LIFE 4 POLLINATORS

INVOLVING PEOPLE TO PROTECT WILD BEES
AND OTHER POLLINATORS IN THE MEDITERRANEAN

HANDBOOK FOR FARMERS

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CREDITS

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INTRODUCING POLLINATION AND POLLINATORS

Plant and animals are linked in many ways, one of them is pollination.

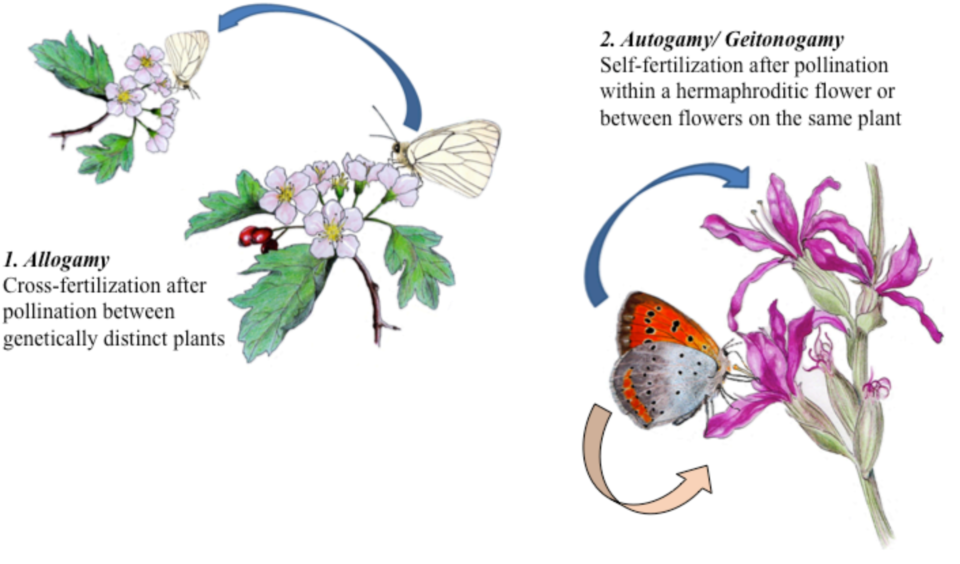


Illustration by Marta Barberis

WHAT IS POLLINATION?

Pollination is fundamental for the sexual reproduction of flowering plants (angiosperms). It involves the transfer of pollen (which contains the male gametes/genetic material) from the anthers (male flower part) to the stigma (female part) of flowers. Transfer may occur in the same flower or between flowers of the same or different plants. Once the pollen reaches the stigma it can germinate, launching the subsequent process of fertilization, which ends with the development of seeds and fructification.

Many plants require a pollination "service", meaning a vector that transfers pollen from one flower to another. In some cases, pollen is transported by wind (anemophily), more rarely by water (hydrophily), but for about 90% of known plant species, the vectors are animal pollinators (zoophily).

The pollination of flowers by animals implies a partnership between plants and pollinators, a partnership that determined their co-evolution. This is why the rapid diversification of angiosperms, since their appearance on Earth 135 million years ago, leading to their great current diversity (an estimated 300,000 species), largely depended on their co-evolution with pollinators.

All over the world, the major and most effective pollinators are insects: bees (Hymenoptera), wasps (i.e. aculeate Hymenoptera), flies (Diptera), beetles (Coleoptera), butterflies and moths (Lepidoptera), as well as certain bugs (Hemiptera). A special role is played by wild bees and syrphid flies. Besides insects, different species of vertebrates and other invertebrates can also act as pollinators: birds, mammals (including bats), snails and even reptiles (lizards, geckos and skinks).

WHY DO POLLINATORS VISIT FLOWERS?

All pollinating animals are attracted by flowers, where they often find a "reward", which may be food, such as nectar and pollen. As the pollinator collects the reward, pollen sticks to its body and it involuntarily "reciprocates" by transporting and depositing pollen on other flowers. This is a fully fledged exchange of goods and services between two organisms, which are therefore mutually dependent.

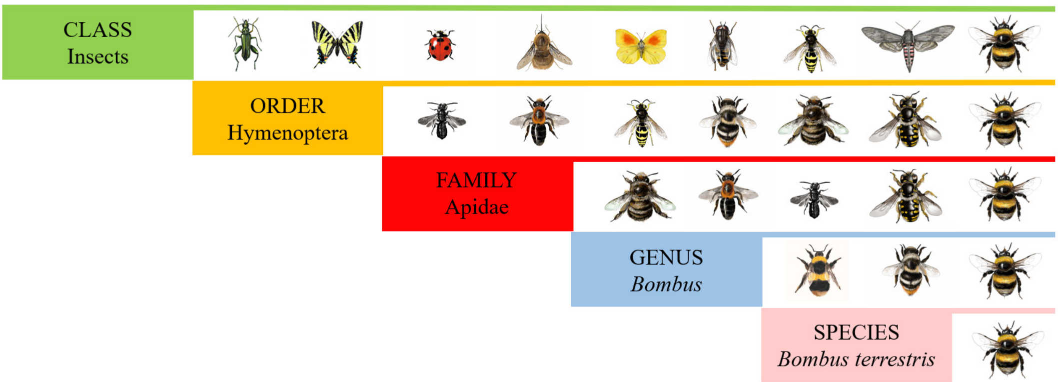
Apart from being indispensable for life, pollination is also an enormously important ecosystem service for humans, as agriculture and food production depend directly on this natural process. Up to 75% of major world crops (111) rely on pollination by insects. Gallai and colleagues (2009) estimated the world economic impact of this ecosystem service in 2005 at €153 billion and €15 billion per year in Europe (EU Pollinators initiative). Crops such as watermelons, pumpkins, melons, almonds and cherries depend on insect pollination for up to 90% of production.

