ASIAN HORNET

(Vespa velutina nigrithorax) Biology, Monitoring, Control and Prevention of Spreading

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BIOLOGY AND BEHAVIOUR OF THE ASIAN HORNET

CONTENT OF PART I

PROLOGUE

Little-studied but already feared area

Vespa velutina nigrithorax is an invasive species of Asian hornet native to China that was accidentally introduced to Europe in 2004 along with Chinese pottery. It is a generalist predator of medium to large insects and also feeds on vertebrate carcasses. It has a major impact on populations of diptera and social hymenoptera, especially honey bees, and poses a threat to European beekeeping.

This hornet species has found suitable habitats in both southern and northern Europe, and has also been successful in spreading to other non-native areas in Japan and South Korea. It is highly likely that it will also adapt to the environment of Central and Eastern Europe within a few years. It is reaching new and new territories through intensive transport of goods and people. In this way it has colonised many areas of Spain, Portugal and Italy, and has spread to Belgium, the United Kingdom, the Netherlands, Germany, the Channel Islands and the Balearic Islands.

This invasive species threatens the honey production and native pollinating insects. It attacks in groups and one hornet nest consumes up to one million of insects per season. It can be accidentally introduced and transported in soil with plants, garden furniture and pots, wood, vegetables, camping equipment, etc., and can appear virtually anywhere that the trade routes of goods and people reach. The speed of its spread depends on climatic conditions, the existence of corridors, watercourses and, naturally, the abundance of food. It has excellent adaptive and reproductive abilities. With the exception of man, it has virtually no significant predators in Europe. In China, Japan and South Korea, the population size of *Vespa velutina* is partly influenced by the world's largest hornet, *Vespa mandarina*.

Vespa velutina poses a significant threat to European biodiversity, causing economic damage and endangering the health of the population. It behaves as an opportunistic predator, targeting mainly locally abundant prey. If bees are present in their nest sites, they will prey mainly on honey bees, but also on flies and social wasps, as well as on a wide range of animal organisms (at least 159 different species have been identified). One hornet nest can consume an average of 1 milion of insect biomass per season. It seeks warmer climates with plenty of food. Prey spectrum is influenced by the nest surroundings, with urban colonies preying more on honey bees and forest colonies more on social wasps. The intensity of attacks reaches its peak in early October.

Hornets have developed excellent nest organization and precise nest structure. They have highly developed mutualistic interactions as well as communication among individuals of the same colony. Before the rapid spread of *Vespa velutina* hornets in the world can ever be effectively stopped, we must first gain a deeper understanding of the biological cycle, the way of life, the communication among individuals in the nest, the methods of hunting their prey, and understand the whole web of relationships that facilitate the successful spread and reproduction of the Asian hornets. All of this is indispensable in order to be able to set up effective measures to stop it and, if necessary, to be able to protect the bee colonies that are its preferred prey.

The risk posed by the *Vespa velutina* to honey bees is considerable. Unlike the European hornet *(Vespa crabro)*, which does not pose a major threat to bees, the *Vespa velutina* attacks in groups and is capable of wiping out large numbers of healthy bee colonies in a relatively short time. This has a considerable impact on the economic activities of beekeepers, the pollination of agricultural crops, fruit growing, wine production, the maintenance of public green spaces and, last but not least, the safety of the movement of citizens, especially beekeepers.

Although the eradication of the *Vespa velutina* from the European continent is no longer possible, it is important that the various stakeholder groups in society, particularly local government representatives, farmers, beekeepers, citizens, scientists, fire fighters and others, are well informed about the biology of the hornet and have the necessary skills and equipment to eradicate the nests. *Vespa velutina* will continue to expand into new territories regardless of the measures taken, so education is an important tool to reduce the negative impact of the *Vespa velutina* on biodiversity and human activities.

There are several types of measures that can be put in place against hornet attacks on apiaries and to control the spread of nests to new areas, which need to be familiarised with both theoretically and practically. In addition to education, early intervention against *Vespa velutina* is proving to be an important key to avoiding economic and ecological damage. This chapter aims to popularize the existing knowledge about the life of a still little-studied but already feared area and for many a fascinating predator, which the *Vespa velutina* undoubtedly is.

Helena Proková, Richard Šníder

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1 • ASIAN HORNET VESPA VELUTINA NIGRITHORAX IN THE WORLD

1 • 1

Current presence of the Asian hornet in the world

The Asian hornet *Vespa velutina nigritorax* became established in several parts of the world in the early 2000s. In 2003 it arrived in South Korea, where it found suitable breeding conditions. It has subsequently spread northwards to other countries at a rate of 10 to 20 km per year. Within a few years, it became the most widespread species among the hornet family (Vespidae) of hymenopterous insects in South Korea. Recall that this country is home to 6 different species of hornets:

1. *VESPA ANALLIS*
2. *VESPA MANDARINIA*
3. *VESPA SIMILLIMA*
4. *VESPA CRABRO*
5. *VESPA DUCALIS*
6. *VESPA DYBOWSKII*

Since the arrival of the Asian hornet *Vespa velutina nigritorax* in Korea, this hornet species has begun to compete with other native species and has caused a decline in the populations of *V. mandarina, V. simillina* and also the European hornet *Vespa crabro.*

According to the published studies on the impact of *Vespa velutina* on native populations of various insect species, they prove to be extremely adaptable to new conditions, colonising new and novel territories, for which they need large numbers of insects.

