Pollinators and agriculture

Agricultural productivity and pollinator protection

ELO
European Landowners' Organization

EISA
European Initiative for Sustainable Development in Agriculture

European Crop Protection

Contents

Acknowledgments

This brochure is the result of fruitful collaboration between the European Landowners' Organization (ELO) and the European Crop Protection Association (ECPA) – key European stakeholders active in the policy and science fields of agriculture and biodiversity.

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Introduction

Pollinators such as the honey bee represent some of our most important species. Pollination allows plants to reproduce, provides the fruits, seeds and foliage that we eat, and much of the flora in our natural environment, gardens and parks. For thousands of years, through the domestication of the honey bee, humans and the iconic *Apis mellifera,* L. (Western honey bee) have together produced flowering fields, abundant fruit and vegetable crops, honey, and a variety of hive products.

In Europe a great variety of bees, butterflies, beetles and other insects are responsible for pollination; their collective contribution to the food in our diet is essential; however, this contribution is often misunderstood and frequently miscommunicated. Around 70% of the world's most produced crop species rely to some extent on insect pollination, contributing an estimated €153 billion to the global economy and accounting for approximately 9% of agricultural production [1].

An understanding of the drivers of pollinator population change is timely and of significance to the future of pollination services, even as decline in the biodiversity of pollinating insects has slowed in recent years [2], whilst Europe continues to experience an overall decline in biodiversity.

The decline in pollinators has been linked to factors including parasites, climate change, habitat loss, availability of food, pollution, invasive alien species, diseases and pesticides. The complex interaction of all these causes that have led to pollinator decline is taken seriously by all those involved; politicians, authorities, scientists, NGOs, farmers, land managers, beekeepers and industry.

In the press and social media, pesticides are among the most frequently cited attributors to pollinator population decline. In Europe pesticides are strictly regulated and this is reflected in highly developed risk management procedures which only allow pesticide use which is safe for bee colonies.

It is vital that industry, farmers, and all concerned parties work together to discover the best treatments for the decline of pollinator populations, and to promote solutions that offer favourable outcomes for both insects and agricultural productivity.

In the context of population decline, no pollinator has received greater attention than the honey bee. One of 20,000 known bee species, the Western honey bee (*Apis mellifera* L.) is the most common pollinator and the iconic provider of honey. Because of its vital importance for farmers and nature alike, a section of this report is dedicated to the honey bee.

At a time of heightened anxiety surrounding this issue, it is appropriate to ask a very basic question: *Are we facing a pollination crisis?* To contribute towards awareness of pollinator decline, possible causes, and the extent of the problem, this report describes the relationship between pollinators and agriculture, explores threats to pollinator species, and pays special attention to the honey bee in recognition of its importance to pollination and the beekeeping industry. Latter sections of this report describe practical agricultural measures for the promotion of pollinator species; measures that can be implemented with relative ease.

Pollinators are essential, and so too is food production; as a society we have an enormous responsibility to maintain both. We hope that this publication raises awareness and inspires good practice.

We are committed to the sensible management of our natural resources and sustainable productive agriculture.

Friedhelm Schmider
Director General, ECPA

Thierry de l'Escaille
Secretary General, ELO

A word from the farm

Agriculture provides habitat and forage for pollinating insects, and therefore contributes to the important ecosystem service of pollination. The implementation of best management practices in agriculture can provide improved crop yields, and at the same time, improved conditions for pollinator species.

The implementation of some best management practices can incur additional financial cost, but can also lead to positive results in yield, the conservation of nutrients, the protection of soil, and the safeguarding and promotion of biodiversity. This is true – for example – of flowering cover crops, which can be sown after early summer harvests, and which can serve to provide forage for pollinators. Grass bufferstrips established for erosion control or water protection might also be planted with a flowering seed mix as additional food for bees and other pollinators.

With regard to the use of chemical crop protection products, all label instructions have to be followed precisely. In addition, weather conditions during a planned application, as well as the timing and appropriate kind of application, need to be taken into account. Integrated Pest Management (IPM) techniques should be the first consideration to allow for best management practices that are favourable to pollinators. This includes an assessment of pest infestation levels in a crop to gauge appropriate treatment measures and the use of non-chemical treatments as long as they offer sufficient protection at economic cost.

Pollinators can also be protected through good communication with local beekeepers. It does not cost much time, for example, to inform beekeepers one or two days in advance of a treatment so that they can take the necessary precautions for the colonies that they manage and move their beehives to another location, if they prefer to do so.

It is not only the honey bee that benefits from improved co-operation between beekeepers and farmers and improvements to habitat and forage; solitary bees, bumblebees and other pollinators, which also play an important ecological role can also benefit.

This report takes a look at the important relationship between pollinators and European agriculture, and with its focus on the safe and sustainable use of pesticides, and best management practices for sustainable productive agriculture, the following chapters offer a useful and informative contribution to an important and highly topical subject.

Patrick Wrixon
President EISA – European Initiative for Sustainable Development in Agriculture

Through necessity agriculture is shaped by a multitude of social and economic variables. However, it is not beyond the capacity of agriculture to continue to implement and improve measures and initiatives for sustainable agriculture which seek to protect and maintain pollinator populations.

Pollination

Pollination is the transfer of pollen between plants enabling fertilisation and sexual reproduction. There are two types of pollination, abiotic and biotic. Abiotic pollination takes place without the involvement of living organisms, for example, where pollen is transported by wind. Biotic pollination is the result of the movement of pollen by living organisms; it is the most common form of pollination and accounts for an estimated 90% of pollination of all flowering plants [3]. In exceptional cases, pollination may be achieved by hand.

Biotic pollination: a successful symbiosis of plant and insect

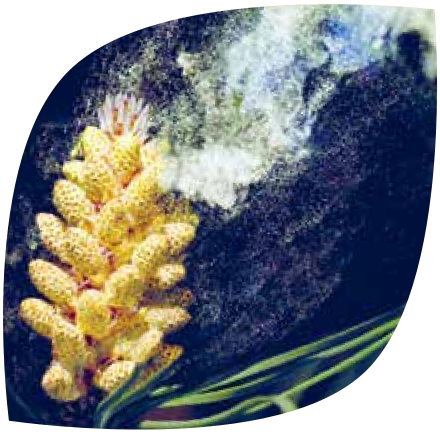
The sexual reproduction of plants mostly requires the transfer of pollen from one flower to another of the same species. There are plant species and plant varieties which are able to self-fertilise, but the exchange of genetic material between different individuals is the most common form of sexual reproduction amongst plants.

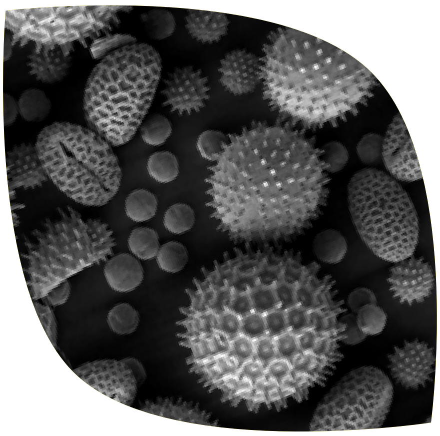
An enormous evolutionary step was taken about 60 million years ago, when plants began to utilise insects as pollinators. An insect flying from one flower to another is by far a better transport medium than the wind as it transports pollen directly from flower to flower. The result of this efficiency is the need for fewer pollen particles to ensure successful reproduction - a clear advantage for plants.

Insect pollination is a symbiotic process, yielding benefits for insect and plant. The main benefit that plants provide to insects is feed, primarily nectar and pollen. Nectar is a solution of sugars mixed with mineral nutrients and fragrances and is usually located at the flower's base. Pollen is rich in protein and a potential food source for many pollinators.

When insects visit flowers, they collect pollen and transport it from anther to carpel and from flower to flower, enabling reproduction. This form of pollination can be considered one of the most successful examples of symbiosis - interaction between the incalculable numbers of species of plants and insect pollinators is an example of fundamental evolutionary design (Figure 1).

Many plants
rely on wind pollination.

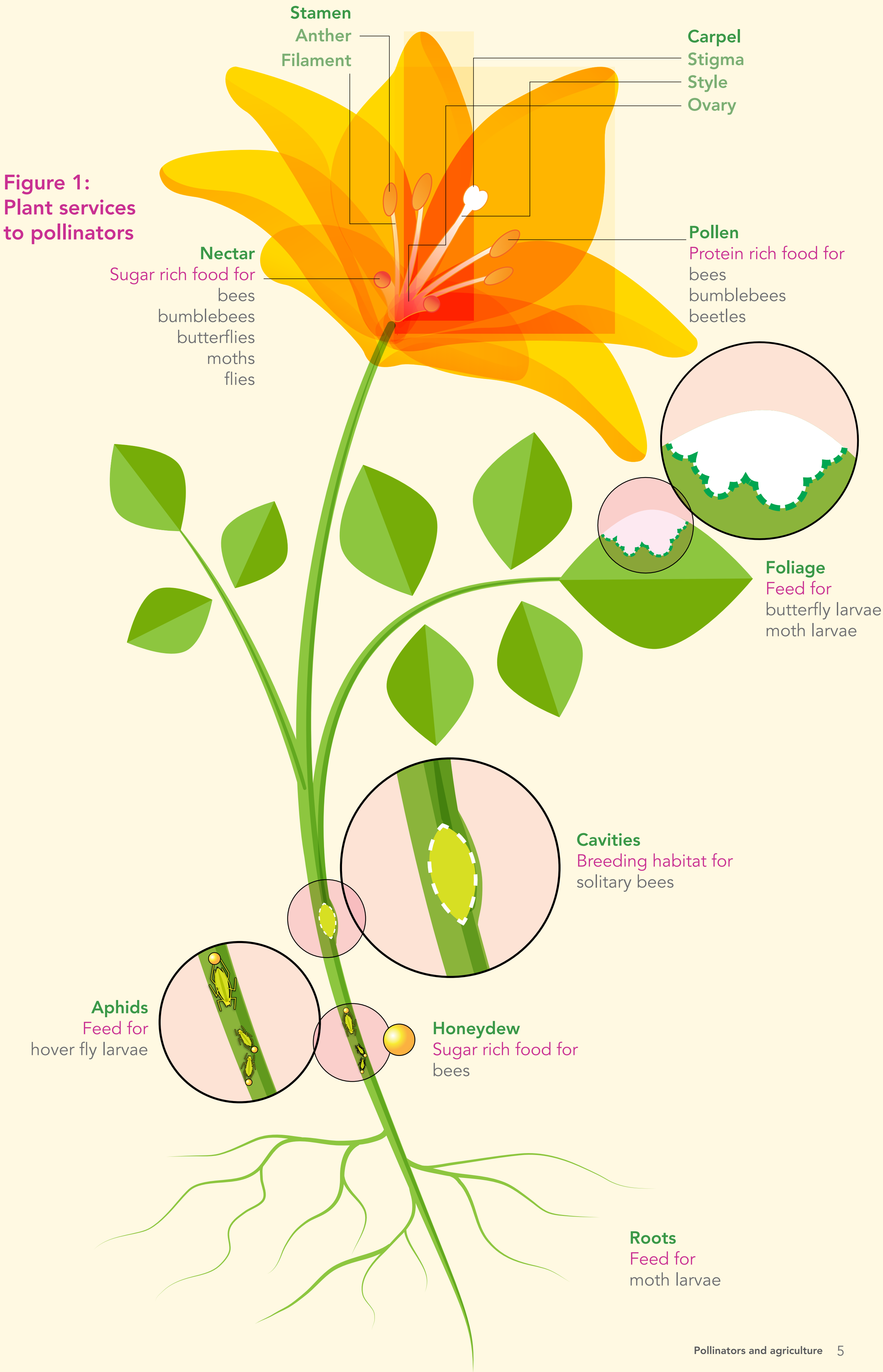




Photos: © Dartmouth Electron Microscope Facility

An electron microscope image
of pollen from various plants including sunflower (*Helianthus annuus*) and evening primrose (*Oenothera fructicosa*).[A]

Figure 1: Plant services to pollinators



A bumblebee in flight

Pollinators in Europe

Several of Earth's animal taxa have developed the ability to pollinate; not only insects, but also, for example, hummingbirds, sun birds and bats are able to fertilise plants. In Europe, only insects act as pollinators.

Flies

The contribution of flies to pollination is perhaps underestimated. Flies are extremely abundant and can be found almost everywhere, and unlike familiar pollinators such as honey bees, they can be active at low temperatures. This comparatively lengthy period of activity offers a broad daily window for pollination.

Several hoverflies mimic the appearance of honey bees, wasps and bumblebees, but they are not able to sting.

Next to their contribution to pollination, the larvae of several species of hoverfly support pest control by feeding on aphids. Aphids (a.k.a. plant lice) are a serious agricultural and forestry pest and a nuisance for gardeners.

Flies belong to the order Diptera; a large order, containing an estimated 240,000 species of mosquitoes, gnats, midges and others.

Not a bee
A hoverfly of the genus *Eristalis.*

Not a wasp
A hoverfly of the species *Volucella inanis.*

Deilephila elpenor (fam. *Sphingidae*) – the Elephant Hawk-moth

A bee beetle
(Trichius fasciatus, fam. *Scarabaeidae)*
feeding on pollen.