Since the end of the 20th century, there has been a decline in insect pollinator populations around the world. Habitat loss, land use change, intensive agriculture, use of pesticides and herbicides, introduction of invasive species and climate change are the main causes of this loss. The IUCN European Red List reveals that the populations of 37% of bee species and of 31% of butterfly species are declining, and that 9% of wild bees are threatened with extinction (Proposal for a EU Pollinator Monitoring Scheme: Potts et al. 2021). The most worrying aspect, however, is that the conservation status of most pollinators is not known, especially in the extremely diverse Mediterranean Region.

[1] Potts, S.G., Dauber, J., Hochkirch, A., Oteman, B., Roy, D.B., Ahrné, K., Biesmeijer, K., Breeze, T.D., Carvell, C., Ferreira, C., FitzPatrick, Ú., Isaac, N.J.B., Kuussaari, M., Ljubomirov, T., Maes, J., Ngo, H., Pardo, A., Polce, C., Quaranta, M., Settele, J., Sorg, M., Stefanescu, C., Vujić, A., Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN, Publications Office of the European Union, Ispra, 2021, ISBN 978-92-76-23859-1, doi:10.2760/881843, JRC122225.

UNDERSTANDING THE CONTRIBUTION OF POLLINATORS

Today we are faced with an alarming decline in pollinators. Conservation measures are necessary to counterbalance this decline. However, this effort cannot be made unless people are properly informed about the threat. Recent opinion polls showed that stakeholders in the agri-food sector are generally unaware of the importance of wild pollinators and their decline. They apparently do not understand how great a risk is posed by intensive agriculture and pesticide use and they underestimate the importance of managing habitats in a pollinator-friendly way. On the other hand, European citizens care increasingly about food safety and environmental sustainability. A growing love of nature and appreciation of open-air activities means that more people are interacting with flowers and flower visitors. Perhaps a better understanding of the work of pollinators may come from direct experience?
Here is a brief guide to the insect pollinators one may encounter on a walk in the fields, a garden or a park. They are introduced with a general description based on taxonomic order or family (see BOX "TAXONOMIC CATEGORIES"), and notes on the biology of some flagship or charismatic species. The pollination service they provide is described.



LIFE STYLES

To protect pollinators and the ecosystem service they provide, we need to know their life cycle, not only their relation to flowers. Although visiting flowers is the activity important for pollination and supports fruit/seed production, all flower visitors need suitable conditions for nesting and feeding their progeny, so they can be constantly available in nature.
Pollinating insects, particularly bees, can be distinguished on the basis of their sociality. Social bees, such as honey bees, bumblebees and a few wild bees, build colonies of many individuals and raise many larvae at the same time. These insects need to forage pollen

and nectar on a grand scale, so abundant availability of flowers is important for the healthy growth and maintenance of their colony. Today, almost all honey bees are managed by beekeepers, who provide nesting conditions with artificial hives, but it is also possible to find feral colonies of honey bees (as for common wasps), in holes in trees and sometimes in the chimneys of houses. Bumblebees may colonize holes in the ground made by small mammals.
Like their social counterparts, wild bees also depend on pollen and nectar for themselves and their larvae. Especially in the Mediterranean, wild bees constitute a large fraction of the rich bee diversity, although their populations are much smaller than those of honey bees. Wild bees are mainly solitary, most living tunnels dug in bare soil, along trails in the countryside or in urban gardens. Their nest entrances may be simple holes in the ground. Although solitary, many females may sometimes nest close to one another. Other solitary bees build their nests in cavities in twigs or reeds. Ground- and twig-nesting species dedicate much time to nesting activities, cleaning and preparing the cells for their larvae and collecting pollen for the larvae. Many wild bees are specialists, visiting one or a few plant species; the variety of flowers available in an area is therefore very important.

Flies, butterflies, moths and beetles do not build shelters for their larvae, but may need particular plant species on which to lay their eggs. The eggs are usually attached to the underside the leaves of plants that will be food for the young caterpillars.

WHAT ARE THE MAIN INSECT POLLINATORS?

HYMENOPTERA

This is a large order that includes the well-known bees, wasps and ants. Although ants sometimes visit flowers for nectar, they are usually considered poor pollinators since pollen does not readily attach to or survive on their bodies.