Research in South Korea has shown that *Vespa velutina* prefers more thermophilic sites and is more common in urban areas compared to *Vespa mandarina, Vespa crabro* and *Vespa anallis*, for which is primarily characteristic the forest environment. Up to 70 percent of *Vespa velutina* colonies live in urban environments, resulting in a significant decline in the population of *Vespa simillina* in the South Korea. The two species are in direct competition, preventing each other from building nests and competing for food resources.

The Asian hornet *V. velutina* has already found its habitat in Japan. The first nests here were discovered in 2012 on Tsushima Island and in 2015 on Kyushu Island. These islands are the closest territories to South Korea and there are many trade relations between them. These are most likely the reasons how *Vespa velutina* hornets could have made their way from South Korea to Japan. It has been shown by analysis that the population of *Vespa velutina nigritorax* in Japan is genetically identical to that in South Korea. According to the studies conducted, the population of hornets that has colonized South Korea presents a lower genetic diversity than that found in China. In this case, we are talking about the so-called "bottleneck effect". This phenomenon occurs when only a few closely related individuals establish a new population. The bottleneck effect results in reduced genetic variation. Despite the very low genetic variability, *Vespa velutina* is able to spread successfully into new territories.

In 2004, *Vespa velutina nigritorax* hornets were accidentally discovered in the Lot and Garonne departments of France. They were found to have arrived here along with imported Chinese pottery. One or only a small number of the fertilized queens came from the Chinese provinces of Jiangsu and Zhejiang, which is close to the port of Shanghai. As was the case in South Korea, *Vespa velutina* colonized the whole of France within a decade. Since 2004, Asian hornets have gradually penetrated into other European countries, both south and north.

According to scientists, the rate of spread of this hornet species is 100 km per year from its original nest. The Asian hornet has been found to spread up to five times faster in France than it did in the study area in South Korea. This may be due to the different natural conditions that exist in the two countries. **It appears that the French territory suits the *Vespa velutina* hornet particularly well. There are suitable climatic conditions, a less rugged landscape and different corridors through which the hornets disperse. The open river courses and the abundance of motorways allow the Asian hornet to spread constantly into new and new areas of France.**

At the same time, the very low level of competition between the different hornet species also helps. As already mentioned, in the case of South Korea, up to six different species of Asian hornet coexist. In the South Korea, ***Vespa velutina*** has to compete for food resources and nest space with six different hornet species, whereas in **France it has virtually no competitors**. The only real threat is intraspecific competition from queens, which establish their primary nests in spring. At this time, so-called nest usurpation by a foreign queen occurs. Another potential threat is the much milder European hornet, *Vespa crabro*. There is, however, no scientific evidence or field observations of competition between these two species, yet.

It should also be mentioned that the largest hornet in the world, Vespa mandarina, is also found in theSouth Korea, which has no predators and feeds not only on hornets, but also other hornet-like species of hymenopterous insects. It is quite likely that *Vespa velutina* is a frequent prey of the *Vespa mandarina* hornet in Asia. These facts shed light on the rapid invasion of *Vespa velutina* hornets in France in a very short time, as well as their spread in other European countries, about which you will learn more in the following section.

FRANCE

100 km/year

The rate of spread of a hornet from its original nest.