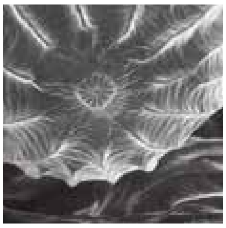
Beetles

Flowers provide feed and nourishment to a diversity of beetle species, this leads to a certain amount of successful beetle pollination. However, the appetite of beetles sometimes results in flower damage. It is no coincidence that the few plant species that rely on beetle pollination usually have carpels that are well protected from the biting mouthparts of beetles.

Moths and butterflies

Adult moths and butterflies mostly feed on liquid food, usually nectar; their choice of food is limited by their specially adapted mouthparts. Flowers that depend upon butterfly pollination typically offer more nectar than pollen. Moth-pollinated flowers are night-opening to profit from the period when moths are most active.

Most caterpillars feed on foliage, frequently causing serious leaf damage to wild plants and crops. Feeding is often limited to specific plants and localised areas, as caterpillars may be adapted to one specific plant species, and select few host plants for survival.



A butterfly egg
Butterflies mostly lay their eggs on specific host plants.

Moth larvae in vegetation
(fam. *Yponomeutidae*).

Two *Cerura vinula* (fam. *notodontidae*) caterpillars
on plants stems. The leaves have been eaten.

A beetle
of the genus *Anthaxia*
(fam. *Buprestidae*).

Photos : © Prof. Dr. Christoph Kuenast

Hymenopterans

Hymenopterans are a large taxonomic group of insects that exhibit diverse interactions with plants. The family Apidae includes bumblebees, solitary bees, stingless bees, and honey bees. These pollinating bees mostly protect themselves with a venomous sting, and in many cases their bodies are covered with hairs which trap and enable the transportation of pollen.

There are around 700 species of bee to be found in Central Europe. In Germany alone, 547 species of wild bee have been identified. Most wild bees depend on wild flower species for nourishment, and their appetite demands a continuous supply of nectar, pollen and honeydew (the sugary excretion of the aphid).

These insects are more than an attractive element of Europe's biodiversity. Recent publications have described the estimated economic value of pollination, and the high figures have surprised many. Pollination is of key importance for agriculture and is supported by a whole community of insects - not only the honey bee - as part of a vital ecosystem service.[4] [5]

Solitary bees

Solitary bees are wild bees; they live alone or in small colonies. Unlike bumblebees and honey bees the solitary bee never establishes complex social interactions. Solitary bee larvae may live in tubular tunnels or burrows dug by adult females, and often make use of opportune shelters such as empty snail shells, dry plant stems and cavities in wood. Many solitary bees have highly selective habitat requirements which limit their exploratory range and therefore their potential for pollinating many different species of plants[6] [7].

Bumblebees

Bumblebees have a plump body which is covered by black and coloured hair that often grows in a characteristic banded pattern. Bumblebees are social insects; they live in small annual-cycle colonies. Only queens (fertile females) are able to hibernate and start a new colony in the next spring.

Bumblebees are sometimes used as pollinators in greenhouses, where crops such as tomatoes can be grown under carefully controlled conditions; for crops that would normally rely on wind pollination a greenhouse can be stocked with bumblebees, their movement around the plants leads to 'buzz pollination'. This mechanical form of pollination results from the vibrations created by the strong flight muscles of the bumblebee; when a bumblebee feeds it 'buzzes' the flower and


Andrena flavipes,
Yellow Legged Mining Bee

dislodges pollen which may fall onto underlying stigma and fertilize the plant. Several species of bumblebee are bred artificially, and whole colonies are available for purchase.

The honey bee

In Europe, the honey bee is the only pollinator species that lives in perennial societies, whose members are connected via complex communication processes, and demonstrate pronounced work-share behaviour. Honey bees are a subset of bees in the genus *Apis*. In Europe and the USA the Western honey bee (a.k.a. European honey bee, *Apis mellifera*) is the only species of honey bee, and the provider of honey, bees wax, and whole range of other hive products.

This species, its unique behaviour, its traditional value to humans and the misconceptions that surround this icon of the insect world, all demand greater attention and protection. The following chapter is therefore dedicated to the honey bee.

Andrena labiata
Girdled Mining Bee

Bombus spec.
A typical bumblebee

The honey bee - a unique insect

The honey bee is one of the most well known insects in the world; even with occasional mistakes we can all identify the honey bee. It is one of the insects we are familiar with when growing up; in cartoons, advertisement and when we go outside, for millennia the bee has been humanity's constant companion.

Humans have for a long time worked with *Apis mellifera*, with which we have a special and perhaps demanding relationship. The remarkable characteristics of this species, its value to human beings, and consequent (over) exploitation all demand greater attention.

The honey bee colony

A honey bee colony reaches its most populous in early summer, at around the time of the longest day. At this point, the hive consists of three types of individual bee - the queen, worker bees and drones.

Typically, there is one queen - the only reproductive animal in the colony - between 40,000 to 60,000 worker bees (sterile females), and some hundred drones which are the only males in the colony.

A queen may live to the age of 3-4 years, but will be typically replaced by the beekeeper after 2 years. A worker bee in summer lives for a brief six weeks, while a drone's life expectancy extends to a few months.

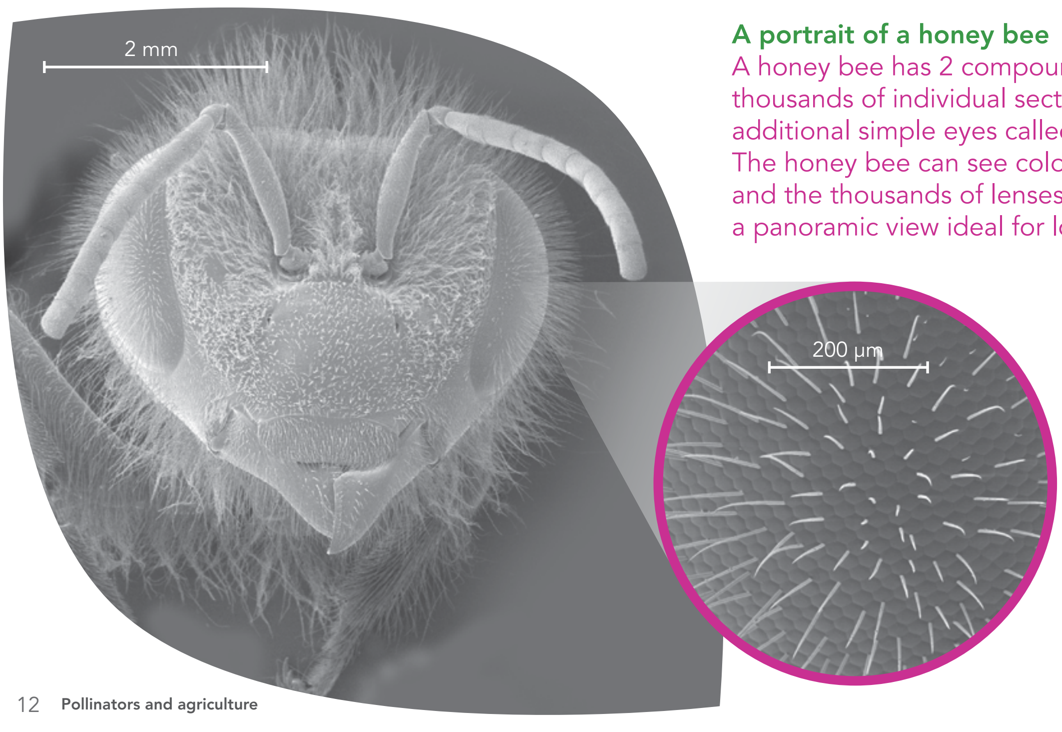
The dynamic worker bee

After hatching, a worker bee passes through several distinct life stages, each to fulfil a function essential for the hive.

The worker bee begins life with a colony cleaning period; the bee then develops wax glands and becomes a honey comb producer. Next, the worker becomes a nurse bee and cares for the brood (embryo/egg, larva and pupa stages of the honey bee). Following the nurse stage, the worker becomes a colony guard and aggressively defends the colony. In the last period of its life the worker bee assumes the responsibility of a forager and collects pollen and nectar for the hive.

The multiple stages of the worker bee's life are essential for maintaining the colony and the hive, the process is 'genetically fixed'. The changes in its life cycle are communicated through chemical stimuli.

Photos: © BASF SE



A portrait of a honey bee
A honey bee has 2 compound eyes with thousands of individual sections, and three additional simple eyes called 'ocelli'. The honey bee can see colours, and the thousands of lenses enable a panoramic view ideal for locating flowers.

German zoologist Karl Ritter von Frisch was awarded with the Nobel Prize in 1973, primarily due to his research on honey bee communication. His discoveries shone new light on insect orientation in space and time. A honey bee on the return from foraging is able to communicate with colony members and share information about the quality and whereabouts of food sources. This information improves the efficiency of food collection, and assists the location of new food sources.

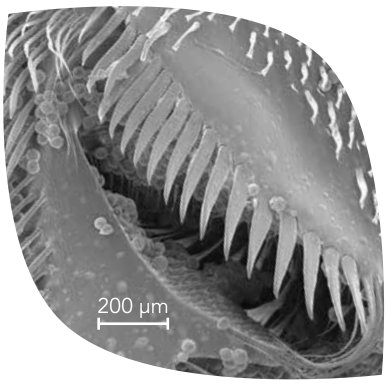
A honey bee feeding on nectar

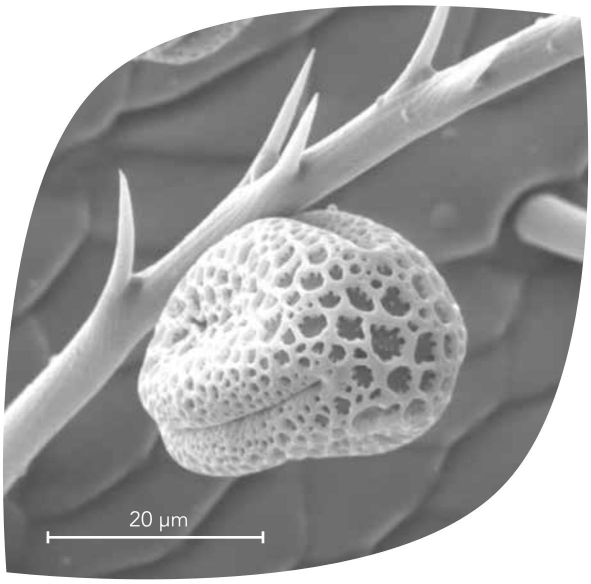
The foraging worker bee

At the last stage of its life, the worker bee becomes a forager. The ability of a foraging worker bee is an excellent example of adaptation; a pollinator adapts to the characteristics of flowering plants and to the needs of the colony. Honey bees are equipped to see colour, shape, and to detect odours. This set of abilities allows for high foraging consistency; worker bees select which flowers they visit, preferring flowers that provide the best foraging. This specialisation allows bees to efficiently locate nectar, and also has advantages for the plant as the likelihood of intra-species pollination is increased.

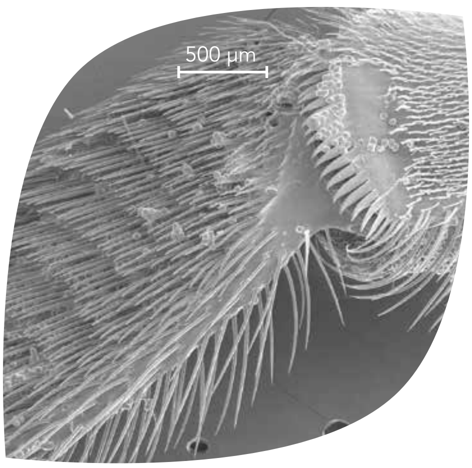
A pollen particle attached to the hair of a honey bee.
The hair has branch-like structures that are perfectly adapted to trap pollen.

The comb-like structure on the hind leg of a honey bee
moves pollen from the opposite hind leg to the pollen basket.





Photos : © BASF SE



The brush-like structure on the hind leg of the bee
brushes pollen from the body hairs to the 'pollen basket'.