Bees

Bees are the most important and probably the largest group of pollinators. All their food requirements come from flowers: nectar, especially rich in sugars, sustains the daily activity of adults; pollen, rich in proteins, is collected by females to feed the larvae. Since bees have evolved in close conjunction with flowers and their activity is focused on visiting flowers, their body is adapted to collect pollen and nectar, which are carried by specific body structures, or

[1] Ngo, H., Pardo, A., Polce, C., Quaranta, M., Settele, J., Sorg, M., Stefanescu, C., Vujić, A., Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN, Publications Office of the European Union, Ispra, 2021, ISBN 978-92-76-23859-1, doi:10.2760/881843, JRC122225.

captured by different types of hairs in the case of pollen. Bees actually collect pollen to feed their larvae, but in the course of foraging, grains of pollen are inadvertently transferred to the flowers they visit. Bees are generally constant to a type of flower, an observation first made by Aristotle. This enhances the possibility of successful pollination and seed production of the plant in question. Besides being constant, bees may be numerous, especially those belonging to social species, their colonies providing an efficient pollination service in the area. Such social bees may visit a variety of plant species at different times of the day or season, and are therefore generalists, whereas other bee species visit one or few plant species during their lifetime, and are thus considered specialists.

European bee species can be divided into two main groups comprising six taxonomic families: long-tongued bees including the families Apidae and Megachilidae, and short-tongued bees including the families Andrenidae, Colletidae, Halictidae and Melittidae. As in the rest of the world, in Europe bees occur in all land habitats. Regarding numbers, the European continent hosts 2,051 of the 20,000 species of bee in the world. The highest species richness occurs in southern Europe, particularly in the Mediterranean, which hosts a large variety of bee species, many of them endemic. For example, Spain hosts >1100 species, Greece ~1200 and Italy ~1000.

The family Apidae, comprising about 30 genera and more than 550 species in Europe, is characterized by a great variety of sizes, shapes and colours. It includes the honey bee (*Apis mellifera*), almost entirely managed throughout Europe, and bumblebees (different species of the genus *Bombus*): both are well-known social species managed or reared and used for the pollination of crops. Many species of the family are rather large, furry, ground-nesting and solitary. Some resemble bumblebees, for instance species of the genera *Anthophora*, *Amegilla*, *Habropoda* and *Eucera*, almost all generalists. The family also includes carpenter bees *Xylocopa* (large) and *Ceratina* (small or tiny), which comprise solitary and social species: all are black and nest in aboveground cavities, often in dead wood and hollow stalks. This family also includes many "kleptoparasitic" bees (e.g. *Nomada*, *Melecta*, *Thyreus*, *Epeolus*, *Pasites*), commonly called "cuckoo bees", which like the cuckoo bird, lay their eggs in the nests of other bees.

Bees of the family Halictidae (also known as sweat bees) are commonly found on wild spring flowers like daises. Their appearance ranges from largely yellow and metallic-coloured, a few millimetres in size, as in the genera *Ceylalictus* and *Nomioides*, to average honeybee-sized bees (as in the genus *Pseudapis*). The most common genera are: *Lasioglossum*, black, almost hairless species resembling ants in shape and size; and *Halictus*, encompassing species that are larger than *Lasioglossum*, with a black and white banded abdomen. *Halictus* and *Lasioglossum* can be recognized in nature by observing the abdomen with a good lens while the insect plunges its head into a flower: females feature a furrow on the tip of the abdomen. The populations of some species of *Halictus* and *Lasioglossum* are often quite abundant because they are very social: indeed, sweat bees are the only group apart from honey bees, bumblebees and carpenter bees, which forms structured social colonies. These bees are commonly generalists, but there are also specialists regarding pollen preference. The family also includes kleptoparasitic species. For instance, the genus *Sphecodes* includes black and red cuckoo bees. Other interesting genera comprising few rare specialized species are *Dufourea*, *Rophites* and *Systropha*.

The large Andrenidae family includes bees of a variety of sizes, from very small to medium-large, most belonging to the genus *Andrena*. Females nest in deep tunnels in the ground, alone or in communal groups. This earns them, and other ground-nesting bee families, the name "mining bees". In the Mediterranean region, andrenids are among the most frequently encountered solitary bees in spring and early summer. Many species have a short period of activity and therefore specialise in the flowers of a plant family or genus. Besides *Andrena*, the family includes the genera *Melitturga*, with large eyes, a trait that makes them resemble flies, and *Panurgus*, small hairless black bees found almost exclusively on yellow, daisy-like flowers.

The family Colletidae contains only two genera: *Colletes*, medium-sized bees with an appearance similar to honey bees; and *Hylaeus*, small black hairless bees with yellow spots on the body and head, earning them the name of "yellow masked bees". *Colletes* species nest in the ground, lining their tunnels with an impermeable cellophane-like secretion, while those of *Hylaeus* nest in pre-existing cavities like the stems of plants or old nests of other bees.

The family Melittidae includes very specialized bees. They are ground-nesters and encountered in a restricted number of habitats. Individuals of the genus *Dasypoda* can be spotted in dry sandy habitats, transporting large masses of pollen attached to their hairy hind legs. The pollen is collected from daisy-like flowers. Bees of the genera *Melitta* and *Macropis* are typically found in marsh habitats or along streams where they specialize in pollen collection from flowers. Individuals of *Macropis* visit *Lysimachia* flowers to collect plant oils.

