LIFE 4 POLLINATORS

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

HANDBOOK FOR MANAGERS OF NATURAL PARKS AND PROTECTED AREAS

CREDITS

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INDEX

INTRODUCING POLLINATION AND POLLINATORS

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

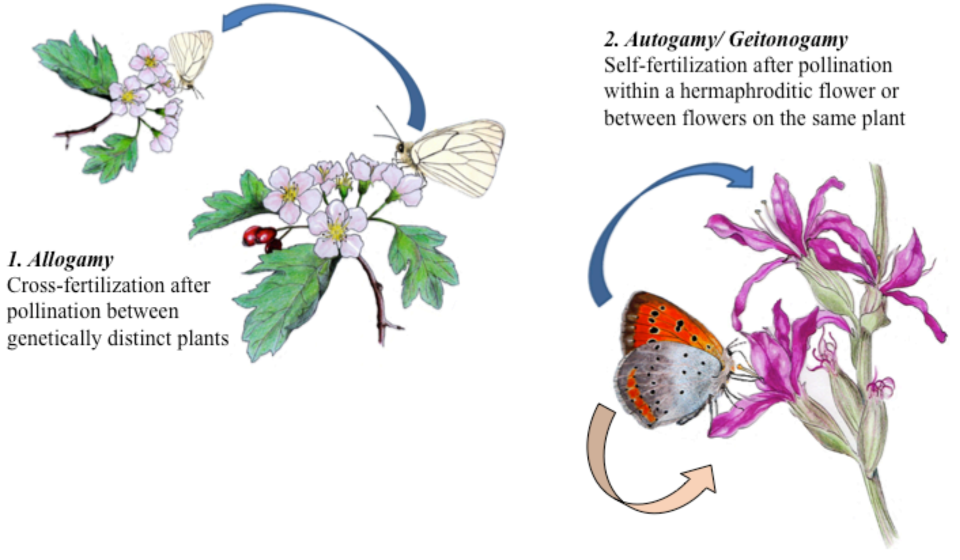


Illustration by Marta Barberis

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.

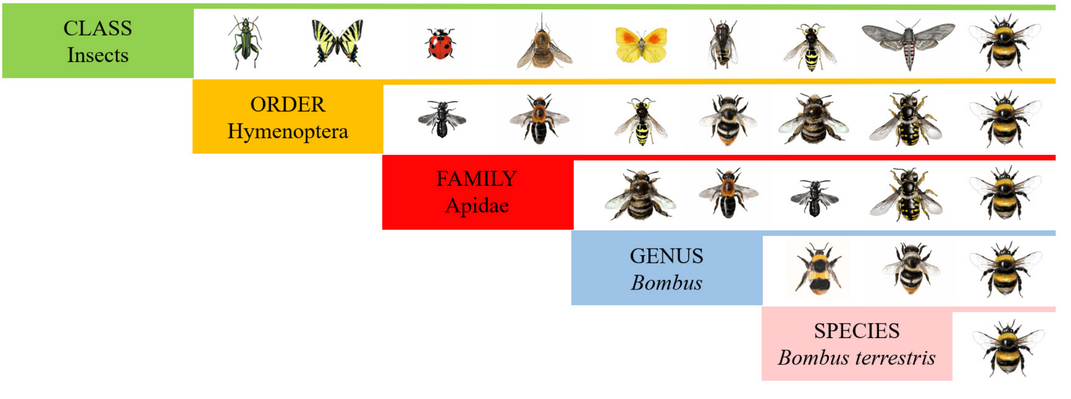
Apart from being indispensable for life, pollination is also an enormously important ecosystem service for humans, as agriculture and food production depend directly on this natural process. Up to 75% of major world crops (111) rely on pollination by insects. Gallai and colleagues (2009) estimated the 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 still 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 bees 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 bees do. 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 areas.**
- **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.

MANAGEMENT OF NATURAL PARKS AND PROTECTED AREAS

GOALS OF THE HANDBOOK

The aim of these guidelines is to provide suggestions to help wild pollinators and reduce the threats to these insects and their habitat. The handbook is specifically for managers of natural parks and protected areas. The term "protected area" is used generically as different countries and even regions protect nature in different ways.