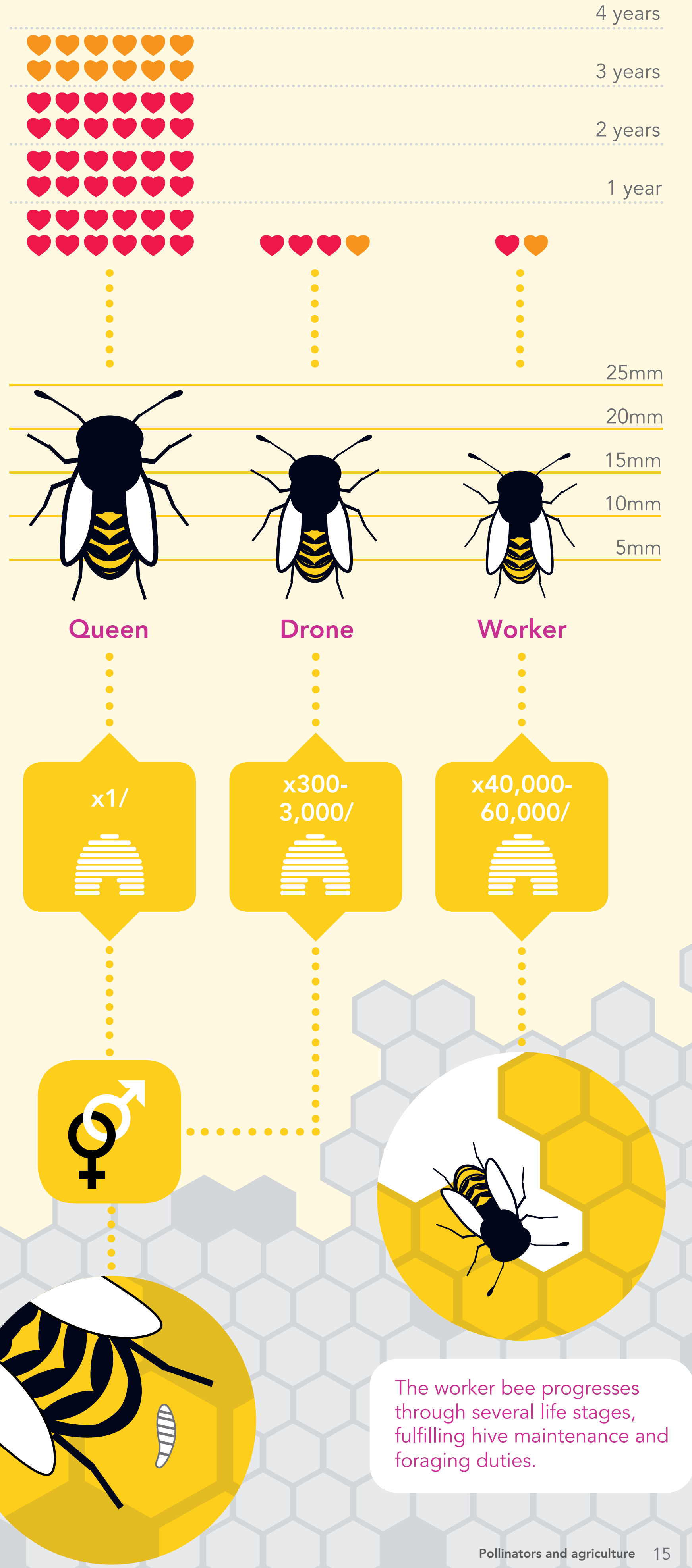
A queen may live for up to 4 years but will typically be replaced by the beekeeper after 2.

Three forms of honey bee comprise a colony - each has a characteristic size.

A colony normally contains only one queen, a few hundred drones and up to 60,000 worker bees.

Worker bees are sterile so breeding is left to drone bees and the queen.

A queen can lay as many as 2000 eggs per day.



As with overall biodiversity, pollinator biodiversity is decreasing; however, pollinator biodiversity loss has been shown to be slowing in recent years [2].

The European Peacock *(Inachis io)*

Pollinator population trends

The ability of agricultural landscapes to provide sufficient resources for pollinator species has a direct impact upon the size and resilience of pollinator populations. The availability of feed and breeding habitats is also a key determinant of the probability of an insect realising all of the stages of its life cycle.

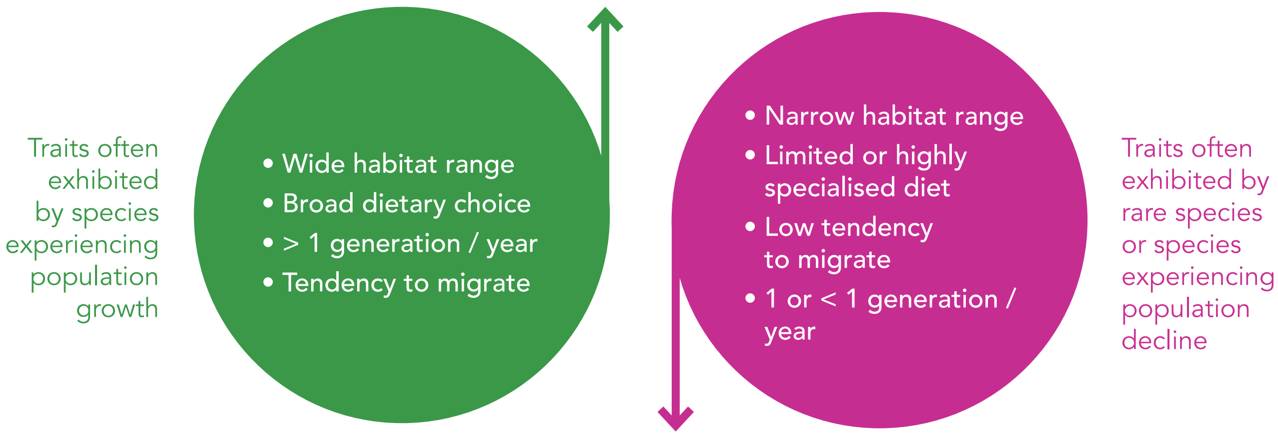
Common pollinators and pollinator species with increasing populations

The pollinators that can be regularly seen in gardens, parks and during walks in the countryside belong to species that thrive in the present agricultural environment. Several attractive butterflies belong to these common species. Examples include the European Peacock (*Inachis io*) and the Small Tortoiseshell (*Aglais urticae*), the caterpillars of which often feed on the stinging nettle (*Urtica dioica*). The Swallowtail (*Papilio machaon*) is a common butterfly in many Mediterranean countries. It is important to note that the plants upon which the above mentioned butterfly species depend are plants that are often found in and on the peripheries of fields and farmed spaces.

The Painted Lady (*Vanessa cardui*) is a common butterfly that migrates over large distances. This species is able to travel from Northern Africa – where the insects hatch in the early spring – across the Mediterranean and over the Alps to the landscapes of central Europe. During the journey eggs are deposited, the larvae develop in time for the return migration of the newly hatched butterfly generation in late summer.

Certain hymenopterans also exhibit a population increase, including bumblebees such as *Bombus terrestris*.

Figure 2:
Traits often exhibited by pollinator species experiencing population growth and pollinator species that are rare or in population decline (according to ref. [8])



Gossamer-winged butterflies
(Fam. *Lycaenidae*)

Pollinators which are rare or exhibit declining population trends

Other species are rare or show declining trends in most cultural landscapes, including the Apollo butterfly (*Parnassius apollo*), which is a brightly coloured insect that inhabits nutrient-poor and flower-rich meadows. Apollo butterfly larvae feeds on a rare stone plant (*Sedum telephium*), and exhibits slow development, taking up to two years to complete its life-cycle. Many butterflies belonging to the family *Lycaenidae* (gossamer-winged butterflies) can today be found on the global IUCN Red List of Threatened Species (Figure 3). Their larvae often follow a specialised diet that requires one or a few species of host plants.

Figure 3: An assessment of species population trends: An example from the European Red List [9]

The IUCN Red List of Threatened Species includes taxonomic, conservation status and distribution information on plants and animals that have been globally evaluated using the 'IUCN Red List Categories and Criteria'. *Lycaena dispar* as shown in this example is classed as 'Least Concern' at the European level.
For more info: www.iucnredlist.org/initiatives/europe

Lycaena dispar - English common: large copper

Taxonomy:	Kingdom	Phylum	Class	Order	Family
	Animalia	*Arthropoda*	*Insecta*	*Lepidoptera*	*Lycaenidae*

Range description:
This species occurs from eastern England via the Netherlands and northern Germany to Finland, southwestern France and from the north of Italy to Turkey. 0-1,000m. It is furthermore found in the temperate and subtropical parts of the palaearctic. The global distribution area of the species is situated both within and outside Europe.

Regionally extinct: UK

NOT EVALUATED	DATA DEFICIENT	LEAST CONCERN	NEAR THREATENED	VULNERABLE	ENDANGERED	CRITICALLY ENDANGERED	EXTINCT IN THE WILD	EXTINCT
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Mutual benefits: agriculture and pollination

Pollination is a natural ecological process that benefits mankind. Insects pollinate crops, assisting with the process of food production; pollination can significantly increase the yield of certain crops. In turn, agriculture provides benefits for pollinators; flowering crops are cultivated, land is left open (i.e. meadows) and – in the context of cultural landscapes – a diversity of ecological niches can be provided.

The benefits of biotic pollination for agriculture

The most produced crops (Table 1) in Europe (by weight) show a high diversity in pollination requirements. Cereal crops such as wheat, rice, and corn are either wind or self-pollinated, they do not require insect pollination. Crops such as potato, sugar beet, spinach and onions do not require pollination; they provide little food for pollinators, but are important elements of the human diet.

Some crops rely on biotic pollination. Pome (such as apple and pear) and stone fruits rely heavily on insect pollination; in fact insect pollination can increase yields in cherry and plum crops by 80% and 30% respectively [10]. The honey bee is the primary pollinator for these fruit crops; however solitary bees, bumblebees and other insects are also important contributors .

Oilseed rape yields can be increased by up to 20% by pollination, even when unfavourable wind conditions offer minimal abiotic pollination, insect (biotic) pollination can contribute a 15% yield increase [11].

Biotic pollination adds variety, fruits, vitamins and other benefits to our diets. A healthy and balanced diet is important, and a diverse intake of vitamins and nutrients is essential. In addition to the aforementioned tree crops, many berry and vegetable crops rely on insect pollination – such as watermelon, cucumber, pumpkin and raspberries, and also many spices.

Globally, 264 crop species have been identified as being dependent or partially dependent on pollination. In fact, 39 of the world's most produced 57 crop species exhibit an increase in yield due to biotic pollination [13]. Pollination improves yields and therefore the availability of food, as a general rule, this makes food more affordable. Some authors claim that about one third of the global food production depends on biotic pollination, however the generally accepted figures are considerably lower [14]. According to the TEEB report (2010), the total economic value of insect pollination globally is estimated to be €153 Billion, this equates to 9.5% of agricultural production [1]; others conclude an overall figure as low as 6.1%[15]. The estimated value of insect pollination for European agriculture is €22 Billion [16].

Table 1:
Agricultural production of the most prominent staple crops in the European Union, 2008 [12]

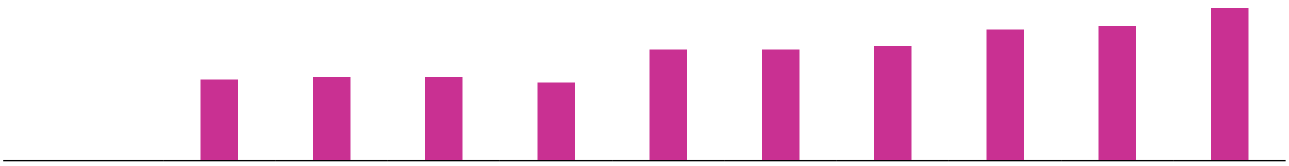
Crop	1,000s of tons	Reliance on biotic polllination		
Cereals	313,759	🔴		not required
Sugar beet	97,299	🔴		not required
Potatoes	61,614	🔴		not required
Fruit	50,271	🟢	🟢	essential
Vegetables	45,161	🔴	🟢	partial
Rape	18,936	🟢	🟢	improves yield

The benefits of agriculture for pollinators

European agricultural landscapes have historically enlarged those habitats suitable for pollinators. The growth of agriculture in Europe has provided a patchwork of diverse and multifunctional habitats, offering a variety of sources of pollen, and including open spaces such as meadows and field boundaries where wild flowers and other non-crop vegetation thrive.[69] Cultural landscapes also offer plentiful options for nesting, breeding space and feed.

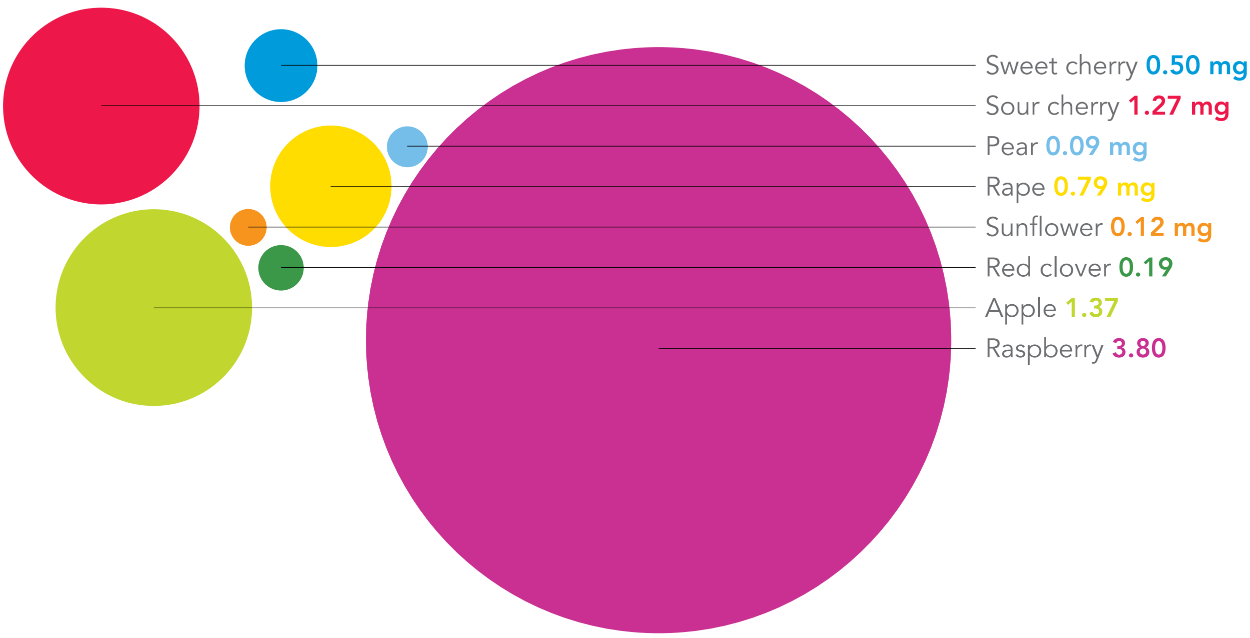
The modern day prevalence and distribution of pollinators has been very much shaped by human behaviour.