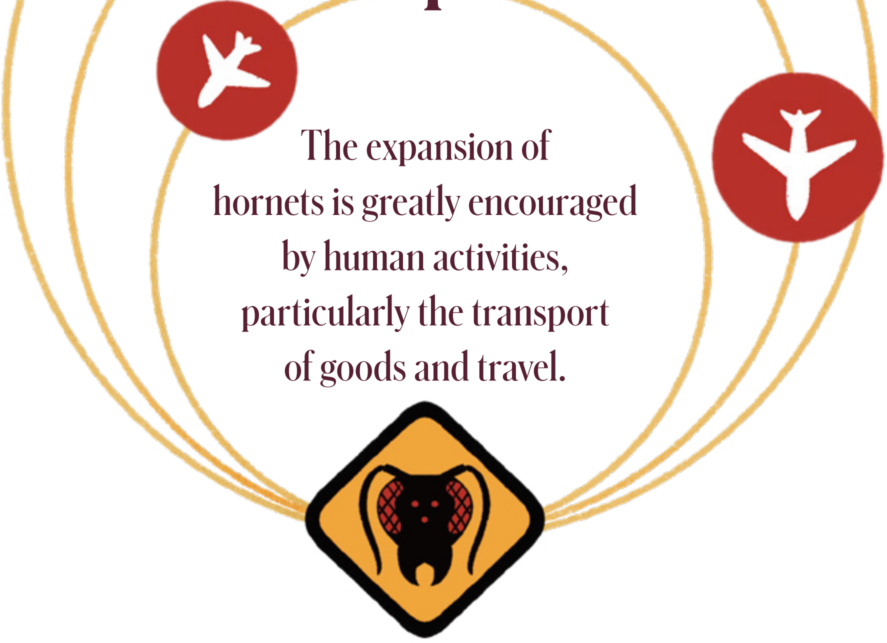
SOUTH KOREA

70 %

of the *Vespa velutina* hornet colonies live in an urban environment.

1·2

Forecasts for the further spread of the Asian hornet in Europe



The expansion of hornets is greatly encouraged by human activities, particularly the transport of goods and travel.

How is it possible that the *Vespa velutina* hornet has spread so rapidly in southern Europe and how is this likely to continue to develop in the near future? Which regions and areas are most at risk? And in which areas does *Vespa velutina* have the best conditions for building nests?

Mathematical modelling has revealed the speed and main factors of the spread of this invasive species in the world. The *Vespa velutina* has **a very high natural ability to reproduce and there are very suitable living conditions for it in Europe**, both climatic, natural conditions and conditions created by man.

Fertilised queens originating from a single colony spread over a certain area both **before** and **after the overwintering period**. In modelling, it has been shown that hornets can spontaneously fly up to 78 km per year from their original nest. The actual distance depends on conditions and existing barriers in the area. The results of this study are almost identical to what has actually been observed in France, where hornets have been recorded to disperse at speeds of up to 100 km per year. This slight difference is related to the variability of the terrain of the different countries where *Vespa velutina* hornets already occur. This is primarily due to **the availability of corridors, the mild climate, the abundance of food, and the existence of highways and water basins that create suitable invasion routes over very long distances. Many hornet colonies are relocating without us knowing it.** The *Vespa velutina* is already found in **northern Spain and Italy, but also in Belgium, the Netherlands, Switzerland, Germany and the UK.** It appears that Asian hornets are colonising territories more rapidly towards the north of Europe than towards the south.

According to this study (Barbet-Massin et al., 2018) the spread of the hornet can also happen quite randomly, as was the case in Italy, Portugal and the UK, where the queens got there by trading goods. These are such large distances where the hornets themselves would never have reached naturally at all. It is estimated that Asian hornets will be found throughout Italy, Portugal, and also in the UK. **Central Europe will be colonised and affected in time as well.**

As with the introduction of the *Vespa velutina* hornet to the Anglo-Saxon islands, they have been introduced to the island of Majorca by human activities. Similarly, hornets may have been spread to other Mediterranean islands (Corsica, Sardinia and Sicily). Analyses have confirmed that the Asian hornets found in England and France are genetically very closely related to each other. Similarly, dead hornets found in campsites in the Netherlands and in England in imported wood that came from France were genetically identical.

Distribution of the Vespa velutina as of 26.01.2022

FIRST NEST RECORD (2004)
FAILED TO ACCLIMATE/ERADICATED
DISTRICTS COLONISED BEFORE 2020
WITHOUT DATA/PROBABLY ABSENT
DISTRICTS COLONISED IN 2020