THE IMPORTANCE OF NATURAL PARKS AND PROTECTED AREAS FOR POLLINATION

The main aim of protected areas is to conserve nature and especially biodiversity. This is true in most cases, though there are differences between regions, countries and classification systems: for example, national parks impose strict protection, whereas other areas may have looser restrictions (BOX 1).
The conservation of biodiversity is not the only function of protected areas. These areas also play a role in maintaining a balance between the conservation of nature and providing benefits to local communities, for example, balancing activities aimed at economic development, such as traditional agriculture, livestock breeding, tourist-recreational use and environmental education.
From a strictly conservationist perspective, the management of protected areas traditionally focuses on safeguarding target species. Conservation priorities are identified on the basis of: i) endangered status (endangered species), ii) ecological importance ("umbrella species" whose conservation also ensures the conservation of many other organisms and "keystone species" essential for the ecosystem regardless of their abundance); iii) symbolic relevance ("flagship species", i.e. popular species that attract public attention for conservation) (Hunter & Gibbs 2007). However, the loss of ecological interactions, as pollination, may occur well before species disappearance, affecting species functionality and ecosystems services (Valiente-Banuet et al. 2019). Thus, it seems time to move forward and to make a further effort to include biological interactions as a motivation for conservation: specifically, the "conservation of mutualisms" and even "restoration of food chains" (Buckley & Nabhan 2016) should be considered when identifying an area to be protected.

The conservation of pollination is linked to many of the purposes that protected areas should fulfil. Pollinators are important because they provide direct and indirect benefits (ecosystem services, educational uses, tourism, etc.) to an area.

Specifically:

- Conservation is more complex than just protection of species, and should include interactions and processes. Pollination should be an aspect of "conservation of mutualisms" and "restoration of food chains" (Buckley & Nabhan 2016).
- Planning networks of protected areas with coordinated management criteria can offer opportunities for large-scale conservation, for example, creating "nectar corridors" that allow pollinator populations to move over long distances (Buckley & Nabhan 2016), especially important in the context of climate change.
- Pollination by insects is essential for ecosystems and many food crops: more than 87% of flowering world plant species, and more than 66% of crop species depend on pollinators, and produce 15-30% of the global food production (Gutierrez-Arellano & Mulligan 2020). Diversity in protected areas and proximity of these areas to farmland favour wild pollinators and have major benefits for agricultural production. Despite the importance of these services, pollinators are hardly ever considered by decision makers and the pollination services that protected areas can provide to surrounding farmland is often ignored. Pollinators and pollination services should be considered important criteria in the management of these natural areas (Hipólito et al. 2019), as are other services, such as logging and fishing.
- The pollination services to crops provided by nearby protected areas cannot be compared to conventional agricultural measures. Several studies have shown that efforts to improve pollination (e.g. elimination of pesticides or use of honeybee hives) cannot match or replace the benefit of being close to a protected area (Kremen et al. 2004, Carvalheiro et al. 2010).
- Some protected areas that may not currently be contributing to pollination in adjacent cultivated lands, could do so in the future, after agricultural expansion or crop changes. This again is especially unpredictable, depending on climate change scenarios (Gutierrez-Arellano & Mulligan 2020).
- Protected areas can become an extremely important educational tool for surrounding communities, at all school levels. The educational function is explicitly mentioned for all IUCN categories of protected areas, at least from "Type II Area" (Natural Park) and upwards.
- Pollination interactions in protected areas are also a good way to attract people in a context of growing demand for eco-tourism, and for greater participation of people in Citizen Science activities.

BOX 1. DEFINITION, CATEGORIES AND MAIN OBJECTIVES OF PROTECTED AREAS ACCORDING TO IUCN (Dudley 2008)

Protected area: A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The following six categories are recognised:

Areas managed mainly for:

- I Strict protection [Ia), Strict nature reserve, and Ib) Wilderness area]
- II Ecosystem conservation and protection (i.e. National park)
- III Conservation of natural features (i.e. Natural monument)
- IV Conservation through active management (i.e. Habitat/species management area)
- V Landscape/seascape conservation and recreation (i.e. Protected landscape/seascape)
- VI Sustainable use of natural resources (i.e. Managed resource protected area)

All protected areas should aim to:

- Conserve the composition, structure, function and evolutionary potential of biodiversity;
- Contribute to regional conservation strategies (such as core reserves, buffer zones, corridors, stepping-stones for migratory species etc.);
- Maintain diversity of landscape or habitat and of associated species and ecosystems;
- Be of sufficient size to ensure the integrity and long-term maintenance of the specified conservation targets or be capable of being increased to achieve this end;
- Maintain the values for which it was assigned in perpetuity;

- Operate under the guidance of a management plan, and a monitoring and evaluation program that supports adaptive management;
- Have a clear and equitable governance system.