The family Megachilidae includes species known as builders of nests, mainly aboveground in pre-existing cavities and less frequently underground. They use various materials (such as plant fibres, leaves, resins, sand and mud) to plaster the walls of their nests. These activities earn them names like "mason bee" (*Osmia*), "leafcutter bee" (*Megachile*) and "wool carder bee" (*Anthidium*). Nests made from colourful flower petals (or even plastic bags) are not unusual! Members of this family are also known for nesting in hollows in objects ranging from snail shells to the key holes of doors. Females are easily spotted by the pollen they carry on their scopa, a thick layer of hairs on the anterior?/ventral? abdomen. They visit many species of plants, but some can be specialists. *Osmia* and *Megachile* species are now increasingly used to pollinate specific fruit crops, like apples, and clover or fodder crops, like alfalfa. By contrast, the genera *Coelioxys* and *Dioxys* include cuckoo bee species which attack the nests of *Anthophora* and other megachilids.

The term "wild bees" is very general: it indicates all bees that are not managed by man. Sometimes the term is also used for honey bees, indicating natural swarms of *Apis mellifera* that abandoned their hives or that still live free in nature, although the latter probably no longer exist.

Wasps

Wasps form a diverse group of insects with different life forms. Some species are eusocial and live in colonies, with different duties allocated to different castes, but most are solitary. There are also parasitoid wasps, which lay eggs in or on other insects (hosts) causing their death, and kleptoparasitic wasps, which lay their eggs in the nests of other wasps or bees, using the resources stored by the host to feed their larvae. There are many families and subgroups of wasps in the world. In the Mediterranean region, the most significant are the cuckoo wasps (Chrysididae), spider wasps (Pompilidae), scoliid wasps (Scoliidae), Sphecidae, ichneumon wasps (Ichneumonidae) and vespids (Vespidae).

Many wasps feed on pollen and nectar during their adult stage and are therefore also frequent flower visitors. Their larvae, however, feed on a variety of other foods as well, implying a much looser relationship with flowers compared to bees. Yet, unlike bees, wasps are not hairy and do not have specialized structures for pollen collection and transport. Pollen is therefore less likely to attach to their bodies when they visit flowers, and so they are generally less efficient pollinators than bees. However, there are exceptions, such as fig wasps, which are extremely specialized pollinators. Wasp pollinators are found in almost all Mediterranean habitats and tend to prefer sunny places. They nest in small holes in trees, walls, ruins or masses of dead plant material. Some species also nest on the ground, in mud or sand.

When threatened, social wasps emit pheromones that induce the hive to defend itself. Only female wasps have stingers. These can be used many times, unlike the stingers of bees. Wasps have a great capacity to control agricultural or forest pests due to their role as predators. That is why they are used as agents of biological control in some agricultural sectors.

Climate change, international trade and global travel have displaced many native species. When introduced into new territory, some may prove invasive, preying on, competing with and displacing native species of insects. A recent case in the Mediterranean has been introduction of the Asian wasp (*Vespa velutina*), a species that attacks the hives of the domestic honey bee and other populations of solitary hymenopterans.

DIPTERA

Flies are an insect guild, second only to bees in importance for pollination. In terms of species dependence on flowers and pollination efficiency, the group is very heterogeneous. Flies visit a variety of flowering species in nature and some of them are important pollinators of several plant crops, especially the carrot, mustard and rose families.

The most important family is the Syrphidae, also known as hoverflies or flower flies, the latter name highlighting their special relationship with flowering plants. In the Mediterranean region, the family includes more than 500 species with varying dependence on flowers and pollination efficiency. Only adults visit flowers for nectar and pollen, which implies that no hoverfly species is exclusively dependent on flowers, as the larvae may be predators, or feed on plants (phytophages), dead or decaying wood (saproxylics), or small particles (microphages). However, they can be regular flower visitors, occur on all continents, and are more common in wetter areas than in dry Mediterranean ones.

Syrphids tend to visit white or yellow, easy-to-handle, mainly open or bowl-shaped flowers in which nectar and pollen are easily accessible. Being slender animals with a very light exoskeleton, many resemble wasps. A species of interest is the (common) drone fly (*Eristalis tenax*), a migrant cosmopolitan species with a very high potential for crop pollination, and is therefore raised in several parts of the world. Another is the genus *Merodon* which includes species that are double-dependent on certain Mediterranean bulbous plants: their larvae feed on the bulbs and the adults visit the flowers for nectar and pollen.

Bee flies (Bombyliidae) have fewer species than hoverflies but are keen flower visitors and some are major pollinators. Their name reveals their appearance: they look like bees, due to their hairy body, and in fact some are bee mimics. Most species are parasitoids of other insects, so their larvae do not depend on flowers; however, the adults of many species have mouthparts, which may be four times as long as the insect's head and adapted for sucking nectar from deep flowers. The proboscis is therefore a distinctive feature of the insect, which along with the discrete colouring of the wing venation and the whirring sound they make in flight, make bee flies easy to spot and recognize.

There are few species in the family Nemestrinidae, but nemestrinid flies, also known as tangle-veined flies, can be found worldwide. They resemble bee flies in having a very long proboscis and wing venation, although they are much less hairy. Since the larvae are parasites of other insect groups, only adults visit flowers, especially deep ones and mainly for nectar.