Figure 4:
Rape production in the European Union (EU27)[12]



year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1,000s tons	11,253.0	11,573.7	11,684.4	10,850.9	15,462.4	15,646.4	16,119.1	18,443.9	18,925.7	21,395.0

Figure 5:
Average nectar production (mg sugar/day/flower) of important agricultural crop flowers[68]



Beekeeping in Europe

Apiculture, more commonly known as beekeeping, describes the maintenance of honey bee colonies by humans in order to gain honey and other bee products, to pollinate crops, and to produce bees for sale to other beekeepers. In addition to the significant industrial nature of beekeeping that has been practiced in many forms for a very long time, apiculture is also an important hobby for many Europeans.

The domestication of honey bees began thousands of years ago. Artwork dated 2422 BC at the Nyuserre Ini sun temple, Egypt, depicts workers blowing smoke into hives and removing honeycombs.

Beekeeping has resulted in the domestication of the honey bee; this is an ongoing process which is driven by demand for honey bee products and shaped by improved scientific knowledge about bees, and by the development of tools for beekeeping.

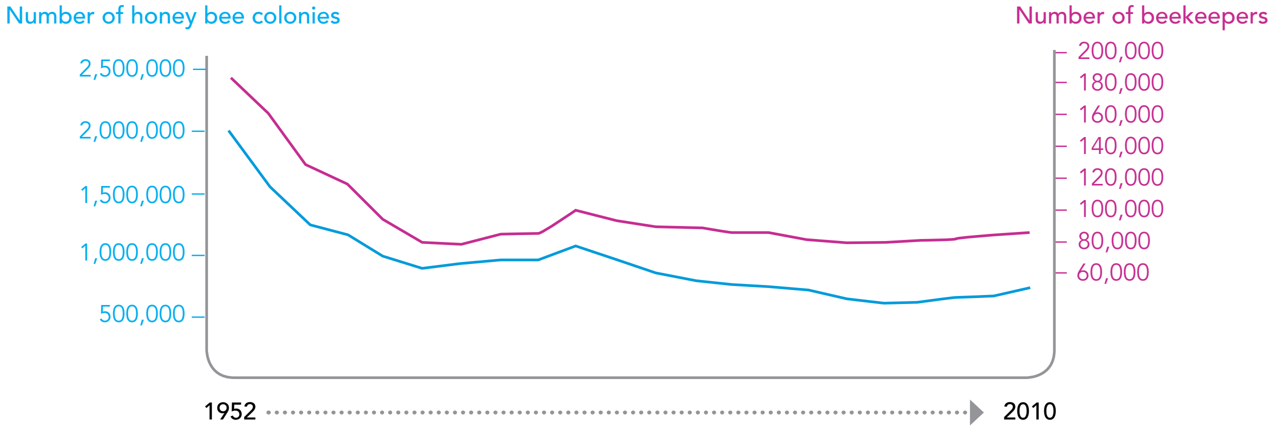
Beekeeping today

Modern beekeeping, which allows the harvest of honey without damaging colonies, did not emerge until the 18th century. Good practice beekeeping techniques are based on improved knowledge of bee biology, and have included, for instance, the development of mobile comb hives with sliding frames. Hive mobility allows the transport of whole colonies to locations that support a high honey yield or require increased pollination, and removable hive parts allow the extraction of honey with reduced damage to bees.

Today, the European honey bee is a domesticated species; it is farmed, managed and adapted for its products, its service as a pollinator, and for beekeeping requirements. Modern beekeeping makes use of tools and techniques that simulate or force natural colony functions, for example:

- It is common practice to artificially inseminate queen bees.
- The natural reproductive cycle of a colony - the 'swarm' - is suppressed to prevent periods of reduced colony size and consequent reduction in hive productivity.
- Colony diseases and parasites are controlled with chemical applications.
- Targeted breeding is used to generate honey bee varieties with traits beneficial to the beekeeper, such as high disease and parasite resistance, good honey production, prolific breeding, and low aggressiveness.

Figure 6:
Honey bee colony count versus number of beekeepers in Germany between the years 1952 and 2010 (adapted from ref. [18])



The life of the domesticated honey bee differs greatly from that of the wild honey bee which once inhabited European landscapes. Beekeeping practices have impacted on the genetic diversity of the honey bee, their resistance to disease, their aggressiveness, and their status as a wild species. The existence of original variety wild honey bees in Europe is the subject of debate; these honey bees may be extinct in the wild, and it is likely that unmanaged colonies are in fact feral (escapees of domesticated colonies) and not truly wild.

There are an estimated 14 million hives in Europe [19], the greatest density is to be found in Spain (2.46 million), followed by Greece (1.5 million). France, Italy, Poland and Romania each have more than a million hives [19]. Since 1965 the number of bee colonies maintained by beekeepers in Central and Western Europe has been declining. However, in Southern Europe (especially Greece, Italy and Portugal) the number of colonies showed an increase between 1965 and 2005. The overall trend for Europe has been a decline (Figure 6) in the number of beekeepers [17].

Removal of protective wax before the extraction of honey.

Honey bee products: human use of the honey bee

Humans make use of several products (Table 2) of honey bee colonies. Honey bee products – honey in particular – and the use of pollination for crop growth are the primary economic driver for beekeeping.

Table 2: Honey bee products and their uses

Product	Origin	Main ingredients	Primary use
Honey	Flower nectaria and honeydew from aphids.	Sugars, water, pollen, protein, enzymes and vitamins.	Consumption as a food source.
Wax	Wax producing glands of worker bees.	Myricin (a waxy substance which forms the less soluble part of beeswax).	Cosmetics, pharmaceuticals and candles.
Propolis	Resin from trees.	A biocidal compound that suppresses bacteria and other micro-organisms.	Dermal and internal application in naturopathic treatments.
Pollen (pellets)	Flower anthers.	Proteins, amino acids and B vitamins.	A food additive.
Royal jelly	Glands in the throats of worker bees.	Carbohydrates, proteins, B vitamins, sugar and water.	Various applications in naturopathy.
Venom	Abdominal glands of female bees.	A variety of toxic proteins (melittin, apamin and others) which act as neurotoxins.	In 'apitherapy' procedures for the treatment of complaints such as rheumatism and sciatica.

The honey comb - produced and maintained by the worker bee.

Propolis

Propolis is a compound of plant resins which the worker bees collect. It has antimicrobial properties that help control the microbes in the colony, and a consistency that allows it to be used for sealing cleavages and gaps in the honeycomb and hive.

The temperature in a bee colony is maintained at around 35°C. This temperature and a high humidity level, combined with the presence of sugars and other organic compounds, create ideal conditions for the propagation of problematic microbes, which can be controlled by propolis. Propolis is used, for example, to treat the wood of stringed musical instruments and in the production of automobile wax.

Honey

Honey is the main food source for honey bees; it is created from the sugary liquids collected by honey bees, such as nectar or honeydew. Nectar is secreted by plants through glands which are mostly located at the base of the flower. Honeydew is secreted by aphids as a waste product following their feeding on plant sap. Worker bees collect these liquids and bring it to the colony, where it is stored in a cell in the honey comb for future consumption. An active and highly populated hive requires an abundant source of food and stock of honey [18].

Honey is mostly based on fructose and glucose. A jar of honey is the product of a bee's hard work and requires up to 40,000 foraging flights during which millions of flowers are visited.

Wax

Wax is secreted by glands which are located on the worker bee's abdomen. The wax is used for construction of the honeycomb, a framework of hexagonal wax cells used to house larvae and pupae, and to store honey. Beeswax finds use in food, cosmetic and pharmaceutical production.

Pollen (pollen pellets)

Pollen is an important part of the honey bee diet and the main source of protein. Pollen particles become trapped on the bee's body hair during foraging. Brush-like structures on the hind legs push the pollen into 'pollen baskets', where it is stored in pellet form for transportation. On returning to the hive, 'pollen traps' placed by the beekeeper detach the pollen pellet from the bee, which is later collected by the beekeeper. Pollen is sometimes sold as a 'food supplement' by health food stores.

A honey bee with pollen pellet attached to hind leg.

Royal jelly

Royal jelly is a honey bee secretion used to feed larvae and adult queen bees. It is secreted by worker bees while in their nurse phase; up to 500g per hive per season can be produced. The copious feeding of royal jelly to selected larvae produces new queens.

Royal jelly is used in naturopathy, particularly in Asia, for lowering cholesterol, as an anti-inflammatory, and as an antibiotic agent. However, there is no conclusive scientific proof of its effectiveness.

Venom

A bee sting delivers the toxic compound bee venom (apitoxin). A bee sting is rather painful, but normally not dangerous, but a bee sting may be deadly if the respiratory ducts are targeted (in which case there is a substantial risk of asphyxia), or when a victim has a severe allergic reaction to the toxin.

Honey bees will usually only sting in self-defence or in defence of their hive. The barbed end of the honey bee stinger often becomes embedded in thick skin following a sting. In such cases the honey bee will lose its stinger and a portion of its lower abdomen of size sufficient to kill the bee. Apitoxin is used a treatment for rheumatism and as a desensitiser to manage insect sting allergies.

A spoonful of harvested pollen pellets.

Beekeeping problems

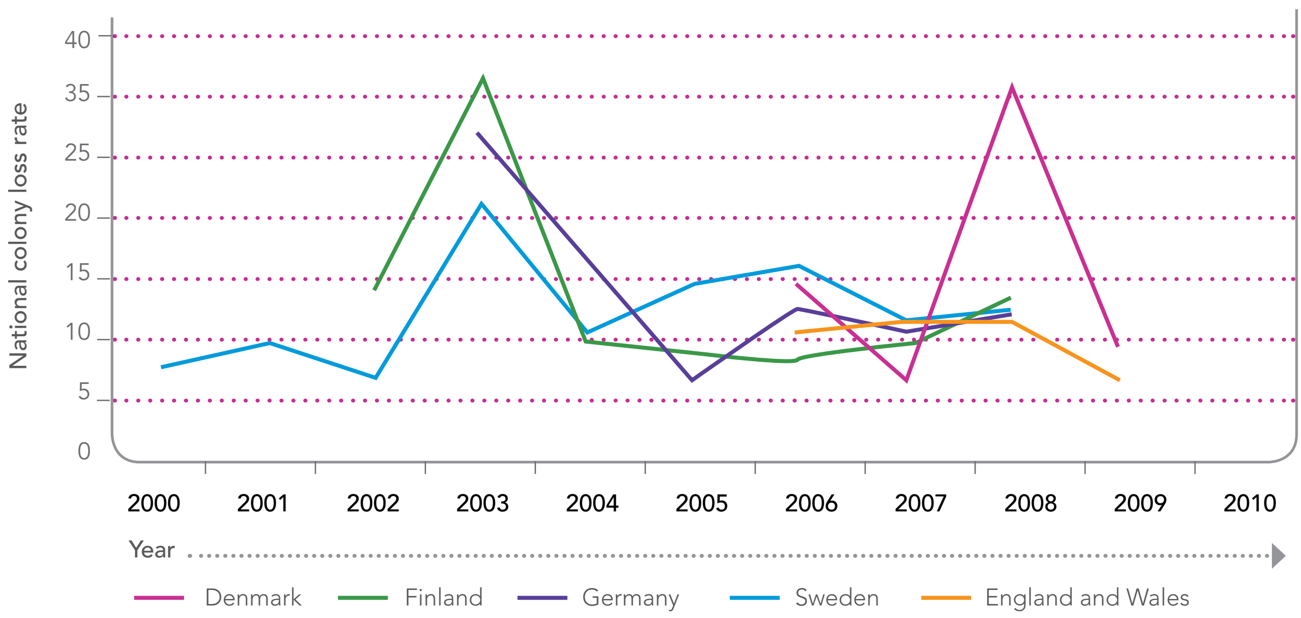
Whilst the reported severity of problems varies from year to year and season to season[70], there is a consistency in the type of problems associated with beekeeping; they include:

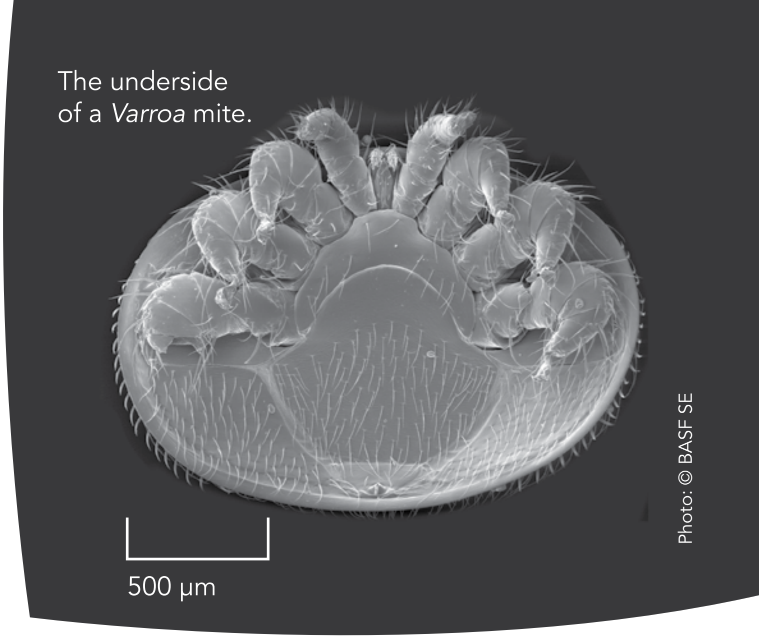
Of the problems identified by beekeepers in Europe 'Colony Collapse Disorder' is reported in error. CCD is a term describing a characteristic phenomenon where worker bees disappear without trace. CCD is an accepted phenomenon in the USA, but in Europe CCD is unconfirmed and bee experts and authorities claim that CCD has not been experienced in Europe. What is experienced in Europe is over winter losses of bees that exceed normal levels.[20] [21] [22]

- Above average colony losses following the winter period. This problem has been identified at the national and continental level (Figure 7). Above average losses would be those that exceed the 5-10% winter losses that are considered normal.
- Localised bee losses, where a defined local area suffers greater than average worker bee mortality.
- The colony exhibiting a 'weakness' that seems to increase the sensitivity of bees to stresses such as diseases and parasites.
- A noticeable reduction in honey yields.
- A condition referred to as 'Colony Collapse Disorder' (CCD).