All protected areas should also aim, where appropriate, to:

- Conserve significant landscape features, geomorphology and geology;
- Provide regulatory ecosystem services, including buffering against the impacts of climate change;
- Conserve natural and scenic areas of national and international significance for cultural, spiritual and scientific purposes;
- Deliver benefits to resident and local communities consistent with the other objectives of management;
- Deliver recreational benefits consistent with the other objectives of management;
- Facilitate low-impact scientific research activities and ecological monitoring related to and consistent with the values of the protected area;
- Use adaptive management strategies to improve management effectiveness and governance quality over time;
- Help provide educational opportunities (also about management approaches);
- Help develop public support for protection.

HABITATS DIRECTIVE AND POLLINATORS IN THE MEDITERRANEAN

The Directive 92/43/CE (Habitats Directive) lists species (Annex 2) and habitats (Annex 1) for which Special Areas of Conservation (SACs) have been designated by EU member states. Among the habitats mentioned in Annex 1, it is not easy to select those most valuable for pollinators, as entomophilous plants are widespread and data on pollinator diversity is generally insufficient. The management measures described below may therefore be applied generically in different contexts.

Mediterranean entomophilous plants and insect pollinators of conservation concern are listed in Annexes 2, 3 and 4 of the Directive and the lists of selected species can be found online at the LIFE4POLLINATORS website. If one or more of these species are mentioned in the Standard Data Form of a SAC/SCI, we strongly recommend adopting the measures proposed below to ensure their long-term conservation.

However, some sites of the N2000 network in Europe are already protected by law, being included in various kinds of protected area (Natural Reserve, Regional or National Parks), while others do not have such effective protection. It is therefore not easy to fully implement the conservation measures as required by the Habitats Directive.

When planning conservation measures at species level, we suggest that the "SHARP" approach should be considered (Aronne, 2017). It is a simple method for identifying bottlenecks (e.g. in pollination services) and requires the implementation of specific conservation measures (see below paragraph "COUNTERACTING THE RISK OF EXTINCTION"). In this sense, it is important to promote natural history studies of threatened species. An example of the importance of knowing in detail the interaction process of the plant with its environment is shown in the following box.

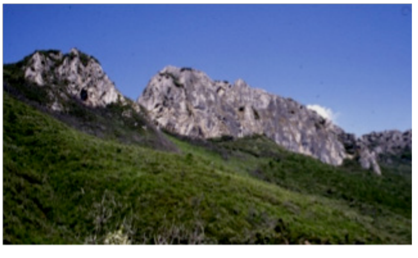
An example of conservation planning of plant-pollinator interactions and protection of endangered species is described in the last section of this handbook with scheme and illustration.

The information on insect pollinators in the standard data forms of certain SACs is often incomplete. So, whenever the presence of a species of conservation interest is recorded, the competent authority should be contacted to update the standard data forms.

For example, Lesvos, with three N2000 sites (GR4110003, GR4110004, GR4110005) host diverse habitat types, flowering plants (1607 species), bees (>600) and hoverflies (143). Many of these insects are new to science, endemic and rare. The standard data forms contain little information on them and there is no quantitative data about them. The LIFE4POLLINATORS Citizen Science activities planned in these areas will also serve to monitor the presence of pollinators. The results will be communicated to the competent authority so that the standard data forms are updated. This practice should be carried out in all protected areas promoting interaction between scientists and managers.

BOX 2. Sometimes conservation requirements related to pollination are not a straightforward thing to say

The case of *Petrocoptis grandiflora* (Caryophyllaceae) in the Serra Enciña da Lastra Natural Park, NW Spain



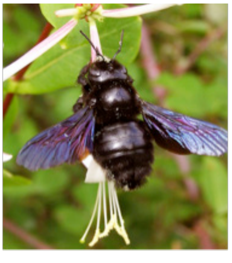
Petrocoptis grandiflora is a narrow endemic species, living only in crevices of some few limestone walls, which occupy less than ten square km in total.

The main threats for its conservation come from some human activities in the area, from stone extraction for cement production to recreational climbing of the walls where it lives.

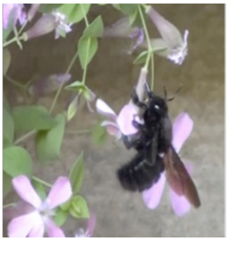
To pollinators, *P. grandiflora* offers an attractive flower with a long calyx closed in the shape of a tube with nectar deep down.

…so, in theory, reward in this flower is only for specialist, long-tongued insects as Anthophora acervorum, Bombylius major and Macroglossum stellatarum. Anthers get in touch with the upper parts of the tongue depositing pollen there that will be delivered to the stigma of the next visited flower.