Another dipteran family to be mentioned in the context of pollination is that of the Calliphoridae (blow flies), dull species with shiny metallic colouring. Though not great pollinators, they are remarkable because they are almost ubiquitous and feed on a variety of food sources, including flowers, thus acting as occasional relatively inefficient pollinators. As they frequent degraded and bee-depleted areas, they may be the only species carrying out pollination. The second reason they are mentioned here is because they can be successfully raised for use in large numbers as crop pollinators in greenhouses (e.g. onion farms).

LEPIDOPTERA

Almost all lepidopteran species have a tongue or proboscis adapted for sucking. Butterflies and moths have very long tongues, and are active by day and by night, respectively. They are typically guided to flowers by colour and fragrance. Moths visit plants with pale or white flowers; these usually diffuse abundant fragrance and offer dilute nectar. Moths do not always land on flowers: sometimes they suck nectar while hovering near them. They may also repose on flowers, landing on their surface. The bodies of moths are furry and attract pollen while reposing, or it sticks to their tongue during feeding.

The beautiful and graceful butterflies fly during warm weather and visit a wide range of flowers, preferring those with bright colours (red, yellow, orange). Butterflies recognize colours, sensing more wavelengths than humans; unlike bees, they can see the colour red. Since they are perch feeders, flowers need to offer them a landing pad. The butterfly's legs and tongue are long, keeping the insect away from the flower's pollen, so it loads less pollen than do bees. However, butterflies tend to visit a few flowers of one plant and then fly to another: this makes them good at transferring pollen, facilitating cross-pollination (i.e. pollination between different plants of the same species) and ensuring a good mixture of genes. Plants benefit from this increase in genetic diversity.

Butterflies live in many Mediterranean habitats, including forest, scrub, swamps, cultivated fields and even parks and gardens in big cities. They are very sensitive to temperature variations and some of them are known to migrate. This is why monitoring of butterfly populations is now normally included in studies on climate change. According to the latest IUCN assessment, the Mediterranean region hosts as many as 462 species of butterflies, 19 of which (5%) are at risk of extinction and 15 of which are endemic to the region.

COLEOPTERA

Beetles are considered to be primitive pollinators from two points of view. First, among the main pollinator guilds, beetles were the earliest in the history of Earth to systematically visit flowers and transfer pollen. They therefore have the longest mutualistic relationship with flowering plants. Second, since their primeval flower-related characters have changed little, their primitiveness is evident from their body anatomy and their flower-visiting behaviour. Beetles' mouthparts are mainly adapted for chewing rather than sipping; their wings (elytra or coleoí, hence the name Coleoptera) are adapted for protection more than for flying; their body is heavy with little hair. Likewise, their behaviour does not suggest high pollination efficiency, as beetles are pretty much sedentary, spend much time on a flower, seldom move between flowers and plants, and most are pollen consumers that treat flowers roughly, e.g. rose chafers (*Cetonia aurata*).

Beetles, however, have been important in the evolutionary history of pollination and continue to be an asset for the pollination services required today. There are several reasons for this: their diversity (they are the insect group with the highest diversity), their large populations, and the fact that they occur in nearly all habitats, from freshwater to very dry habitats and deserts. In the Mediterranean region, they are particularly present in the dry season, their massive presence on flowers denoting the onset of summer drought. The order includes generally polyphagous species, i.e. not exclusively dependent on flowers. They visit "primitive syndrome" flowers that are relatively easy to handle (open or bowl-shaped and inflorescences suitable for repose, with easily accessible floral rewards). Such flowers are large and mostly white, creamy or yellow in colour with a relatively functional smell ranging from sweet to fermented. For example, several Mediterranean *Arum* species are known to attract saprophilous flies and beetles through olfactory deceit: most emit a dung/urine-like smell that these insects find irresistible when searching for a place to lay their eggs.

Anthophilous (i.e. flower-visiting) beetles are a heterogeneous group including species spanning from "mostly consumers and poor pollinators" (e.g. the species *Mylabris quadripunctata* visiting a variety of flowers, sitting on them and consuming pollen, nectar and other flower tissues), to gentle legitimate pollinators (e.g. the eastern Mediterranean genus *Pygopleurus*). *Pygopleurus* species are very selective, visiting red bowl-shaped flowers of the anemone–poppy guild, for which they are very effective pollinators. Another significant Mediterranean anthophilous species with considerable pollination potential due to its large body size and ceaseless activity is the scarabaeid *Tropinota hirta* and species of the genus *Oxythyrea*, all of which visit a variety of flowers in late spring and summer. Some smaller beetles, like those belonging to the genera *Podonta* and *Variimorda*, are also notorious flower visitors, evident as many black dots on white daisy-like flowers.

FEAR OF STINGS

Many people of all ages are afraid of bees. Some are even terrified of them. Some know their importance, others certainly agree that their contribution is fundamental, but almost everyone prefers to maintain a safe distance.

What are people afraid of?
They are afraid of being stung.