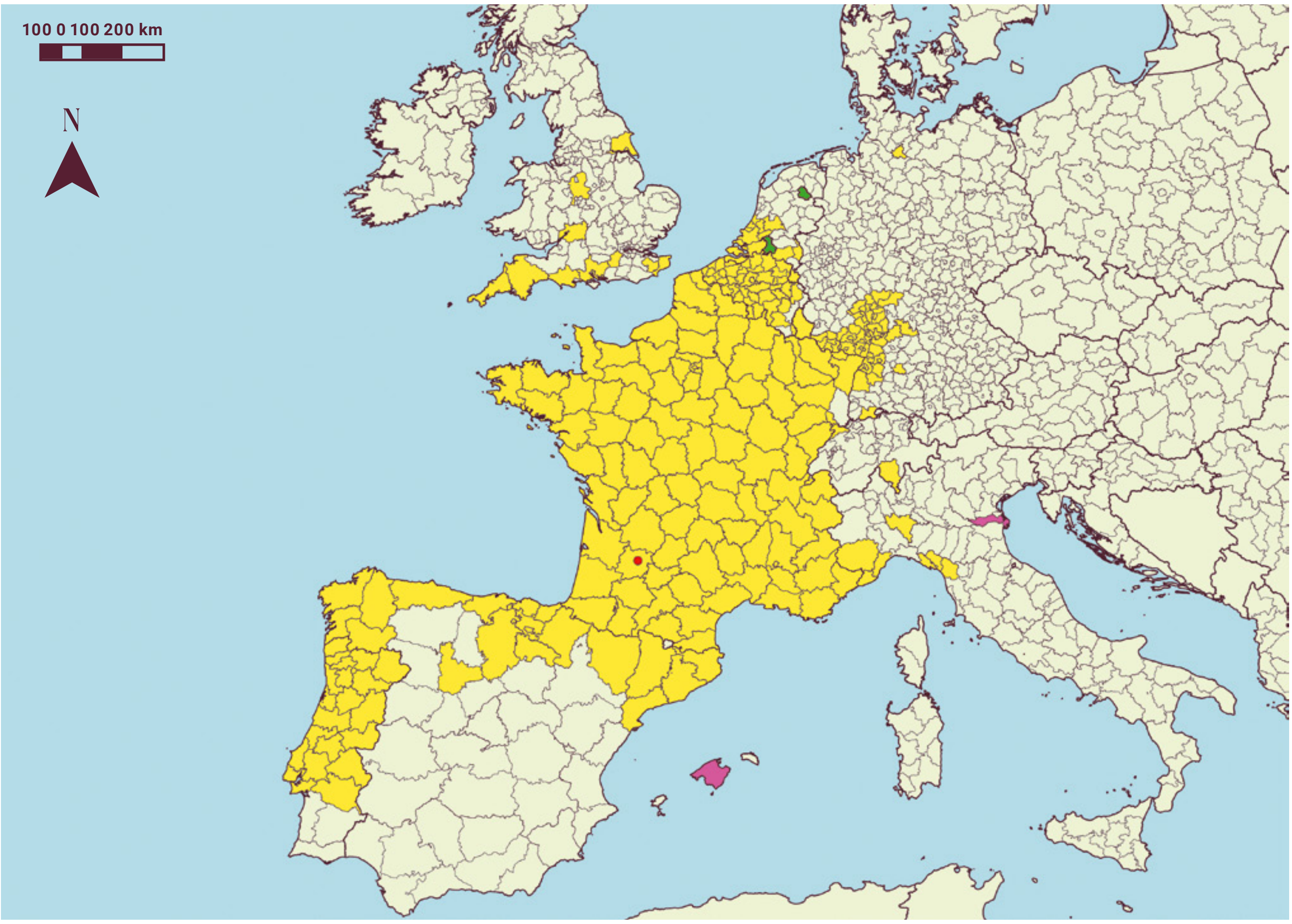


Figure 1: Distribution of the Vespa velutina as of 26.01.2022 [MNHN, 2022].

And what if the weather gets mixed up in the whole situation. Weather patterns and the overall climate development play a significant role in the intensity of the spread of Asian hornets. Expansion of hornets in Europe may accelerate even more as a result of warming. The lack of watercourses and vegetation is probably the most limiting factor in the spread of *Vespa velutina* in central Spain. **The north-east of Spain,** such as Galicia, **where the climate is not so hot, is much more suitable for the uncontrolled spread of hornets compared to the very hot south of Spain.** In 2018, more than 10,600 hornet colonies were found in Galicia, with densities of up to 20 nests per km^2!

It is expected that Vespa velutina shall colonise a very large part of the European continent.

Climate modelling has also helped to determine the geographical zones where Asian hornets can spread most rapidly. The studies took climatic conditions into account and compared them with those in China. At the same time, future climate change scenarios were also considered. If we do not prevent the spread of this hornet species, **areas along the Atlantic and Mediterranean with very suitable conditions for hornets will be the most affected.** Further east, i.e. **the Baltics and Turkey, are also highly likely areas where hornets will become established.**

These studies have not concentrated on Europe alone. There are other countries in the world where hornets can thrive. Just as the *Vespa velutina* has made its way to France through commercial activities, **this hornet species may be spreading through human activities to other continents.**

2 • MATRIARCHAL SOCIETY AND THE WORLD OF CASTES

2 • 1

Matriarchal society and the world of castes

The Asian hornet colony has an enormous organizational structure and the entire community revolves around one individual: the queen, the founder of the nest. Her main task is to lay eggs in the cells of the combs. **The queen is the founder of the whole colony**, she is the mother of all the individuals in the nest. She lays approximately 15,000 eggs a year. **If she dies, the entire hornet community perishes within days or weeks.** If the queen dies while the first workers are still hatching, the nest will disappear within a few days. If the queen dies sometime in the mid-summer, when the nest has a sufficient number of workers, then the workers lay unfertilized eggs and the colony lasts until the last worker dies, which can be 5 to 7 weeks. The subsequent development of mothers (queens) in the same nest, within the same colony, is not possible.

Like all colonies of hymenopterous insects, which are social insects, for most of the year hornet colonies are composed entirely of females. Males appear in late summer or as late as mid-September, in the period of reproduction.

Each individual belongs to a certain caste and plays a specific role in the survival and development of the whole colony.

The queen is the only sexually mature female capable of producing an offspring. The other members of the caste capable of reproduction are of two different sexes and hatch in the nest from September to December.