…but someone else manages to get to the nectar in an "illegitimate" fashion. Some flowers are usually pierced through the tubular perianth to dig a shortcut to the nectar



…and the responsible are opportunistic insects without long tongues but with strong mouthpieces, mainly Bombus terrestris and Xylocopa violacea. By accessing that way to the nectar their heads are far from the anthers and stigmas, so one could assume that these nectar robbers are not giving any service in exchange



…but things are not always so easy to grasp: it is their rear part that gets in touch with the sexual structures of the flower; although they were not "designed to work that way", the interaction between the plant ant the nectar robbers result also in pollination in this case.

…and this is a clear reminder of the importance of figuring out the complete picture of the interaction between flowers and pollinators for the decision making in conservation: some illegitimate visitors are also important for pollination and must be preserved!

More on this in Navarro, Guitián & Guitián (1993); Navarro & Guitián (2000) and Navarro & Guitián (2003)

FACTORS LIMITING POLLINATOR LIFE IN PROTECTED AREAS

Protected areas are not spatially isolated from the surrounding landscape. This means that their ecosystem value can be affected by environmental degradation. Degradation can be the result of catastrophes, such as periodic fires or droughts that may be related to climate change, or due to human activities classified as „conservation compatible" (allowed in protected areas though not in fact fully compatible). Below we mention some of the main threats, highlighting the challenges they pose in the management of protected areas.

HABITAT LOSS

More than 70% of the earth surface is modified by humans, causing damage on habitat diversity, and in the interaction between species (IPBES 2018). The loss of suitable habitat and foraging resources is among the main causes of bee population decline (Bates et al., 2011; Biesmeijer et al., 2006; Goulson et al., 2008; Hicks et al., 2016). Likewise, intensive agricultural practices, such as use of herbicides and insecticides, are the main cause of loss of habitat connectivity and reduction of nectariferous plants and wild insects in areas adjacent to crops. However, in many natural areas, mainly IUCN types III to VI, conservation of biodiversity is not the only concern (see BOX 1). Protected areas may combine conservation with other uses that contribute to the economic development of local communities: agriculture, livestock breeding, tourism, education and recreational activities. Management plans should therefore take into account the risk of habitat loss associated with such activities.

CLIMATE CHANGE

Pollination in protected areas is impacted by climate change, including phenological mismatch between flowering plants and pollinator emergence, as well as invasion of foreign species. In addition to temporal shifts, prolonged droughts or heat waves due to climate change can lead to local extinctions of pollinator populations, or may also modify the spatial distribution of species, which will attempt to respond to new environmental conditions through migration. This can lead to loss of wild pollinator species from certain protected areas, with cascade effects culminating in extinction of endangered species (and the consequent loss of biotic interactions and ecosystem functions in which they were involved). Prediction models are already alarming, especially for mountain pollination biota and their interactions, such as in the case of Mt Olympus, Greece (Minaheilis et al. 2020, 2021).
In general, less habitat connectivity combined with climate change can harm pollinator populations and increase their risk of extinction, particularly specialists and those unable to migrate (Settele et al. 2016).

INTRODUCTION OF INVASIVE AND ALIEN SPECIES (IAS)

In general, the presence of alien species (species introduced accidentally or intentionally into a natural environment outside their original geographical range) in a community is considered a disruptive factor that has negative impacts on local pollination networks. Below we describe how invasive species may alter plant-pollinator relationships.

Alien pollinators that may compete with native pollinators have been studied much less than other biological invasions that may affect pollination. Major negative effects are caused by competition with native pollinators for flower resources and nesting sites. Additional impacts caused by alien pollinators may be co-infection with pathogens and parasites, inadequate pollination of local flora or unwanted pollination of exotic flora (Russo 2016). Alien insect invasions presumably affect native entomofauna in complex ways, such as indirect competition for resources, transmission of diseases and disruption of pollination networks (Kenis et al. 2009).

The effect of invasive plants on pollination networks is better documented than the effect of invasive pollinators, and some studies underline how changes in plant communities in the wake of invasions of exotic plant species seem to be one of the main drivers of pollinator diversity loss. The introduction of new species into a community normally leads to severe and unpredictable modifications in the structure of the pollination network. In the Mediterranean area, the negative impact of invasive plants on the pollination and reproduction of native plants has been demonstrated, since invasive plants compete with native flora for pollinators, increase pollen limitation of the native plants or usurp ‚links' in pollination networks (Morales & Traveset 2009, Vilà et al. 2009, Tscheulin & Petanidou, 2011, 2013, Ferrero et al. 2013). But it is also true that in some cases the invaders attract pollinators, to the benefit also of nearby native plants (Bartomeus et al. 2008). It is therefore difficult to generalize: the overall effect of invasive plants will depend on the specific context, as well as on the characteristics and abundance of the invader. This dependence on context should be considered by managers of protected natural sites; if they consider pollination networks among their conservation priorities, they should remember that there are not universal solutions.
Regulation (EU) 1143/2014 on Invasive Alien Species (IAS Regulation) provides the list of invasive alien species of Union concern (the Union list). We initially suggest monitoring this selection of species as potential enemies for Mediterranean native pollinators and plants (Annex 1). However, an updated selection of species that we suggest monitoring as potential enemies for Mediterranean native pollinators and plants will be available on project's website (https://www.life4pollinators.eu/en/submission).