Over-winter hive losses are not a new phenomenon; they have been repeatedly recorded since the late 19th century[25], and causes of localised bee losses are often quickly identified. The identification of the source of a problem ensures that appropriate action can be taken to prevent future cases.

Figure 7:
National percentages of colonies lost after winter from 2000 to 2009 in Denmark, Finland, Germany, Sweden, and England and Wales (adapted from[21])





The underside of a *Varroa* mite.

In spite of the considerable research into bee health there is neither a precise quantification of beekeeper-reported problems nor a valid data-based explanation for what precisely impacts honey bee colony survival or fitness [26]. The list of factors currently suspected of influencing honey bee colonies is long; the 'usual suspects' are described in the following sections.

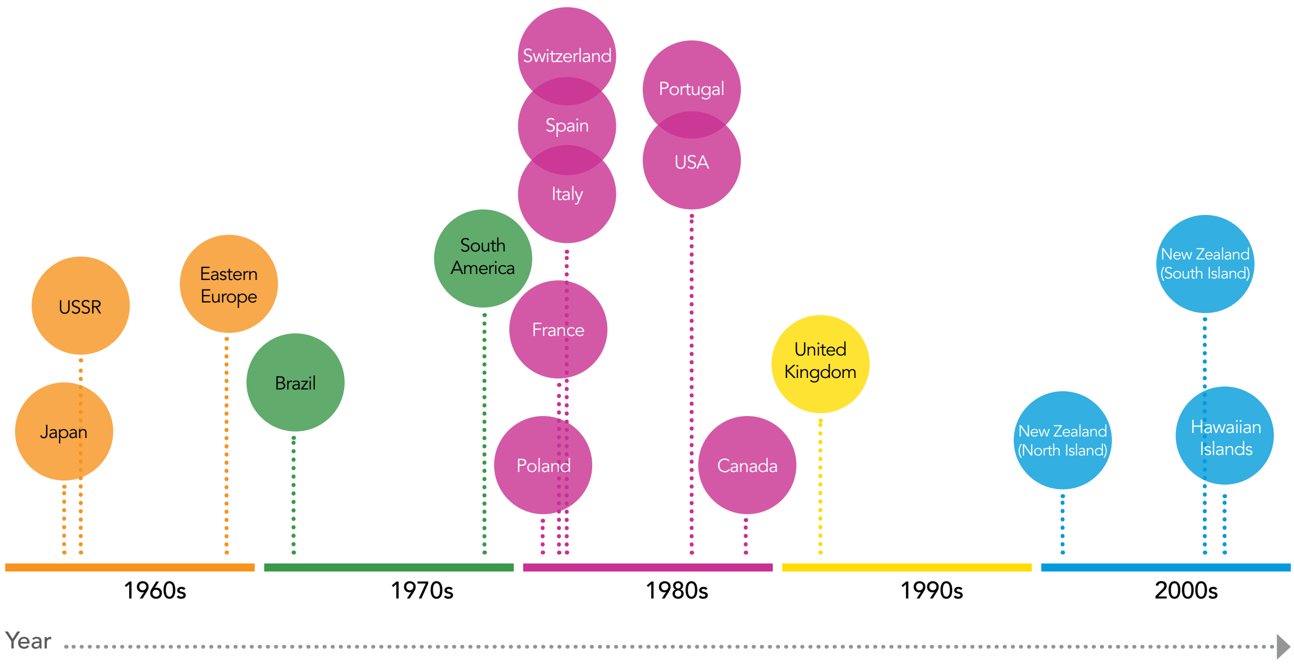
Any decline in pollinator species is most likely contributed to a variety of the problems. A honey bee colony damaged by one of these problems can often fall prey to another due to its weakened state.

Varroa

The parasitic mite *Varroa destructor* is an invasive alien species (Figure 8) [32] and was introduced to Europe by infested Asian honey bees that were imported during a research program and escaped into the wild. The mite damages bees by sucking body liquids and by transmitting viral diseases [27]. It is largely agreed in the pollinator research community that most current beekeeping problems are caused, directly or indirectly, by this parasite.The *Varroa* mite is the factor with the most pronounced economic impact on the beekeeping industry [27] [28] [71].

The relatively new threat posed by the *Varroa* mite, and its staggered progress from country to country may be responsible for some of the unexplained bee problems, and erroneous reports of CCD.
If a beekeeper is unaware of a *Varroa* infestation in their colony, it is understandable that preventative measures will not be taken. It is possible that beekeeping practices in some areas have not kept pace with the progression of *Varroa*.

Figure 8:
Timeline of the spread of *Varroa* mite around the world



Diseases

Honey bees are subject to many diseases which are caused by a variety of pathogens. Bacterial diseases (e.g. American foulbrood and European foulbrood), fungal diseases (like chalk brood or stone brood) and a long list of viral diseases (e.g. deformed wing virus, acute bee paralysis virus, Israel acute paralysis virus or the Kashmir bee virus) impact individual bees and may have significant effects at the colony level.

The relatively new nature of certain bee diseases (for example, *Nosema ceranae*) [29] [30] and their gradual movement around the globe complicates their management. The lag time experienced between disease contraction, correct identification and appropriate disease management can contribute to greater than necessary bee or colony losses.

Pesticides

Pesticides are toxic by their very nature; the goal of these products is to reduce or eliminate the damage done to crops by harmful insects. Due to their nature and any possible interaction with pollinators, farmers must exercise good practices and adhere strictly to the directions on the label when applying these products.

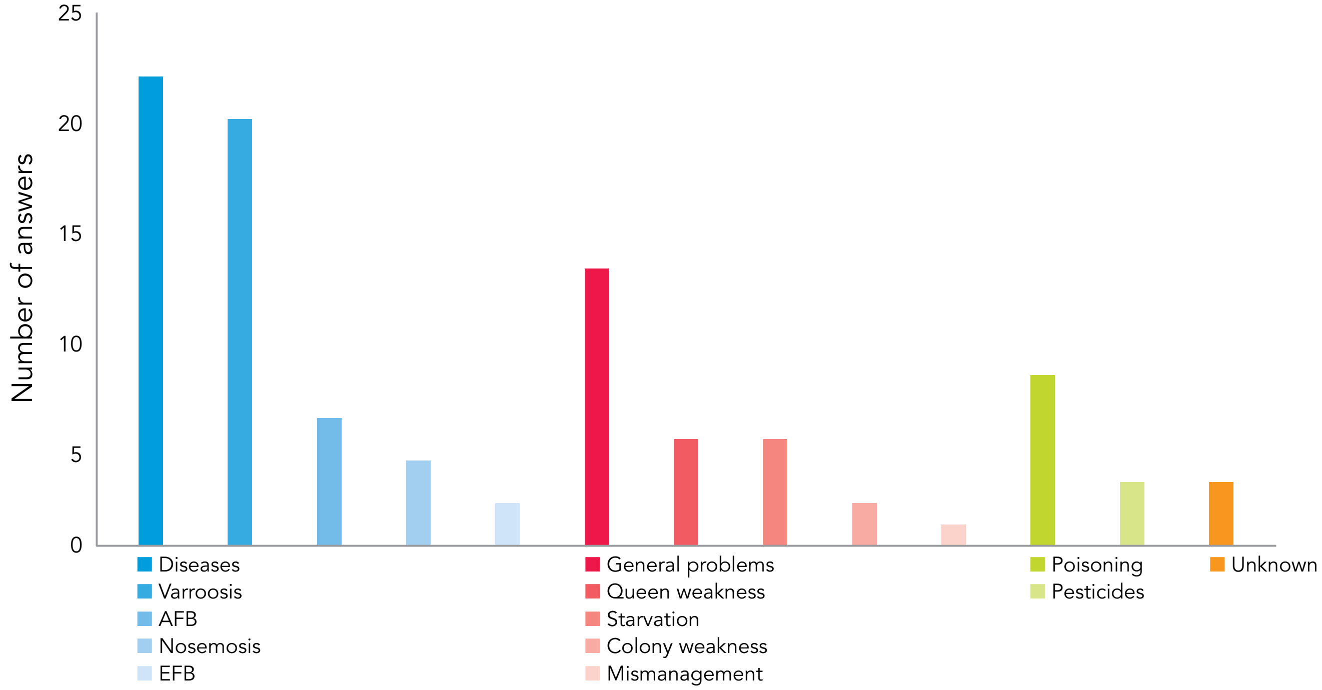
The potential side effects of exposure to low or accepted dosages and their impact on bee colonies are subject to detailed research [31].

Localised bee losses have sometimes occurred due to the misapplication of plant protection products. However, such incorrect use does not represent the safety of these products – in this case it is simply due to human error.

Farmers and the agrochemical industry work together to promote good practice that helps reduce the occurrence of such incidents.

Due to their importance in the current debate, pesticides are covered in more detail in the following section.

Figure 9:
Main causes of colony mortality reported by the beekeepers (source : EURL) [72]



Invasive alien species

The history of beekeeping in Europe has shown that invasive alien species pose significant threats for native species, and their introduction can result in disaster. *Varroa* and *Nosema ceranae* are parasites and pathogens in Europe considered alien invasive species. Introduced in recent decades, these pests are a serious threat to honey bee health.

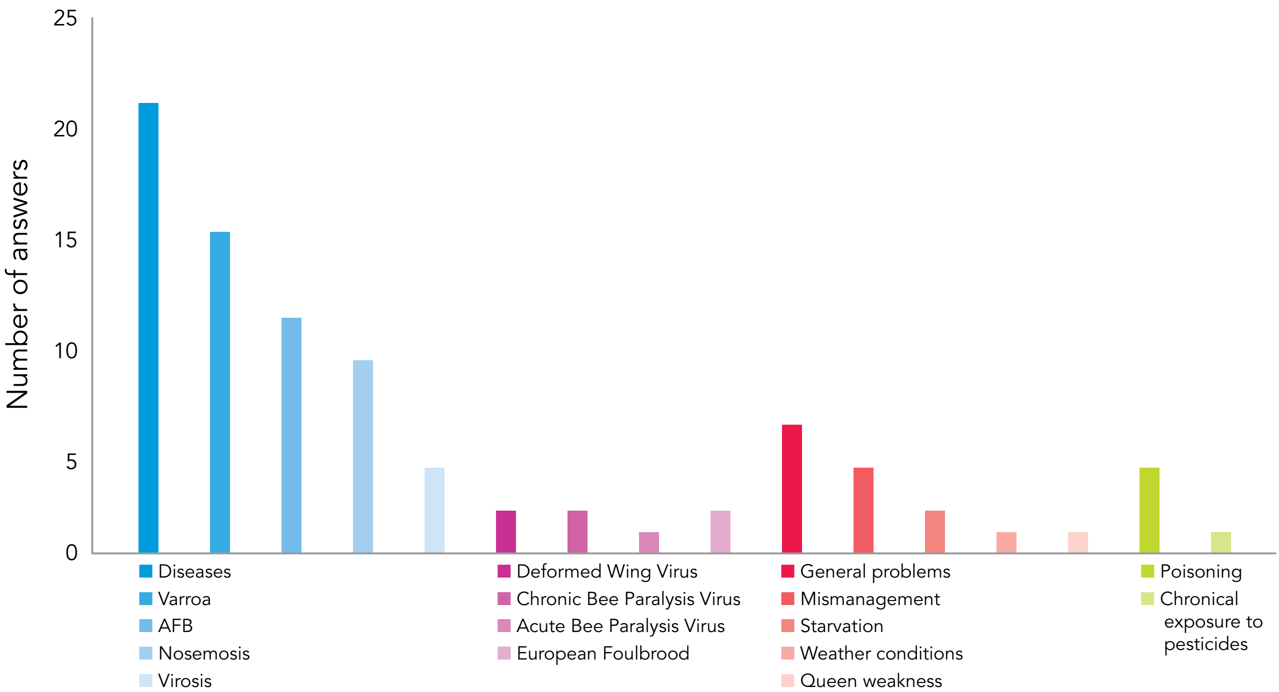
The European Union defines 'Invasive Alien Species' as those that are, firstly, outside their natural distribution area, and secondly, threaten biological diversity [32].