Females capable of reproduction who have not yet established their own nests do not participate in the reproduction of the same colony. They always establish new colonies of their own, but only in the following year after overwintering. They leave their maternity nests after they have sexually matured in the nest and have built up sufficient fat reserves for overwintering. At the time of sexual maturity, they fly out to mate. After mating, they never return to the maternity nest. After overwintering, in the spring, they establish their own nest and become the new queens of their new colonies. We'll talk more about them in the next section.

The males have only one job: to seek out young queens and mate with them. They have no other role in the colony that we know of. All other individuals in the colony are workers who must provide all the activities for the survival of the colony, specifically related to nest building, brood care, maintaining the temperature of the nest, food gathering, and nest defence.

REPRODUCTION OF THE HORNET ***VESPA VELUTINA***

~15 000

EGGS LAID PER YEAR

2 • 2

The hard life of female workers

In *Apis mellifera* bees, worker bees provide different activities according to their age. During the first few days, the young bees first stay in the nest, where they clean the cells of the combs, care for the queen and the brood, and build the combs once the wax glands have been activated. Approximately 20 days after hatching, they leave the shelter of the nest and become flyers - hornet workers. In addition to age guiding their actions, what to do and when to do it, worker bees also adapt to the needs of the colony/hive. In this way, even young bees can provide the tasks of adult flyers or vice versa. The bees can revert back to the most common activities according to the needs of the colony/hive. This relationship, age and function, has been studied in great detail in honey bees.

Like worker honey bees, female **worker hornets undertake tasks that are based on the needs of the colony.** However, this appears to be much less age-distributed than is the case of the honey bees. Among the activities they must perform are nest building, brood care, and cooling inside the nest by flapping their wings. Maintaining a stable and constant temperature inside the nest is a prerequisite for the proper development of the individuals in the nest. It is also the construction of new cells and the expansion of the nest, the collection of raw materials to build and enlarge the nest, as well as the collection of food, which consists of protein and sugar components. Like bees, hornets also collect nectar and like to suck the juice of fruits or any other sweet substances they find in nature. They obtain the protein component of their food from hunted insects or from dead animal remains. **Only the larvae feed on this protein part** of the food. They live for a few days up to 4-5 weeks.

LIFE EXPECTANCY OF FEMALE WORKERS

4 – 5 weeks

2 · 3

Who's who in the nest?

Adult *Vespa velutina* are approximately 22 mm in length. We can use the black and yellow colouration of the *Vespa velutina's* legs to distinguish it from the similar European *Vespa crabro* hornets. Males and females can be distinguished from each other by the different size of the antennae, with female antennae being thinner and shorter compared to males. As with all hymenopterous insects, **females have a sting and males do not.**

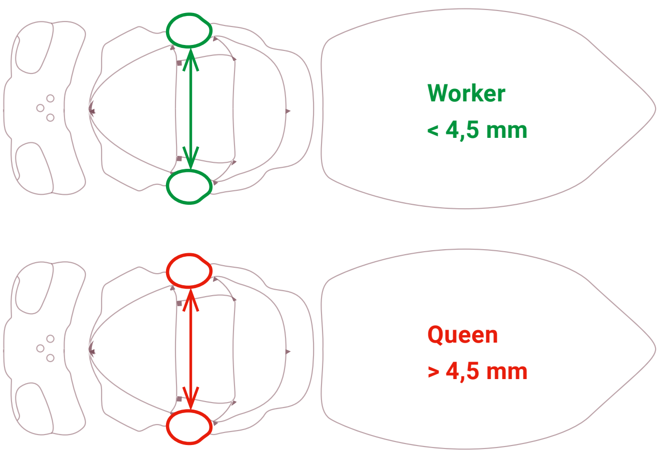
As with honey bees, there is sexual dimorphism in hornets - sexually distinct individuals differ from each other in size and behaviour. **Male hornets have longer antennae than females and their abdomens are more oval than those of females. They live in the nest until mid-September.**

Among the females of the same colony, adult workers live for a time (late summer and autumn) with the future queens. How do we tell which are the future colony founders and which are the workers?

We can distinguish these two female castes by their size, weight and behaviour. In general, **worker females weigh slightly less than the future nest founders.** In the case of workers, their weight is around 400 mg and future queens have a weight slightly higher. **In some colonies these morphological characters do not apply and the differences between them are very small, not observable to the naked eye.** It is necessary, therefore, to use the additional differences in the abdominal part, the size of the fat body, which is far larger and better developed in the nest founders than in the workers. This method of identifying individual female castes requires first killing the insect and then making a detailed analysis using a microscope, which is not possible in the field. **Other differences between workers and founders of future colonies are in the different chemical composition of their cuticle. This characteristic chemical composition clearly distinguishes them from other individuals in the nest.** Such chemical analyses are lengthy and very expensive, used only in research. When observing a nest, we cannot tell whether it is a worker or a young queen.