A paradigmatic case that worries the competent authorities and the population is the invasion of the Asian wasp Vespa velutina nigrithorax (see drawing below). The voracity towards native pollinators deserves a dedicated paragraph. This species is in full expansion in large areas of Asia and Europe, including the Mediterranean (www.vespavelutina.eu, www.stopvelutina.it), and the attention paid to it today is greater than that paid to other biological invaders. This is because of the economic impact this Asian honeybee-attacking wasp has on Mediterranean beekeeping, and of course the social alarm caused by its often fatal attacks to humans. However, because its invasion of Europe is recent, its impact on wild pollinator populations is still unknown (but see Rojas-Nossa & Calviño 2020). Since its invasion, i.e. in the last ten years, most studies have focused on quantifying and monitoring the species in invaded areas and specifically on measures to control economic damage to beekeeping. Proper management of a protected area requires knowing in detail how affects the incorporation of an invasive species into the networks of mutualistic interactions of protected area.

MASSIVELY INTRODUCED MANAGED SPECIES

The massive introduction of individuals belonging to species valuable for humans implies inevitable changes in natural habitats. This is evident in activities such as agriculture and even extensive breeding. Yet other activities that have traditionally been considered innocuous, and are therefore tolerated or even favoured in many protected areas, may also alter natural ecosystems. Geslin et al. (2017) grouped these cases under the name Massively Introduced Managed Species (MIMS).

Perhaps the most notable case of such human activity is beekeeping: traditionally considered an activity, innocuous or even beneficial for pollination and therefore allowed in most European protected areas, it has lately been compared to extensive breeding. Indeed, it has been demonstrated that introduced bees (Apis mellifera, see the drawing below) and bumblebees can act as vectors for the spread of infections that harm wild pollinators (Fürst et al 2014), while indirect competition for floral resources is now well documented (Herrera 2020; Lázaro et al. 2021). The latter large-scale study from the Greek Cyclades showed that honeybees had a negative effect on wild bee species richness and abundance, and influenced the structure of wild bee pollination networks. Geslin et al. (2017) cite four possible causes of this indirect effect: 1) the enormous disproportion between the number of introduced bees and that of wild bees, 2) introduced colonies are capable of collecting an enormous quantity of floral resources, both nectar and pollen, from different plant species, 3) honeybees remain active all year, except in the coldest months, while most wild bees are only active for a few weeks or months, 4) honeybees have much wider foraging ranges (average distance 1.5 km) than wild bees (100-500 m). The density threshold above which honeybee colonies have a damaging competitive effect on wild bees depends on many factors, such as geographical location, climate, habitat, distance between hives, etc.

Site managers should set reasonable limits to beekeeping in protected areas. Since it is extremely difficult to establish recommendations for maximum colony densities due to the heterogeneous nature of floral resources (Torné-Noguera et al. 2016), it is best to err on the low side.

GRAZING AND FIRE

The effects of grazing and fire on Mediterranean ecosystems deserve more attention. The flora of the Mediterranean has been exposed to grazing, especially by sheep and goats, for almost 10,000 years, since domestication began. In the recent past, the Mediterranean landscape was grazed even more intensively with high livestock densities, sometimes leading to degradation of the landscape. But grazing is also necessary to maintain the diversity of plants, especially flowering ones, and pollinators. Moderate grazing in phryganic ecosystems is optimal for plants and pollinators, so other ecosystems in natural parks and protected areas may also benefit from moderate grazing pressure (Lázaro et al. 2016a, b).
Livestock densities should be monitored and not exceed thresholds that clearly damage vegetation, e.g. flowers should be available in all seasons. A rotational grazing system can provide space and the necessary time for plants to flower, seed and enhance populations of flower-visiting insects (e.g. Enri et al. 2017). Site managers of protected areas should take responsibility to set up a (rotational) grazing system that benefits pollinators and the plants they pollinate.