When we ask where this phobia comes from, many remember childhood events: some squeezed a nest in their hands, others found themselves with a bee in their mouth, others running in the woods found themselves in a cloud of stinging insects. What these stories have in common is that all the insects were presumably wasps, and not bees. And in almost all cases, whether they were wasps or bees, they had to defend their nest or themselves from arbitrary attack.

Only female bees have a stinger. The stinger has a barbed tip: once it pierces the skin it lodges in the flesh and everything connected to it remains attached, from the poison sac to the stomach of the bee. This kills the bee, which is a good reason for bees not to attack for fun.

Wild bees are even less likely to sting: like their domestic relatives, they use the stinger only if they are annoyed, if you pinch or step on them (they prefer to move away rather than attack), or if someone destroys their nest (honey bees only sting when their nest is threatened).

Since people are taken to the emergency room every year for insect stings, it is legitimate to say that while „phobia" may be an overreaction, the fear caused by stinging insects can be real, therefore it is useful to know real ways to prevent such stings:

- **Wear shoes, especially in grassy areas.**
- **Since stinging insects are attracted to sweetness, do not leave sweet drinks or food in accessible ar-eas.**
- **Do not attempt to remove a nest on your own or swat at stinging insects; an aggressive reaction and repeated stinging may occur.**
- **Keep windows and doors properly closed if you have nests around.**
- **Promptly remove garbage and store it in sealed containers.**
- **If you react to a sting, seek immediate medical attention as reactions can be severe.**

Don't worry!
We can safely coexist with bees, observe them and grow plants that attract pollinators.
By observing and respecting pollinators, we can all find ways to deal with and reduce our fear.

HOW TO CONSERVE POLLINATORS AND ENHANCE POLLINATION SERVICE

OBJECTIVES

Together with pest control, water and fertilizer management, pollination is a key element in agriculture. Since many fruits and vegetables require insect pollination in order to produce, many agricultural practices have to be coupled with pollination strategies. This handbook offers guidelines and a code of conduct for farmers to conserve pollinators and enhance pollination service on their farms. The initiative is a part of the “European Green Deal” with which the European Commission intends to tackle climate change and environmental challenges, making the economy of the European Union efficient, sustainable and competitive. In particular, the European Commission has adopted a “Farm to Fork” strategy, which focuses on accelerating the transition to a sustainable food system, restoring biodiversity and mitigating climate change.

FACTORS LIMITING POLLINATORS IN AGRO-ECOSYSTEMS

Agro-ecosystems, particularly those managed intensively, are homogeneous habitats with low plant diversity and high input requirements. Agricultural intensification is considered one of the main drivers of pollinator decline, because it not only reduces the availability and quality of floral and nesting resources but also exposes pollinators to a variety of toxic plant protection products.

LIMITED AVAILABILITY OF FLORAL RESOURCES (QUALITY AND QUANTITY)

In agricultural environments dominated by monocultures, the quality and quantity of nutrients from floral resources (e.g. nectar and pollen) are low or limited in space and time. Flowers are usually only abundant for a short period of time and do not meet the foraging needs of many pollinator species. Since different pollinator species are active in different periods of the year, many may remain without a source of food. Other pollinators, mainly monolectic and oligolectic species, which visit one or a limited variety of plants, might not find their food sources in these homogeneous habitats. The lack of floral resources also has strong repercussions on natural enemies, such as ladybird beetles and parasitoids that supplement their diet with nectar and pollen.

LIMITED AVAILABILITY OF NESTING SITES

Cultivated fields usually offer few opportunities for pollinator hibernation and nesting. Since many bee species nest or overwinter underground, soil management can greatly affect their survival. Soil texture, bare ground and other abiotic soil conditions can limit the populations of soil-nesting bees.

USE OF PESTICIDES

Cultivated fields expose pollinators to agro-chemicals, which have been identified as one of the main factors associated with their widespread decline. Honeybee poisoning events are often reported by beekeepers and most can be attributed to malpractice in pesticide application. However, adverse effects on bees may occur even when farmers use pesticides according to label specifications, for example when bees are simultaneously exposed to fungicides, which by virtue of their low toxicity can be applied during bloom, and residues in flowers of systemic insecticides, which were applied pre-bloom.

Honeybees and other pollinators can be exposed to pesticides in different ways: a) when they collect contaminated nectar, pollen, water and propolis; b) when they are directly contaminated by spraying or drift (Figure 1); c) through contact with contaminated nesting materials. Some cavity-nesting bees use mud to build nest partitions and most bee species (~70%) nest underground. For these bees and other insect pollinators with soil-dwelling life stages, such as larvae of flies and beetles, pesticide exposure via soil can be a major exposure route. Pesticide exposure via stems and leaves can affect species with herbivore life stages or that shelter on plants or collect parts of plants as nesting material (e.g. leafcutting bees, *Megachile* spp.). Pollinator adults may also be exposed to pesticide residues by direct contact with leaf surfaces.