Finally, there remains one morphological criterion that does not require complex material for analysis. It is sufficient to measure the wingspan at the level of the wing attachment to the thorax, which will show us whether it is a founder or a worker. A length that is less than 4.5 mm indicates that it is a worker. If the length is greater, it is a future nest founder.

Scale 1:1



1000 µm

A nest of the *Vespa velutina* hornet.
Sourcej: Francis ITHURBURU
he female workers are placed in different positions so that they can use the pheromone trail to examine anyone who wants to enter the nest.

When and where will the nest founder start laying the eggs of the future queens? **Workers are not likely to select an egg or larva to feed with special food, but will build a separate comb for the future queens and a separate comb for development of males at the bottom of the nest.** As with honey bees, the quantity and quality of nutrition is expected to play an important role in the queen hornet.

Males, females - future queens - do not hatch until late summer and early autumn. It also depends on the size of the nest, the more workers the nest has, the more males and future queens the workers will raise. With fewer workers in the nest, there will be few or no queens hatched.

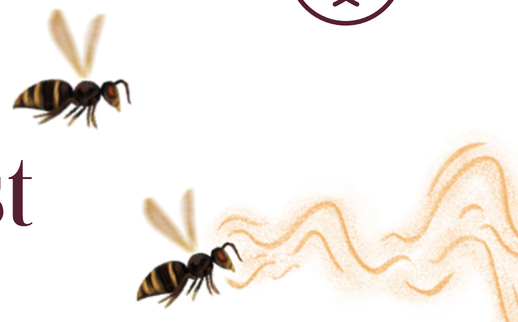
The first worker hatch smaller because the queen, the colony founder, made smaller cells and fed them smaller amounts of food. At the end of the summer, the workers feed the future queens and males mainly with fruit juices and sap from different types of trees, which allows them to develop better.

The queen lays worker eggs first, followed by male and female eggs in late summer and autumn, from which the future queens hatch. In the meantime, she stops laying worker eggs. The hatched workers save food for individuals capable of reproduction. In the autumn, the numbers of workers decrease day by day in favour of new queens and males. The hornet colony is dying because of the lack of workers in the nest.

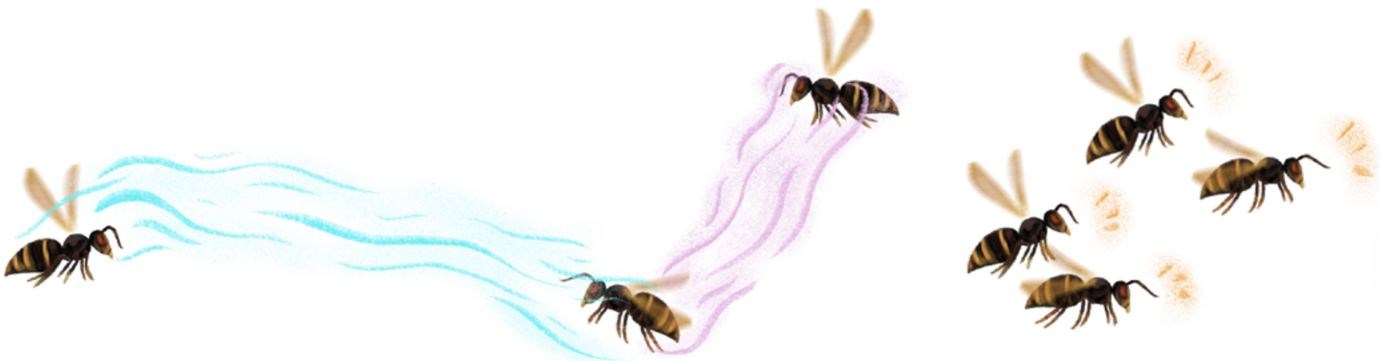
The female workers are placed in different positions so that they can use their pheromone trail to investigate anyone who wants to enter the nest.

Hornets communicate by sight, smell, taste and touch. The sounds that create vibrations are picked up by hornets with their antennae. They have two large compound eyes on their head, which are very good at registering even the smallest movements. The three simple eyes on the top of the head are primarily used to distinguish between light and dark. Hornets also perceive the ultraviolet spectrum and polarized light, which serves them in foraging and nest finding. Their sense of smell is particularly important for foraging, as they can detect even minute amounts of aromatic chemical compounds secreted by ripening fruit and nectar-bearing plants. They can also use their sense of smell to distinguish individuals of their nest from intruders of foreign hornet communities. Males use their long antennae with exquisitely developed olfactory receptors, which perform a tactile function in addition to an olfactory one, to locate unmated queens. The sexual pheromones spread by queens can be detected by males from several kilometres away. However, we do not know the exact distance.