Fire also plays an important ecological role in the Mediterranean, where ecosystems are prone to fire. Many flowering plants and also pollinators have therefore evolved with and are adapted to this natural disturbance. Moderate fires can create opportunities for species and often increase the diversity and richness of plants and pollinators (Carbone et al. 2019, Lazarina et al. 2016, 2017, 2019; Petanidou & Ellis, 1996; Potts & Dafni, 2001). Although this is a common land management practice in North American protected areas, prescribed burning rarely happens in Europe and the Mediterranean. Prescribed burning on a small scale could help site managers maintain and enhance fire-prone vegetation that also provides good pollinator habitat.

MANAGEMENT MEASURES FOR A POLLINATOR FRIENDLY PROTECTED AREA

MANAGEMENT PLANNING

Protected areas are mainly devoted to nature conservation and observation, as well as the monitoring of wild flora and fauna. Local stakeholders are often unwilling to apply protection measures because it reduces their scope for using the land as they want. However, having an activity near or within a protected area could be an advantage if the activity is developed sustainably. The activity could acquire prestige and any food produced would be healthier, because pollution is lower and ecosystems are healthier. Managers of protected areas should therefore highlight these characteristics and plan on this basis. To be effective, management plans and regulations for the use of protected sites should be drafted with the participation of local stakeholders (farmers, beekeepers, etc.). A specific part of the management plan should analyse the presence of invasive plant and animal species and propose measures (prevention, early detection, rapid eradication and management), as suggested in the IAS regulation, to eradicate them or mitigate their spread.

The involvement of citizens and local stakeholders in biodiversity monitoring, also using a citizen science approach, could be useful for inducing local populations and stakeholders to accept protective measures and restrictions. Citizen Science should be promoted using easy but specific schemes for pollinator monitoring, e.g. through BioBlitzes or projects for schools and citizens with the support of local associations.

REDUCING THE IMPACT OF AGRICULTURE

As already mentioned, intensive agriculture is the main factor that can damage protected areas. Since the late 20th century, policies to mitigate this impact have been developed in Europe. A common measure is creating „wildflower strips" near cultivated areas to increase: i) landscape and pollination service complexity, ii) biological control of certain pests, aimed at eliminating the use of pesticides, iii) plant diversity and iv) bird populations by providing food resources, such as fruits, seeds or invertebrates. However, if the planted species are not correctly selected, this measure could be considered a MIMS. Studies on the effects of such practices show that they favour the diversity and abundance of common insect species, but not that of threatened or specialized ones. So although this management technique is theoretically positive, designing the floristic composition of the "flower strips" to meet the ecological needs of local pollinators should be a priority (Geslin et al. 2017). This approach is especially desirable for farmlands within protected areas, where biodiversity conservation is a primary goal. However, in order to carry out this management practice correctly, it is essential to have prior knowledge of the local pollinator and plant communities.

In general agriculture, breeding and beekeeping should be implemented in a sustainable way, in order to limit their impact on pollinators. This can be achieved by avoiding pesticides, fostering crop rotation, keeping at place native flower strips (with seeds of regional origin), avoiding mowing during flowering; promoting shelters such as bee- and bug-hotels and leaving uncultivated patches for pollinator nesting. Flower strips should be designed to have flowers available all year and using species with high pollen yield. Mowing of forage in meadows and pastures should be regulated and planned to let at least part of the plants bloom.

SUPPORTING WILD POLLINATOR POPULATIONS

A recent study (Fisogni et al., 2021) showed that conservation measures can counteract the decline of pollinators in protected areas. The authors installed artificial nesting sites to support solitary bees, reinforced populations of native plants to increase foraging resources for pollinators, and released in the study area colonies of bumblebees, reared from wild queens captured in the surroundings. The results showed that overall plant-pollinator network generalization increased after implementation of the measures and interactions were more evenly distributed, reflecting higher robustness and resilience against species loss. The reinforcement of plant and pollinator populations also increased visits to flowers. Providing nesting sites and reinforcing native entomophilous plants and pollinator populations are therefore successful strategies for mitigating loss of pollination and pollinators. A Life Project PP-ICON example can be found at “The Knowledge Platform” online database (https://pdc.minambiente.it/it/area/temi/natura-e-biodiversita/progetto-pp-icon).

MONITORING

Monitoring is the main way to detect risk of extinction in advance so as to activate countermeasures.

Data on pollinators should be collected constantly to update pollinator checklists and transmit news on pollinators and their habitats, to highlight specialist species and night pollinators (e.g. moths), to record pollinator behaviour such as foraging, nesting, mating and wintering, and to monitor the presence and distribution of invasive alien species so as to plan specific eradication or mitigation.

Promotion of studies to determine thresholds above which the densities of honeybee colonies have a detrimental competitive effect on wild bees should be a priority for protected areas where beekeeping is extensively practised. It is important to know the optimal hive density and regulate beekeeping or if necessary temporarily suspend it.