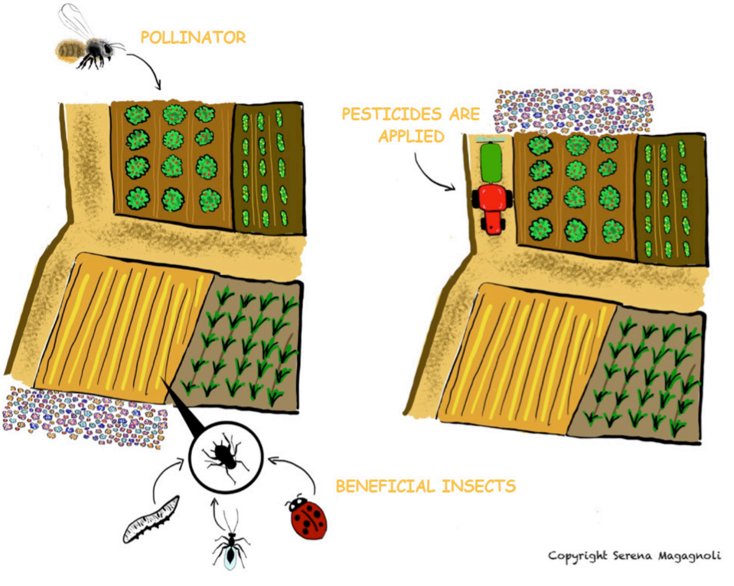


Figure 1. During the blooming period of the wildflower strip, many beneficial insects are attracted to a small area. The wildflower strip may become a deadly trap if contaminated pesticides, decimating beneficial insects, including pollinators.

HABITAT MANAGEMENT STRATEGIES TO CONTROL PESTS AND ENHANCE POLLINATOR DIVERSITY

In recent years, sustainable strategies focused on reducing non-renewable inputs have become a new challenge for agriculture in Europe. A real contribution in this direction comes from Conservation Biological Control through habitat management strategies, such as the introduction of ecological infrastructures (EIs) (also known as ecological compensation areas, ecological focus areas, non-crop habitat and semi-natural habitat) into agro-ecosystems. Ecological infrastructures include hedgerows, wildflower strips, cover crops, living mulch, catch crops, beetle banks (among agro-ecological service crops) and buffer zones (Figure 2). All these natural elements are important to support pollinators and other beneficial insects by providing resources (such as nectar and pollen), alternative prey, alternative hosts, shelters and reproductive sites. Many semi-natural habitats act as buffer areas, protecting beneficial fauna and water against pesticides.

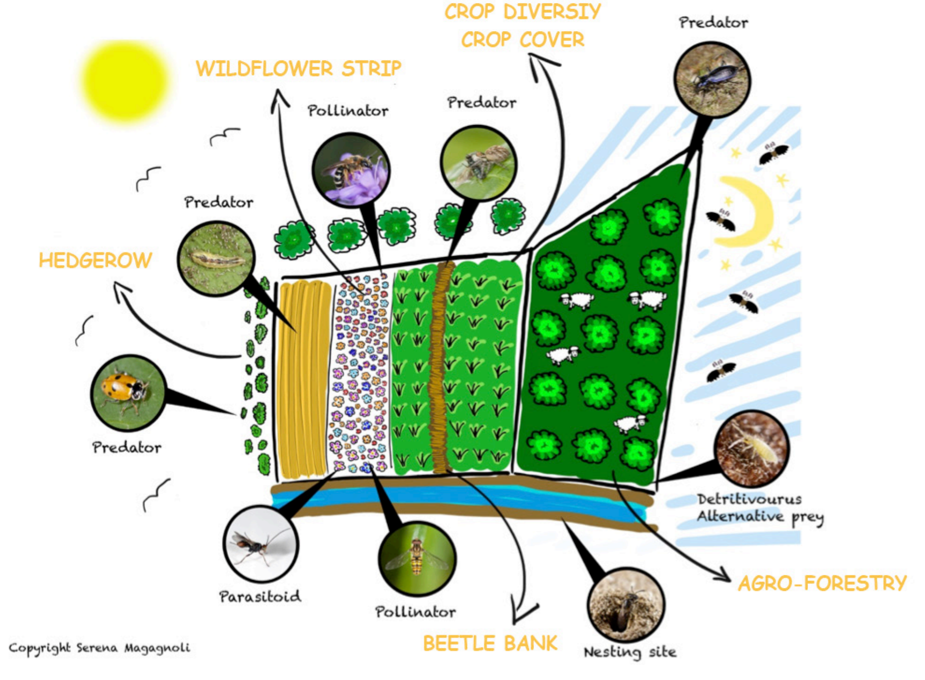


Figure 2. Habitat management strategies, such as the introduction of ecological infrastructures (EIs), provide natural elements (like indicated above in yellow) that enhance biological control and pollination in agricultural environments. Diversified cropping systems are more resilient than simplified ones, and improve pest control.

ECOLOGICAL INFRASTRUCTURES

- **Hedgerows**: boundaries consisting of shrubs and trees that provide food, shelter and alternative prey for natural enemies and pollinators. They can also prevent soil erosion and act as windbreaks;
- **Wildflower strip**: a mixture of flowering plants to increase food availability for pollinators and natural enemies. If the strip is along field margins, the crop benefits from many ecosystem services;
- **Beetle bank**: grassy mounds in large arable fields. This strategy is mainly used in northern Europe and provides important shelter for many natural enemies;
- **Crop diversity (including cover crops)**: crops sown to provide or promote agroecological services. Cover crops improve pest management (increasing soil biota and providing alternative prey for natural enemies), enhance soil structure (improving aeration and infiltration of water), increase soil organic matter (improving nutrient cycling), and reduce soil erosion, N-leaching and water run-off.