Availability of forage

During springtime, agricultural landscapes with crops and wild plants can provide a surplus of nectar and pollen. However, the yearly cycle also sees a reduction in the availability of forage to levels which can be insufficient to maintain robust colonies later on. To survive the periods of low forage in fall and winter, the honey bee stockpiles honey during the spring and summer – a behaviour unique amongst pollinators.

A reduction in numbers and diversity of local flowering plants can be the result of land-use changes, including those brought by intensive agriculture, such as shorter mowing intervals. The general result of these practices is the reduced availability of pollen and nectar.

Figure 10:
Main causes of colony mortality reported by the laboratories (source: EURL) [72]



Climate change

Changing climatic conditions can have influence over the health of honey bees, but are probably minimal as bees are quite resilient to seasonal changes in weather; they inhabit the extremes of Europe's climate, from Finland to Portugal. Bees may be affected indirectly through climate driven changes to plant communities, competitor species, parasites and pathogens. Extreme weather events, including those resulting from climate change may also contribute to localised colony losses.

Beekeeping practices

Beekeeping practices are very diverse and differ between individuals and regions. Appropriate animal husbandry is a key factor in successful colony development and should consider many factors including the control of *Varroa* and diseases, hibernation, food quality, hive transportation technique, and cleanliness and quality of suitability of equipment.

Figure 11:
The number of reported studies of each beekeeping factor responsible for bee mortality [23]

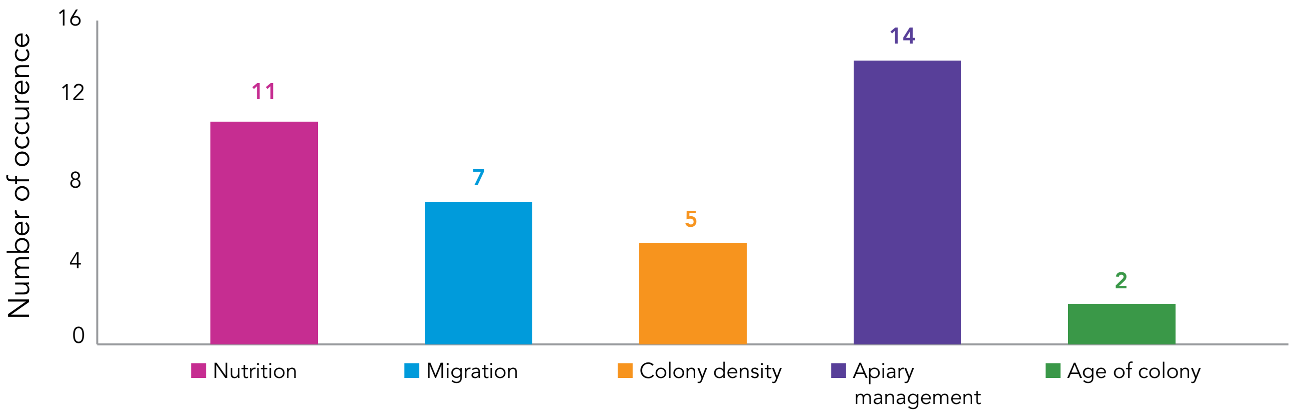



Photo: © USDA Agricultural Research Service

A *Varroa destructor* mite on a honey bee host.


Photo: © Waugsberg

Varroa destructor mites on honey bee pupae.

Pesticides and Pollinators

Plant protection products (pesticides) contain biologically active compounds developed for the purpose of protecting plants. Insecticides control pest insect populations; herbicides control weeds, while fungicides are used to control fungal plant diseases. Pesticides are essential for providing safe, affordable and nutritious food at the quality and quantity required by today's large and rapidly growing population.

In order for pesticides to fulfil the role of crop protection, they must be biologically active against the targeted pests. Because non-target organisms (i.e. organisms which are not pests) can also be exposed, a comprehensive body of legislation has been established to evaluate the safety of plant protection products to non-target organisms. European regulations ensure that when applied properly, pesticides do not have unacceptable effects on non-target organisms, such as honey bees, earthworms, fish, algae or wild birds.

Studies and risk assessments on organisms follow scientific principles found in ecotoxicology and must be completed before product registration. According to Regulation (EC) No.1107/2009, a plant protection product shall be approved only when it *"…has no unacceptable acute or chronic effects on colony survival and development, taking into account effects on honey bee larvae and honey bee behaviour"* [33] [42].

Accordingly, complex data sets are generated in the context of registration. Testing is undertaken using a step-wise approach incorporating many different levels of testing, for example, laboratory, semi-field (cage tests) and field studies. If needed risk management can be developed for registration, or the substance may not be registered for certain uses or crops.

Most studies are based on guidelines of internationally accepted organisations like EPPO (European and Mediterranean Plant Protection Organisation) or OECD (Office for Economic Cooperation and Development). Based on the information collected during these studies, risk assessments are conducted by applicants and reviewed by independent authorities.

Fundamental changes to test requirements, and accordingly of the risk assessment procedures have been recently published in new European Food Safety Authority (EFSA) guidance on risk assessment for bees.[34].

Additional parameters include:

- Survival and development of colonies
- Health of larvae
- Bee behaviour
- Abundance of bees
- Ability to reproduce

During product safety testing, data exceeding the standard data set may be required to address complex and often product-specific questions.

This process allows scientists to assess the potential likelihood and magnitude of effects and if necessary propose risk mitigation measures to avoid unacceptable effects on the honey bee.

Honey bees might come into contact with pesticides through several potential routes of exposure. Exposure can occur if there are flowering plants in fields or in the vicinity of treated fields. Flowers provide nectar and pollen, which are the main food sources for bees, although they are also known to collect honeydew from aphids. Honey bees are also known to collect water. Water can be collected from ponds and streams and is also provided by the bee keeper as part of good practice. Under special circumstances some plants may also produce guttation fluid which may sometimes be collected by bees – although not a primary source of water for bees, this might constitute exposure at the individual level.

The complex interaction of plants, other insects, and farming and beekeeping practices gives rise to several possible exposure routes.

Guttation droplets
on corn seedings

In addition to exposure to agricultural chemicals, honey bees may also be exposed to pesticides applied by bee keepers for the management of *Varroa* mite and/or other parasites and diseases in honey bee colonies.

Risks which are related to definite exposure scenarios are quantified in the risk assessment process and where the risk exceeds a critical level, the implementation of risk mitigation measures is required. The application of risk mitigation measures are specified on the label of each product and are obligatory for pesticide users.

Standard risk mitigation measures for intrinsically bee-toxic products applied as spray include:

- Restricting pesticide applications to the evening, to avoid the flight period of the honey bee
- Selecting spraying periods to avoid spraying crops whilst flowers are in bloom
- Limiting the application rate of plant protection products
- Use of drift reducing technologies to avoid deposition of spray drift onto nearby flowering areas (e.g. adjacent to crops in bloom)
- Removing flowering weeds from cropped areas prior to application

Risk mitigation measures are easy to implement when the conditions of risk occurrence are clearly defined and directly relate to a specific practice. When exposure depends on infrequent events that do not occur as a function of a specific action, taking measures is less easy.

Residue concentrations in guttation droplets are time dependent; the first droplets after germination of treated seeds being the most concentrated, followed by a rapid drop in concentration as residues are excreted. The definition of risk mitigation measures to prevent the exposure of bees to guttation droplets must therefore be proportional to the risk they are designed to manage.

Exposure related to applications via spray and the presence of flowers:

- Spray residues on flowering crops following foliar pesticide applications
- Spray residues on flowers in areas adjacent to treated fields, following wind driven pesticide drift
- Residues in pollen and/or nectar from crops treated with systemic compounds before flowering, which may move to flowers

Exposure that depends on the properties of the product in flowering crops and plants:

- Residues in pollen and/or nectar from crops prepared with systemic compounds as seed treatments
- Dust drift on flowers in areas adjacent to treated fields, following seed drilling of poorly treated seed or use of inappropriate drilling equipment

Exposure that depends on the presence of other insects – such as aphids – on the crop:

- Residues via honeydew, a sugar rich exudate of aphids which may be attractive to honey bees.

Exposure that depends on the physiology of the crop/plants and on the weather conditions:

- Residues in guttation fluids

Systemic plant protection products

Systemic plant protection technology – seed and soil treatment – aim at protecting the early stages of cropped plants. There is in general a lower impact for the environment, as the pesticide is more precisely applied and requires lower volumes than above-ground spray applications. As explained above, seed treatments may also lead to exposure that requires particular risk mitigation.

A few bee incidences occurred in the past, most of them caused by the use of a faulty batches of treated seeds, which during sowing released dust containing insecticide into the environment. This resulted in an important incident of bee kills. The incident triggered further research and the implementation of risk mitigation measures to minimise emissions of dust particles at sowing.

The current debate around systemic plant protection products is complimented with an array of publications on the subject; some confirming that there are no detectable effects on honey bee colonies in the field [20] [36] [37] [38], others reporting critical findings made primarily with test scenarios using exposure and dose levels that are rarely, if ever, found in the field [31] [39] [40] [43].

Insecticidal seed treatments, for example those containing neonicotinoids, follow very strict control measures such as quality assurance schemes or specific risk mitigation measures[41] [42] as follows:

A tunnel (semi field) test

Seed treatment

Seed treatment should only be performed in professional seed treatment facilities by trained staff. To ensure minimal risk, treatment facilities must adhere to the following conditions:

- Facilities must apply state of the art techniques in order to ensure that the release of dust during coating, storage, and transport can be minimised.
- Facilities should register to a 'quality assurance' program that is independently audited, to assure compliance with legal requirements and industry guidelines. Only these facilities should be considered 'professional facilities'.
- The quality assurance program should include professional training and procedures to continuously assure best practice.
- An EU guidance document on Seed Treatment is under development.

Due to a recent decision by the European Commission, after no qualified majority could be found among member states, neonicotinoids will be severely limited in their use for two years, starting at the end of 2013.

Use of treated seeds

Adequate seed drilling equipment has to be used during sowing of treated seeds to ensure incorporation into soil, to minimise spillage and dust emission; the latter requiring appropriate devices fitted to drilling machines to minimise dust emissions to the air (e.g. deflectors).

Further risk mitigation measures may be enforced as appropriate, such as requiring use only by professional applicators, farm application record keeping, applicator training, not loading seed drilling equipment in close proximity to bee hives, better exchange of information between farmers and beekeepers, clear labeling of treated seeds, as well as further improvements in seed coating. For example, the farm manager may exchange information related to the area designated for the sowing of the treated seeds with local beekeepers prior to sowing; the beekeepers can then choose whether or not to site hives in that area.

Evidence concerning the safety of pesticides that comes from monitoring approaches is particularly important since potential effects of the products are surveyed under realistic field conditions and normal agronomic practice. Further enforcing the Commission Directive 2010/21/EU, more monitoring activities which *"verify the real exposure of honey bees (…) in areas extensively used by bees for foraging or by beekeepers"* and addressing realistic use conditions would be implemented.[43] [44] [45] [46] [47] [48] [49]

Risk mitigation measures are described on product labels to instruct the farmer in the appropriate use of a product; adhering to product label specifications is obligatory. Incident surveys reveal that the failure to follow the instructions is the main cause of harm to honey bees due to pesticides. These records indicate that bee kills take place in most cases in an identifiable and localised geography, and over a strictly limited period of time. They also confirm phenomena that do not resemble what is termed 'Colony Collapse Disorder' (CCD), as recorded in North America, which corresponds to significant bee losses and differs to acute mortality events. CCD is recorded as taking place over wide areas of North America, and is not linked to spray events. Incident surveys also reveal a decrease in the number of bee incidents resulting from the misuse of pesticides, as awareness of both farmers and beekeepers about protective practices and uses spreads.

It should be noted that the plant protection product registration and risk management process is not fixed; these processes are kept dynamic because science, farming practices and plant protection products and methods evolve. This work continually improves the effectiveness, safety and sustainability of pesticide use in agriculture.

Table 3: Specific measures to mitigate risk to honey bees under complex exposure scenarios

Route of exposure	Potential risk mitigation measure
Flowers beside the treated field which are exposed to liquid spray drift.	Application of drift-reducing nozzles in the spray equipment.
Flowers beside the treated field which are exposed to solid dust particles coming from treated seeds.	Use of sticking agents to improve adhesion of pesticides to the treated seed to minimise dust formation in the bag and during drilling. Reduction of dust particles by mechanisms in the application machinery that minimise dust emission.
Honeydew	Application of bee-toxic products before aphids populate the crop in high densities.