COUNTERACTING THE RISK OF EXTINCTION

Some types of rarity can be considered natural, while others are associated with high risk of extinction. Plant species become rare due to natural and anthropogenic selective pressure (Briggs, 2009). However, it can be said that long-term survival of a species relies on maintenance of genetic variability and natural selection through successful reproduction and generation turnover. According to Aronne (2017), for conservation purposes, priority should be given to studies that focus on life-cycle bottlenecks which prevent or slow down natural selection. Systematic Hazard Analysis of Rare-endangered Plants (SHARP) is an exploratory tool to apply to single rare endangered species to identify any constraints in generation turnover and their causes. It finds bottlenecks in the life cycle of plant species in a given geographical area and pinpoints factors limiting generation turnover. The assessment is species-specific and proceeds in two steps. STEP 1 involves gathering data in the field and narrows investment of conservation resources (in terms of cost and time) by identifying which stage (flowering; seed production and dispersal; seedling recruitment; cloning) is most critical for the species in question. Identification of a breakdown at a specific stage (STEP 1, in Figure 1) indicates a bottleneck. Researchers with expertise in the corresponding field are then engaged to discover the causes of the breakdown in generation turnover, so that specific conservation measures can be planned (STEP 2).

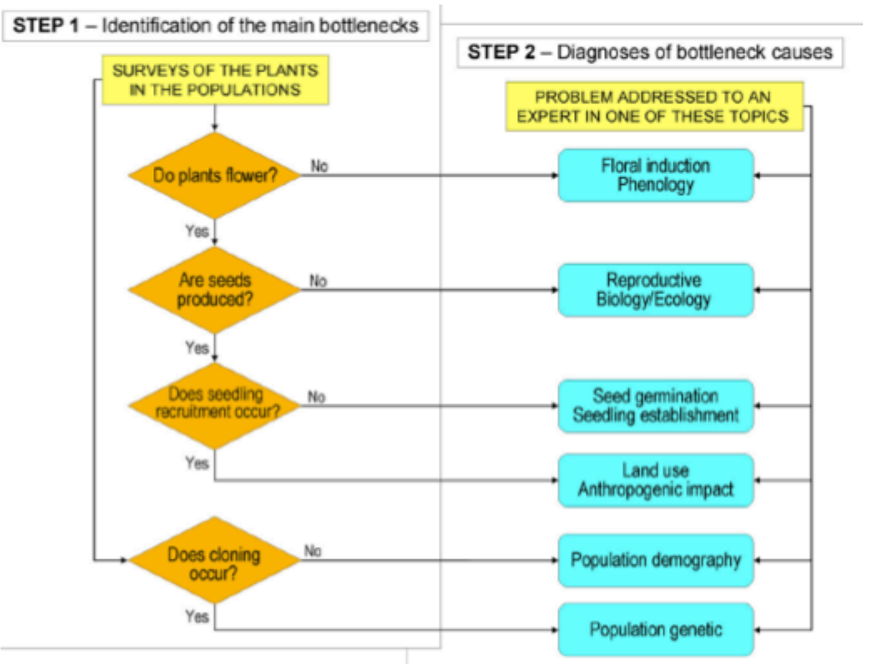
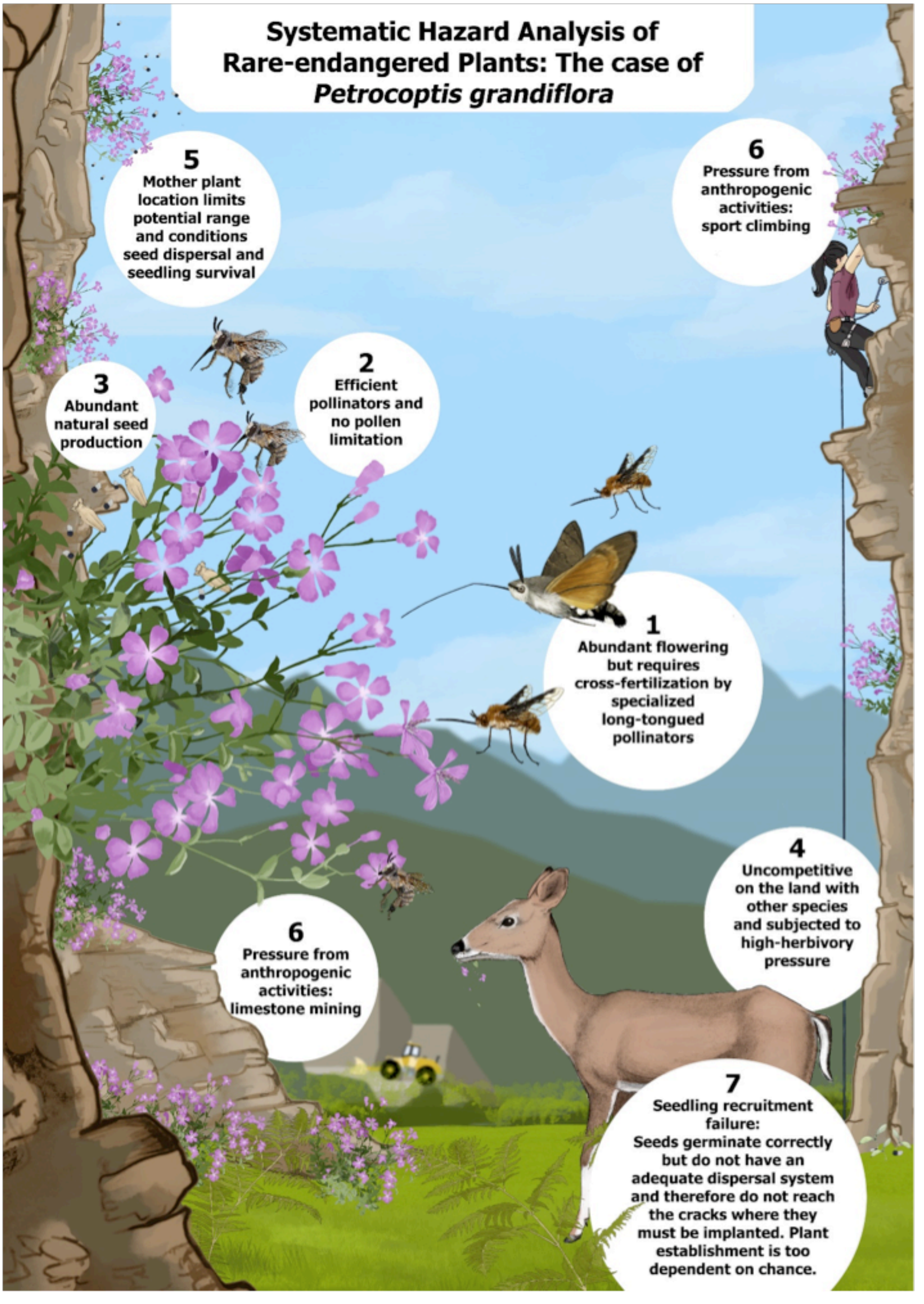