2 • 4



Communication in the nest

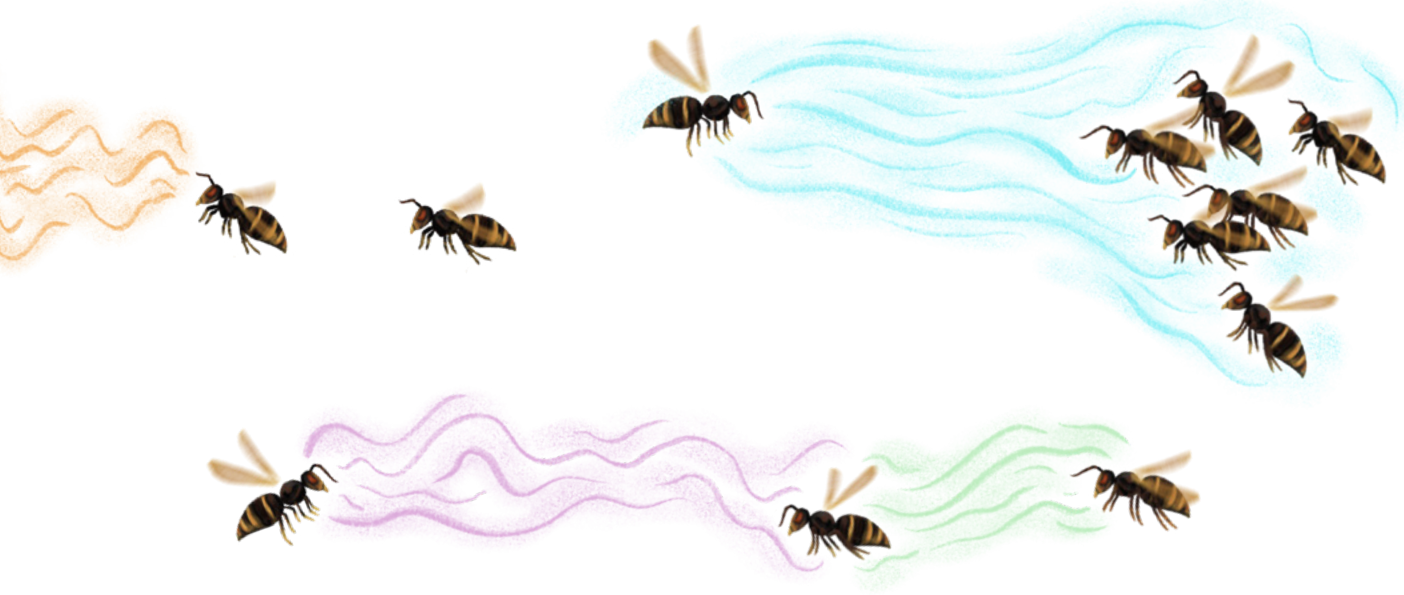


Communication is essential for the survival of social insects. It enables social cohesion, helps the whole community to survive and allows individuals to communicate with each other. Since all activities are carried out collectively in the nest, including prey hunting and nest defence, this requires having an efficient communication system by which to communicate with a large number of individuals at once and to influence activities such as nest construction, queen care, brood care, collection of raw materials for nest construction, food gathering activities, and so on. As with honey bees, hornets have developed different ways of communicating.

Chemical identification card or "colony signature"

The Asian hornet has molecules on its body that can be used to identify it. These molecules are made up of hydrocarbons, of which their cuticle is also composed. Beneath its surface are special cells which then migrate up to the surface of the insect's body and can be discharged out of the body through the molecules that carry them.

The detailed chemical composition of the cuticle of each individual in the nest represents a specific chemical clue by which the colony as well as the individual castes can be identified. By examining individuals originating from different colonies of *Vespa velutina*, it has already been possible to identify a number of different chemical compositions of the cuticle. As is the case with the honey bees, hornets have their own characteristic 'colony scent'. One could say that this **is a kind of chemical identification card that is specific to a given colony, to a certain caste, as well as to a certain sex. We can speak here of the so-called signature of the colony. As a result, any individual of a given colony who encounters his own kind can identify, by means of antennae, whether he is an individual of his own colony or an intruder.** It has been shown that in *Apis cerana* bees this chemical description can also have specific roles according to the activities that the individual bees have to perform in the nest (foragers, guardians...). Such diversification according to activities has not yet been identified in the individuals of the Asian hornet.



Queens are characterized by the presence of specific substances that are either completely absent in workers or are present in very small amounts in them, so that they have no significant effect on the functioning of the colony. These molecules form only queens. When the workers recognize them, this is a chemical signal that a queen is present. At the same time, the existence of these molecules hinders the development of reproductive organs in other workers. **In addition to their essential role, these substances also play a strong chemical barrier that prevents the loss of water in their body.** These hydrocarbons thus also play a protective function.

The main role in communication is played by pheromones, volatile compounds that disperse very easily in the air and spread over very long distances, even several kilometres from the point of release. When hornets recognise the given pheromone, they can immediately change their behaviour. Some pheromones enable the workers to be attracted to a particular location, while others play the role of triggering the insects' aggressiveness and aggressive behaviour. In Asian hornets, these are two basic pheromones whose composition we already know. They are the danger-warning pheromone and the queen sex pheromone.

