in the use of herbicides and pesticides	++
Mechanical rather than chemical weed control	
Refraining from the use of pesticides with side-effects on non-target species	
Reduction in N-fertilizer use on grassland	++
Refraining from the use of mineral N fertilizer	
Applying compost instead of slurry	
Refraining from the use of fertilizers on selected plots	

+++ = very high; ++ = high

A species- and flower-rich arable flora provides nectar and pollen for wild bees and is indispensable to the survival of certain species of wild bees.

Multi-annual wildflower-rich plots are indispensable food sources for wild bees and provide crucial over-wintering sites to species nesting in plant stems.

Organic farming can promote wild bee diversity and abundance not only at the individual farm level but also at the landscape level[43]. Several studies have shown that organic farming positively impacts on wild bee species diversity, abundance and reproduction rates[43-47] (Fig. 3). Especially in relatively homogenous landscapes, organic farms enhance reproduction (nesting sites) in solitary bees (such as *Osmia lignaria*)[48].

On organic farms, wild bees can ensure higher crop pollination success, especially in demanding crops such as watermelons, making the farms less dependent on the more expensive pollinators such as bumblebees and honeybees[49][50]. Key to this success are the greater diversity and abundance of pollinators on organic farms. Andersson et al.[50] have studied pollination in strawberry crops and have shown that pollination success was higher on organic farms compared to conventional farms. As early as 2 to 4 years after conversion to organic management, this resulted in greater crop yield and fewer losses from misshapen or deformed and thus not marketable fruit (Fig. 4). Pollination of insect-pollinated crops was found to correlate positively with increased pollinator abundance and diversity.

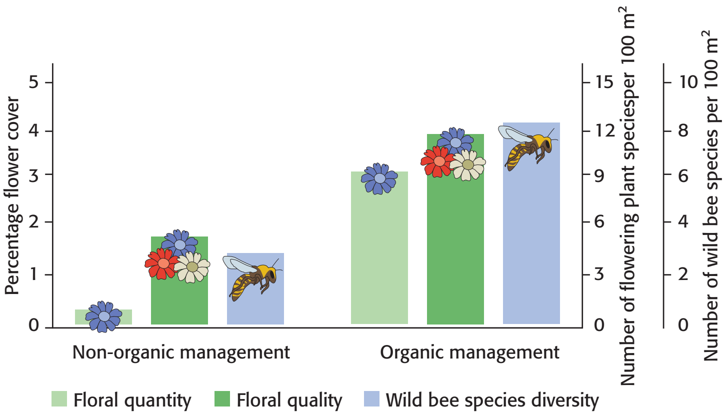

Fig. 3: *Organic management on arable land promotes wild bee diversity by providing a greater abundance and diversity of floral resources (simplified based on the results by Holzschuh et al., 2007)*[45]*.*

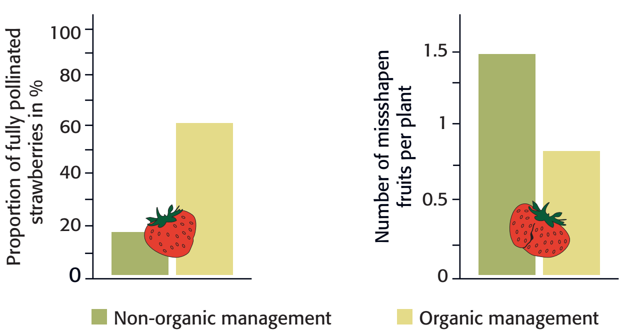

Fig. 4: *Organic farming can contribute to improved pollination in crop plants and thus result in an increase in the proportion of produce of marketable quality (such as strawberries)*[50]*.*

Conclusions for the farming sector and society at large

In light of the research to date, the provision of near-natural sites rich in floral resources and structural features should be increased to the extent that there is a maximum distance of 100 to 300 metres between such sites. This would ensure the survival of wild bee species, thus assuring pollination and safeguarding agricultural yields. This measure would best be supplemented with heterogeneous land use in combination with less intrusive production methods such as low-input farming, organic arable cropping, and no chemical inputs. Considerable synergies can be achieved by combining wild bee promotion with honeybee protection and the promotion of agricultural beneficials.

More landscapes rich in floral resources will be needed in order to halt the decline in wild bee populations; in addition to the well-known instrument of ecological compensation areas already established in Switzerland, tailor-made pollinator-friendly flower-rich plots must be established[51][52].

Ultimately the pollination of crop plants and wild plants by wild insects is the basis of sustainable food security and substantially contributes to the maintenance of biodiversity as the foundation on which life is built as well as to safeguarding many key ecosystem services.

Moreover, cropping systems that are optimized in agroecological terms can intelligently utilize the synergies resulting from ecological enhancement measures, contribute to improving pollination as well as self-regulation of pest organisms, and thus bring about significant advancements for both producers and the environment[53].

Wildflower-rich margins alongside paths, hedges and fields are suitable to supporting wild bees.

Patchy pioneer or ruderal vegetation is essential in particular for ground nesting miners and species that use stems for nesting.

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Wildflower-rich oligotrophic and mesotrophic meadows are amongst the most important habitats for wild bees.

In soft-fruit production, wildflower-rich margins maintained over several years improve pollination and thus help ensure crop yield security.

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Richly structured habitats with abundant flowers in a matrix of diverse land uses foster wild bees and ensure natural pollination of many species of wild plants and crop plants.