Figure 1. Aronne Bottleneck Identification for Plant Conservation

This slide illustrates a case study of how detailed evaluation of the natural history of an endangered species can quickly shed light on the potential bottlenecks of that organism.



LIST OF ALIEN SPECIES THAT, IF PRESENT IN THE PROTECTED AREA, SHOULD BE MONITORED

LIST OF INVASIVE AND ALIEN PLANT SPECIES	
Acacia saligna	*Hydrocotyle ranunculoides*
Ailanthus altissima	*Impatiens glandulifera*
Alternanthera philoxeroides	*Lagarosiphon major*
Andropogon virginicus	*Lespedeza cuneata*
Arctotheca calendula	*Ludwigia grandiflora*
Asclepias syriaca	*Ludwigia peploides*
Baccharis halimifolia	*Lygodium japonicum*
Cabomba caroliniana	*Lysichiton americanus*
Cardiospermum grandiflorum	*Microstegium vimineum*
Carpobrotus edulis	*Myriophyllum aquaticum*
Cortaderia selloana	*Myriophyllum heterophyllum*
Ehrharta calycina	*Oxalis pes-caprae*
Eichhornia crassipes	*Parthenium hysterophorus*
Elodea nuttallii	*Pennisetum setaceum*
Gunnera tinctoria	*Persicaria perfoliata*
Gymnocoronis spilanthoides	*Prosopis juliflora*
Heracleum mantegazzianum	*Pueraria lobata*
Heracleum persicum	*Salvinia molesta*
Heracleum sosnowskyi	*Triadica sebifera*
Humulus scandens	

LIST OF ALIEN SPECIES POTENTIALLY HARMFUL TO POLLINATORS	
Major concern	**Less concern**
Vespa velutina (Asian yellow-legged hornet)	*Lasius neglectus* (invasive garden ant)
Megachile sculpturalis (Giant-resin bee)	*Cacyreus mashalli* (pelargonium butterfly)
Linepitema humile (Argentine ant)	*Vespa bicolor* (black shield wasp)
Zelus renardii (leaf hopper assassin bug)	*Megachile disjunctiformis*

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