Other factors that influence pollinator health

Whilst the *Varroa* mite is the main problem for honey bees, exposure to a variety of stressors, like parasites, pathogens, pesticides and environmental conditions justifies the hypothesis that honey bee health problems are multifactorial. A bee monitoring study conducted in Germany over several years identified several factors, namely, *Varroa* infestation, occurrence of 'deformed wing virus', 'acute bee paralysis virus', the health status of the colony in autumn and, the age of the queen [71].

Beyond these colony and bee-specific factors, the health of pollinators is closely linked with the composition of the landscape and the availability of suitable habitats. Approximately 25% of the European landscape is used for permanent crops and arable land [50] (Figure 12); it is therefore no surprise that agriculture is an influential factor for pollinator species. The huge variety and combination of European landscape types and habitats make it difficult to assess one-dimensional causal relationships between pollinator species and their external environment.

A network of influencing factors

The survival of pollinator populations depends upon many factors, including the availability of suitable food in sufficient quantities. The availability of the right amount of the right foodstuff at the right time is dependent, for instance, on a good combination of local agriculture (types of crop and coverage and the availability of meadow) and non-farmed land (field margins, buffer strips and natural areas). When we focus only on short-term ecological causes, we can miss the more complicated reality of many causes working in combination with each other [71].

To illustrate a complex series of relationships, a stage-to-stage concept has been chosen to illustrate the factors that can influence pollinators. However, this illustration (Figure 13) is far from comprehensive – it does not illustrate the interactive complexity characterising the dynamics of European agricultural landscapes nor the conditions which drive their change.

Competition and cooperation between Pollinators

Competition is exhibited between pollinator species under certain conditions; for example, when a limited resource is needed by several organisms. Experts continue to debate the occurrence of competition between honey bees and other pollinator species such as solitary bees or butterflies [51].

Some pollinators actively parasitize other pollinator species; so-called cuckoo bees do not make their own nests, but instead, invade the nest of solitary bee species and lay their eggs there. Cuckoo bee larvae kill the eggs or young larva of the host bee, and feed on the pollen stores of the host bee. However, under field conditions the parasitic behaviour of the cuckoo bee seems to have minor impact on population levels of other bee species[52].

There are also examples where the actions of one pollinator species are (albeit inadvertently) advantageous to another; 'nectar robbery' is one such example. During nectar robbery a pollinator removes concealed nectar by drilling a hole into the side of a flower. These holes are often made by relatively robust pollinators and provide access to the nectar for species either too fragile or lacking the necessary body parts to perform the same operation[53].

Agriculture and land use

In Europe, policies, regulations and market conditions play a significant role in determining agricultural activities. However, farmers have the freedom to manage their land in ways that can have a range of implications for biodiversity. These implications are often the result of shifting market conditions, consumer demands, and the prices of different farm inputs such as fuel and fertilizer.

Certain land management practices do not favour pollinating insects. For example, in many areas of Europe flower-rich meadows have been replaced by crops or grassland over time due to an increase in population and changes in diet. Some of these crops and grasslands provide little or no resources for pollinators during the summer months. Large cereal fields and meadows that receive frequent fertilisation or mowing inhibit flower development and promote a landscape of mostly wind-pollinated grasses – a poor resource for pollinators.

The loss of structures, flowers and forage is not limited to farmland alone. Often, our preference for tidiness results in immaculate green lawns around homes and offices; these tidy spaces may be aesthetically pleasing, but they are also species-poor. The complete removal of shrubbery, 'weeds' and coppice to beautify an area destroys food sources, foraging material, breeding and nesting areas and shelter from precipitation.

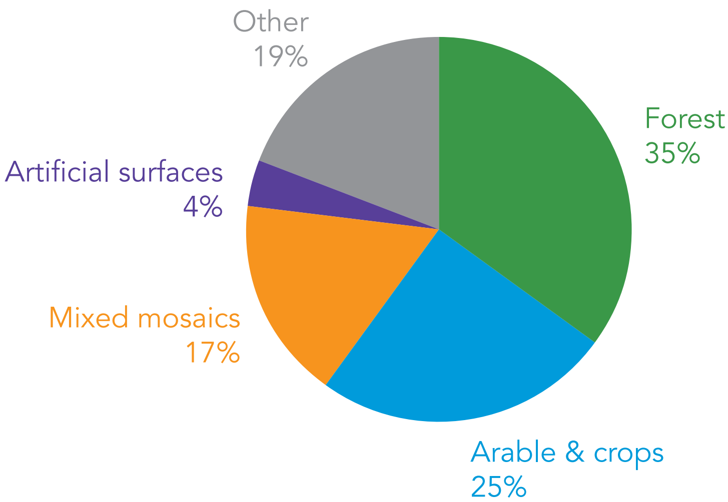
On the other side, there are many positive steps farmers have taken, or that are easily applicable to improve pollinator health. By using the concept of multifunctional landscapes – where field margins and other marginal spaces are specifically seeded and managed for pollinators and other species, farmers can create plant-rich biotopes where pollinators thrive. There are many initiatives, by most all stakeholders, to improve bee health and colony survival.

Other landscape features that support pollinators include orchards, managed grasslands, hedges, flowering crops and fallow land and green cover.

The structural elements of cultural landscapes and typical features of agricultural land use offer a variety of opportunities for shelter and breeding. Many pollinators also depend of the availability of 'natural' landscape elements such as sandy areas, bare grounds, and stones, rocks, and stone walls.

Not only cropping regimes can have significant impact on pollinators. Rotating land use from one agricultural crop to another over time is also an element of good agricultural practice; crop rotation provides a seasonal diversity of pollen sources,

Figure 12:
The distribution of selected land uses in Europe (an assessment of 38 countries)



(European Environment Agency (EEA), 2010)

and can reduce requirements for fertiliser. Crops can be planted to allow soil recovery and support soil organism development, such as legumes like clover (*Trifolium*), or scorpionweed (*Phacelia*). Improved soil functions can result in a greater diversity and occurrence of flowering plants, this is of course of value to pollinator species.

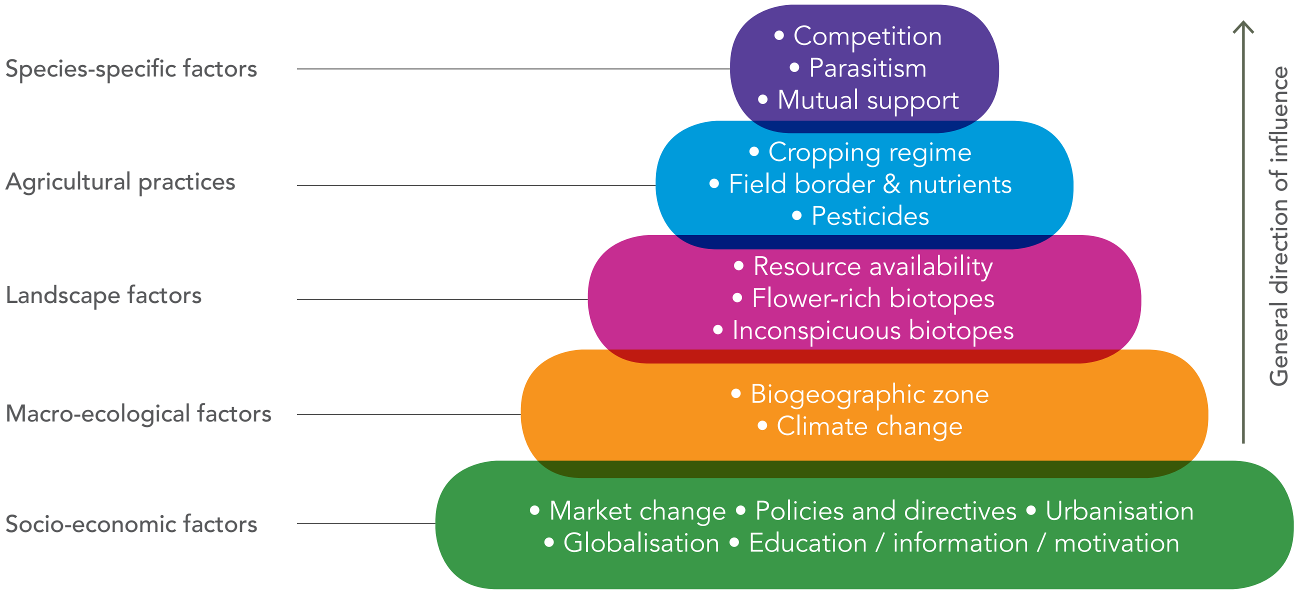
Pollinators require shelter, food and breeding areas; they are mobile creatures so these resources may be located all within a single field, or spread over a local area. However, the f light range of non-migratory pollinators is limited, so local resource diversity is not just advantageous, but an important element for pollinator health.

The land that surrounds and divides cultivated areas has tremendous capacity for pollinator promotion. Pollinators can benefit from increased habitat and food provision where buffer zones (uncultivated vegetation next to water bodies) are established. Multifunctional landscape elements such as buffer zones and managed field margins also serve to improve the connectivity of green infrastructure, which is of value to biodiversity in general.


Cherry blossom

The range of non-migratory pollinators is limited, so local resource diversity is not just advantageous, but an important element for pollinator health.

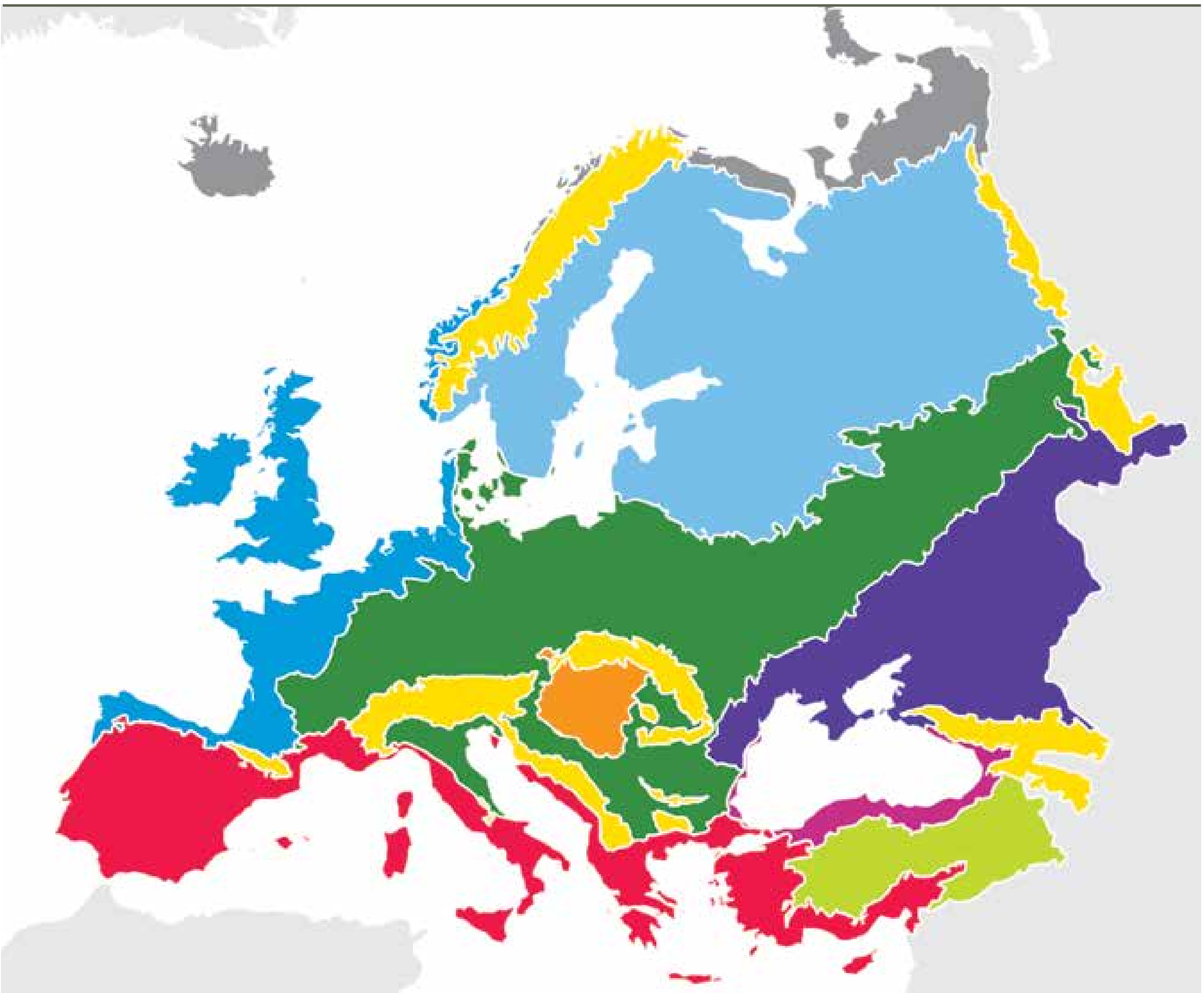
Figure 13: Hierarchy of factors which influence the diversity of pollinators in Europe



Macro-ecological factors

European pollinator habitats are shaped by regional conditions. These regions are independent of national political boundaries. Species dependence on the availability of a suitable habitat results in a specific distribution of pollinator species throughout Europe's biogeographic regions. Honey bees can be found across the majority of Europe's regions, whilst some butterfly species rely upon circumstances so specialised that they exist in a solitary location. Species that live on the margins of their optimal habitat are often labelled as 'rare', and become the subject of European protection measures.