HOW FARMERS CAN INCREASE THE ABUNDANCE AND DIVERSITY OF POLLINATORS

INCREASE THE AVAILABILITY OF FORAGING HABITAT

To do this, farmers can increase plant diversity by planting wildflower strips and hedgerows at field edges, by planting cover crops on fallow fields, by intercropping, by growing polycultures rather than monocultures, and by tolerating weeds along crop borders. Habitats need to provide an unbroken supply of pollen and nectar from March to September, the main period of pollinator activity. Because flowers with different shapes, sizes, and colours attract different pollinator species, an optimal flowering source should provide a succession of plant species with different flowering periods and flower traits, so as to be attractive to the widest range of pollinators (Box 1).

Box 1: Basic rules in the choice of plant species as flower resources for pollinators:

1. **Local species;**
2. **Species adaptable to the local environment/climate;**
3. **Species with long and abundant blooming;**
4. **Species (trees and bushes) with foliage offering nesting sites and shelter.**

Ecological infrastructures (EIs) can also produce ecosystem disservices. Several pests can take advantage of EIs. Disservices depend on what crops are growing nearby and their potential pests. For example, nettles near vineyards can host the planthopper *Hyalesthes obsoletus* (Hemiptera: *Cixiidae*) which is a major vector of phytoplasma diseases of the grapevine (bois noir). If the wildflower strip is sown near a cultivated field, the plant selection should consider plant dispersal and weed potential, limiting or avoiding, for example, plants belonging to the Brassicaceae family. Some EIs may play contradictory roles. For example, hedgerows, woody and spontaneous vegetation near watercourses may host the brown marmorated stink bug (*Halyomorpha halys*), an invasive stink bug native to eastern Asia, which is causing damage in northern Italy. However, the same EIs are also critical shelter for *Trissolcus japonicus*, a wasp that parasitizes the brown marmorated stink bug.

Another important point is to avoid spraying pesticides near the wildflower strip, which could turn it into a deadly trap for beneficial insects (Figure 1).

CREATE NESTING SITES

Because many pollinators nest or overwinter underground, maintaining or creating some bare ground in dry sunny locations is essential for these species. Farmers can leave some undisturbed areas (unplowed and unmowed) for bumblebees to hibernate and nest in. The nesting of many wild bees can be enhanced by reducing tillage (for those nesting below ground) or by providing artificial nesting materials (for those nesting above ground).

REDUCE PESTICIDE RISK TO POLLINATORS

Pest management affects the health and survival of bees and other pollinators. Minimizing pesticides or using alternative strategies (agronomic practices, biocontrol agents, etc.) to manage pest insects promotes pollinator health and their ecosystem services. If there is no alternative to pesticides, it is important to select those less toxic to pollinators. Always check the label (avoid those indicated as "highly toxic to bees") and read the instructions before handling and application.

POLLINATION CROP MANAGEMENT AND COLLABORATION WITH BEEKEEPERS

In intensive agricultural landscapes, an absence or scarcity of wild pollinators can cause a pollination deficit, which means that the quality and quantity of pollen received by plants limit agricultural output in yield and economic terms. Under such conditions, the use of managed pollinators may mitigate the dearth of wild pollinators. Colonies of *Apis mellifera* can be rented by farmers to improve pollination of their crops. This partnership is established through pollination contracts in which the rights and obligations of the parties are clearly stated. Collaboration between farmers and beekeepers is a central pillar for establishing a virtuous circle of bee-friendly practices. A good agricultural environment strengthens bee colonies, enabling them to provide a better pollination service.

Besides the honeybee, other pollinator species are commercially available for crop pollination (see Box 2).

Box 2: Main managed pollinators for crop production

Bumblebees (*Bombus* spp.) are primitively eusocial species that produce annual colonies with a variable number of workers (10 to 400). They are mainly reared and traded for the pollination of Solanaceae (tomato, pepper) in greenhouses, but can also be used in open fields to pollinate many different crops (such as eggplant, melon, strawberry, apple, cherry).

Mason bees (*Osmia* spp.) are spring-flying solitary bees. They are reared and traded for orchard pollination (e.g. almond, peach, cherry, apple, pear) but can also be used in greenhouses to pollinate Brassicaceae for seed production.

Leafcutter bees (*Megachile* spp.) are solitary bees that nest in summer. They are widely used in North America for the pollination of alfalfa.

The common fly (*Sarcophaga carnaria*) and the common green bottle (*Lucilia sericata*) are Diptera Calliphoridae that can be used to pollinate seed crops which are not attractive to bees, such as carrot, onion and fennel. They do not nest but visit flowers to consume nectar and pollen.

Some hoverfly species (e.g. *Eristalis tenax*, *Episyrphus balteatus*, *Sphaerophoria rueppellii*, *Eupeodes corollae*) can be used as crop pollinators. Most feed on different kinds of aphids in the larval stage and therefore play a dual role as pollinators and predators of crop pests.

LIFE 4 POLLINATORS

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