Map 1:
Biogeographic regions of Europe (2001) [54]



Alpine	Atlantic	Continental	Pannonian
Anatolian	Black sea	Macaronesia*	Steppic
Arctic	Boreal	Mediterranean	

* Excluded from this map for presentation purposes, the macaronesia zone incorporates the 5 North Atlantic Ocean archipeligos of the Azores, Canary Islands, Cape Verde, Madeira, and the Savage Islands.

EU Policy and Conservation

Regional changes to agricultural ecosystems are mostly influenced by socio-economic conditions [63]. These changes occur frequently, in response to agricultural market conditions, and sometimes on extremely short notice; consequently decisions are not always thoroughly analysed with respect to their ecological implications. Political decisions also have a profound influence on agricultural ecosystems; policies and regulations affect pollinator habitats. In Europe the rise and fall of 'set aside' regulations has directly influenced the availability of pollinator habitats. Pollinators generally benefit from initiatives which increase the biodiversity of agricultural landscapes.

The European Commission has renewed ambitions for biodiversity with a headline target to halt biodiversity losses and the degradation of ecosystem services by 2020. The 2020 strategy aims to achieve a significant and measurable improvement in the status of all species and habitats covered by EU nature legislation [55]. The European Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) aims to protect approximately 1,000 species and some 220 habitats [56]. Annex IV of the Directive contains a list of 38 butterfly species, many of which inhabit areas located on or adjacent to farmland or depend on traditional farming practices; these species receive a legal protection status [56]. Furthermore, the EU's Natura 2000 network has designated areas for species protection that includes areas for rare pollinators such as certain butterfly species.

The 2020 biodiversity strategy also refers to the creation of green infrastructure (GI) to reinforce the Natura 2000 network and to prevent further habitat loss and fragmentation. These green infrastructures would act as wildlife corridors between existing nature areas; wild plants and animals need to be able to move, migrate, disperse and exchange populations between protected areas [57]. In practice, GI will be applied with an integrated approach to land management, land use and land use planning for operators which aims to improve the connectivity of nature sites. This could have a positive impact on pollinators as the number of wildlife strips along field margins and hedgerows would likely increase.

Supporting measures have been introduced by the European Commission, including the 2010 Communication on honey bee health, which pledges the establishment of a pilot surveillance programme and an EU Reference Laboratory (EURL) for bee health.

The European Parliament has also taken an active interest in pollinators, issuing a resolution on the situation of the beekeeping sector at the end of 2010 and calling on the Commission to conduct further research into bee mortality, to promote pollinator-friendly farming practices and, to include bee diseases in EU veterinary policy. The Common Agricultural Policy (CAP) has been an important influence on agricultural landscapes. Several agri-environmental measures have a positive effect on pollinators, in particular payments for buffer strips and traditional landscape features such as hedges. The new greening measures in the CAP could provide a positive impulse for the provision of such measures.

Drawing more attention to the importance of the less attractive or inconspicuous yet highly functional insects and habitats, such as overgrown hedges and fields that are often underappreciated now, should be considered a key challenge for the future of appropriate nature and biodiversity conservation. Consideration of habitats and species from the perspective of payment for ecosystem services provision – also addressed by the TEEB report – is perhaps a step in this direction.

Parnassius apollo
The apollo butterfly

Is there a pollination crisis?

Are honey bees nearing extinction? Are pollinators being reduced to numbers that pose a risk to survival of the human species? To answer these questions, we need to understand the relationship between pollinator and pollination, and the pollination requirements of crops and wild plants. We also need to define in broad terms the characteristics of what constitutes a 'pollinator crisis'. Under ideal pollination conditions, there should be as many pollinators as needed to fulfil the many and varied pollination services demanded by both farmers' crops and the natural world.

The reality is of course neither simple nor balanced. Both sides of such a supply/demand equation depend on economic, social and environmental factors, and are therefore in constant flux.
In addition, the extent (supply) of pollination service is directly influenced by local conditions – usually environmental – that are in turn vulnerable to economic, social, and climatic stimuli. To determine the existence or extent of any pollination crisis there are many questions to answer, such as:

- How many pollinating insects are required to maintain a crop, wild plant society, habitat, or landscape?
- Which pollinator species are required; honey bees and / or other hymenopterans, and/or other insects?
- To what extent can one pollinator species fulfil the pollination role of another?
- Are negative trends in pollinator populations exhibited in all pollinator species?
- Are population trends the same for both wild (e.g. butterflies) and farmed (e.g. honey bee) pollinators?

This mere snapshot of considerations indicates the complex interplay of potential variables influencing the health and wellbeing of pollinator populations.

The tip of a Tulip Stamen covered in grains of pollen

Photo: © J.J. Harrison

Studies into the health of pollinator species reveal an overall lack of consensus on both the existence of a pollinator crisis, and the extent to which a whole range of potential factors influence pollinator health.

Those that support the pollinator crisis hypothesis warn of future large-scale losses of agricultural productivity due to the decline of pollination services. In most cases these conclusions are drawn from extrapolating pollinator declines observed at local level which exhibit only temporary impact [58] [59].

There are also many experts who do not support the pollinator crisis hypothesis, but all recognise the importance of pollination services and biodiversity, support continued research and monitoring so that any problems can be verified and appropriate mitigation can be designed.
We should also take care not to let ourselves be guided into actions that may have far-reaching and misplaced impact before we have the facts necessary to make considered decisions [60] [62].

Regardless of the existence of an imminent pollinator crisis, there is strong evidence of an overall European decline in pollinator populations and individual pollinator insects – the Millennium Ecosystem Assessment describing *'medium certainty'* of a global decline in pollinator diversity [62] [63]; this follows the trend of an overall net loss of global biodiversity. Nearly one third of Europe's 435 butterfly species are reported to be in decline [62].

These figures remind us that, regardless of the terminology and heated debate around a pollinator crisis, humanity must increase its responsible stewardship of the many species on this earth.
It is up to all stakeholders, including industry and farmers, to improve the conditions of farmland species with targeted and effective measures such as the use of multifunctional landscapes.

Ways forward

Pollinators face a diversity of challenges and opportunities in European agricultural landscapes; dependent on local conditions and a range of external influencing factors, species or taxonomic groups can thrive in one area, and struggle to survive in another. We are generally aware of the requirements of pollinator species for a stable and healthy population; it is possible to manage agricultural landscapes to optimise conditions for the health and wellbeing of pollinator species. In practice, 100% ideal management is something to strive for, but may not be realistically attained in the face of commercial and other factors. The needs and demands of agriculture are shaped by social and economic variables, and these can often be contradictory to ideal management practices. However, it is not beyond our capacity to implement and improve best practices and new technology that can ensure safe fields for pollinators and farmers alike.

The honey bee

The parasitic *Varroa* mite remains the main cause of colony health problems, and it is generally accepted that more should be done to control the impact of the mite on European bee hives. There are already several tools at the disposal of beekeepers, such as synthetic and natural pesticide treatments, including new application technologies. The physical removal of heavily infested cells is a common intervention. Continued research and development of chemical treatments is a realistic option for future improvements in *Varroa* management; the basis of all of these measures is a precise monitoring of the *Varroa* infestation rate by the beekeepers. However, the ideal solution would be the identification and successful breeding of a *Varroa* resistant honey bee.

The mutual benefits brought by bees to beekeepers and farmers are an incentive for cooperation. Professional beekeepers often move their hives during the seasons to improve honey bee access to forage. Cooperation with farmers can make this process more efficient if beekeepers are alerted to crop flowering regimes and, for instance, the further development of pollinator strips and multifunctional landscapes [64] [65] [66].

The domestication of the honey bee tasks our own species with the responsibility for the success of colony development. Good beekeeping practices are essential. The value of the honey bee and a long history of beekeeping are the motivation and experience required to ensure effective management of this species for the future.

Other pollinators

All adult pollinators depend on flowers, but most of them require additional habitats during the larval stage; quite often relying on a very select group of plant species as forage or on specific habitat elements. Habitat conservation programmes could be more considerate of the needs of pollinator species, and promote flower strips, perennial and annual plants and an agricultural landscape that accommodates a suitable green infrastructure. Conservation measures should not only be driven by the attention afforded to more popular species, in particular those belonging to the bird and attractive animal classes [67]. Given the importance of pollination for agriculture, diversifying the suite of crop pollinating species should be an appropriate management response.

Agricultural practices

The farmer has several options at his disposal to improve the situation for pollinators, most of which could support crop yields.

Soil protection conserves the arable farmer's most valuable resource. Protecting soil with intermediate or cover crops (crops that do not interfere with the preferred cropping regime) can improve the quality of the soil and also produce flowers for the benefit of pollinators.

Farmers must take care to apply pesticides only when necessary and in accordance with instructions. Dosage, application timing (including time of day and weather conditions) and application technology are all taken into account. Some insecticides are the subject of special use instructions because of known effects on honey bees when used incorrectly.

More land for flowers

The larger part of agricultural land consists of cultivated areas like fields or orchards. However, the remaining spaces are often underestimated, and could be managed to promote plant and biotope diversity. There are waysides, railroad and highway embankments, set-aside areas of different kinds near roads and bicycle paths, and field strips within agricultural land. These are all potential space for flowers and habitats of value to those pollinators which are well adapted to the resources provided in an agricultural environment. Natural or semi-natural habitat remnants provide nesting sites and reliable food sources for pollinators. Conserving these areas can benefit biodiversity, and can offer potential for improved crop productivity.

Technical innovations

Technological innovations play an important role in pollinator protection. Modern pesticide application technologies are an example from the world of agriculture. Application technologies allow for reductions in spray drift; this helps prevent pesticide residues in non-target areas. This is achieved through the use of application nozzles that create spray droplets large enough to be less affected by wind.

Cereal seeds treated with plant protection products; stained with colour for identification

Photo: © BASF SE

Lupine (genus *Lupinus*), an efficient nitrogen fixing perennial

Conclusion

Comprising much of the European landscape, and shaped by a multitude of social and economic variables, agriculture has a constantly fluctuating impact on pollinator populations. Farming is an essential activity for the survival of our own species, but it is not beyond the capacity of agriculture to continue to implement and improve measures for sustainability that seek to protect and enhance pollinator populations and biodiversity at large.

Of all pollinator species, the honey bee receives the most wide-spread attention. The honey bee has been a domesticated species for thousands of years and needs to be managed through good beekeeping. While the *Varroa* mite currently has the most pronounced impact on beekeeping and bee health, it could be said that humans are simultaneously the biggest hope for honey bee survival, and the biggest threat to their population. Our special demands and relationship with the honey bee tasks us with a clear responsibility for their care, one that is easily separated from wider concerns for the conservation and enhancement of biodiversity.

Interconnections with agronomy, nature conservancy, science and beekeeping make pollination a fascinating and very timely subject for discussion. In the context of agriculture, this report has identified several key points that may be considered in any initiative to reverse the trend for pollinator population decline:

- Specific landscape uses, cropping regimes and other agricultural practices can offer both threats and opportunities for pollinators.

- The application of plant protection products according to label instructions.

- Honey bees are a domesticated and highly managed species; as a result they are subject to threats unique among pollinators.

- The decline of pollinator populations, and particularly that of the honey bee, have been the subject of much research and speculation. Whilst extensive data on honey bee populations and health exists, there is no expert consensus on the cause of reductions in honey bee populations; however, the *Varroa* mite is most frequently blamed, and lack of suitable forage (loss of habitat) receives significant mention.

- There is clearly a need for more research to achieve clarity on the European pollinator situation. Evaluation and assessment criteria need to be established and applied to achieve reasonable understanding of the status quo of European pollinators.

- European agricultural landscapes have the potential to offer a much greater resource to pollinator species, particularly through the application of field margins, flowering strips and the incorporation of the idea of multifunctional landscapes into European fields.

Whilst there is still much to learn about pollinators and how we may best conserve them, it is clear that European agricultural practices have a central role to play. The collaboration of multiple stakeholder groups is essential if we are to meet demands for agricultural productivity and enhance pollinator populations.

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European
Crop Protection

The European Crop Protection Association (ECPA) represents the crop protection industry at the European level. Its members include all major crop protection companies and national associations across Europe.

ECPA promotes modern agricultural technology in the context of sustainable development; to protect the health of humans and the environment, and to contribute towards an affordable healthy diet, competitive agriculture and a high quality of life.

ECPA members support fair, science-based regulation as a guarantee to the consumer, and the crop protection user, of high standards and safe products.

ELO
European Landowners' Organization

The ELO is a European organization representing more than 54 national associations of private landowners across the EU 27. It is a non-profit organization committed to promoting a sustainable and prosperous countryside and to increase awareness relating to environmental and agricultural issues.

By engaging various stakeholders, ELO develops policy recommendations and programmes of action targeted to European policy makers.

ELO also organizes interdisciplinary meetings, gathering together key actors from the rural sector and policy makers at local, regional, national and European level.

EISA
European Initiative for Sustainable Development in Agriculture

EISA, the European Initiative for Sustainable Development in Agriculture is an alliance of national organisations from France, Germany, Luxembourg, Sweden and the United Kingdom. Founded in 2001, EISA has the aim of promoting and developing sustainable farming systems that are economically viable and environmentally and socially responsible.

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