The danger-warning pheromone is produced by hornets in their venom glands. They're composed of different molecules. Its job is to attract workers and attack the intruder. If a worker attacks a prey, it releases a warning pheromone that attracts other workers nearby, and together they seize the prey. Only females produce this pheromone, as they are the only ones in the nest with a venom gland.

Another important pheromone is the **queen sex pheromone**. Future colony founders produce complex compounds to attract males to mate with them in the autumn. Also, sex pheromones are produced by glands that open probably) at the level of the abdominal internal segments. Depending on the species of insect, males can trap these molecules for miles. **In the case of *Vespa velutina*, we already know the queens sex pheromone composition, but we do not know the exact distance of detection of these sex pheromones by males.**

A French-Chinese team of scientists led by the University of Tours in France, who have succeeded in identifying the exact composition of the sex pheromone, have developed a pheromone trap targeting only male *Vespa velutina*. The traps have already been tested in both China and France between September and November, the main mating season for hornets. The results of the testing have not yet been published.

In the *Vespa crabro* there is also another type of pheromone for locating food (ripe fruit) with which the hornet marks the bitten fruit and can return to it during the night. In this way, the workers of the same nest also pass on information about the location of the food. Hornets can gather food almost continuously.

Another peculiarity in the larvae of the *Vespa crabro* hornet is the way in which the larvae communicate hunger to the workers. The sounds spread across the webs in the form of vibrations, which the workers pick up with their antenna and feet.

2 · 5

Nest structure

The nests of Asian hornets are very precisely structured. They are the common work of all workers. What characterizes the building instinct in the nest of a social insect species is precisely the participation of a large number of individuals in certain activities. All workers participate together in the formation and structure of the nest, in a so-called self-organized manner.

The architecture of the nest has common structural elements as it is the case with other social insects of the hornet family. **The nest itself is something like a multi-storey building.** The multilayered cover of the nest is formed by curved coils. The cover protects the honeycomb from bad weather, cold or heat.

The queen, the founder of the nest, moves regularly between the floors of the honeycomb. It is up to the workers to care for the eggs that the queen lays in the cells. The nest is composed of several horizontal floors made of combs that have **brood cells built on the inside of the comb. These are open downwards, containing eggs, larvae and pupae. All the cells are identical,** meaning that we cannot tell from the shape of the cell whether a worker, male or future founder has hatched.

In the case of the hornet *Vespa crabro*, the first third of the upper combs are always worker cells, the remaining 2/3 are male cells and the lower parts of the combs are the cells of future queens. The differences in cell size are minimal, but the male cells differ from the worker cells by having convex caps. Observations and scientific laboratory experiments on the development of future queens have not been carried out yet.

Unlike bees and bumblebees, the hornet nest contains no food stores, so **the cells are used only for brood development.** The combs are held together by sturdy pillars. The workers gradually expand and enlarge the nest. They remove the old inner shell, which they recycle and use to build new honeycomb cells or outer shells. The outer shell is gradually layered and filled with air chambers that increase the nest’s thermal insulation properties. At the end of the season, a nest may have as many as twelve combs. The texture of the nest’s outer shell is multi-coloured, each colour coming from a different plant material found by workers in the nature.

At the end of the year, the nests of *Vespa velutina* hornets contain an average of 12,000 cells. In the case of the hornet *Vespa crabro*, it is only about 3 000 cells. Although a single Asian hornet colony may have thousands and thousands of cells built in its nest, we do not think that such a large number of individuals live in it at one time. In fact, there are only a few hundred of them during the breeding season. **Based on the results of experiments of hornet nests that have been frozen, removed and examined, on average there are about 2,000 individuals in a given time period.** If the primary nest is built in a confined space, the hornets will swarm and, along with the queen, build a secondary nest in another safe location.

***Vespa velutina* nests can be built in different locations and at different heights.** They can be found under eaves pipes, in cellars, in smokehouses, in garden houses, on building facades, under roofs, in birds' nests, in empty hives, in trees and even at heights of 25-30 metres. This is again a proof of the ability of *Vespa velutina* hornets to adapt to different living conditions.

Many nests are found along watercourses. In such areas it is not unusual to find a very high concentration of nests, i.e. **20 colonies per km².**

Nests exposed **in bushes or trees are shaped like water droplets.** The upper part of the nest is built in the shape of a cap. It is about one third the size of the nest. Hornets do not stay in this part. This part of the nest has a sponge structure and contains many air bubbles and parts of materials that are more compact than the rest of the nest. The cap serves as the roof of the nest and is protective of the entire colony against inclement weather. Nests built under a balcony or shelter, for example, do not have a cap, as it would be useless in well-protected places. Such nests are attached to several parts of the top of the nest, which at the same time prevents the construction of the cap.

Fig. Nest of *Vespa velutina* hornet in bushes. Source: Julien Vallon ITSAP)

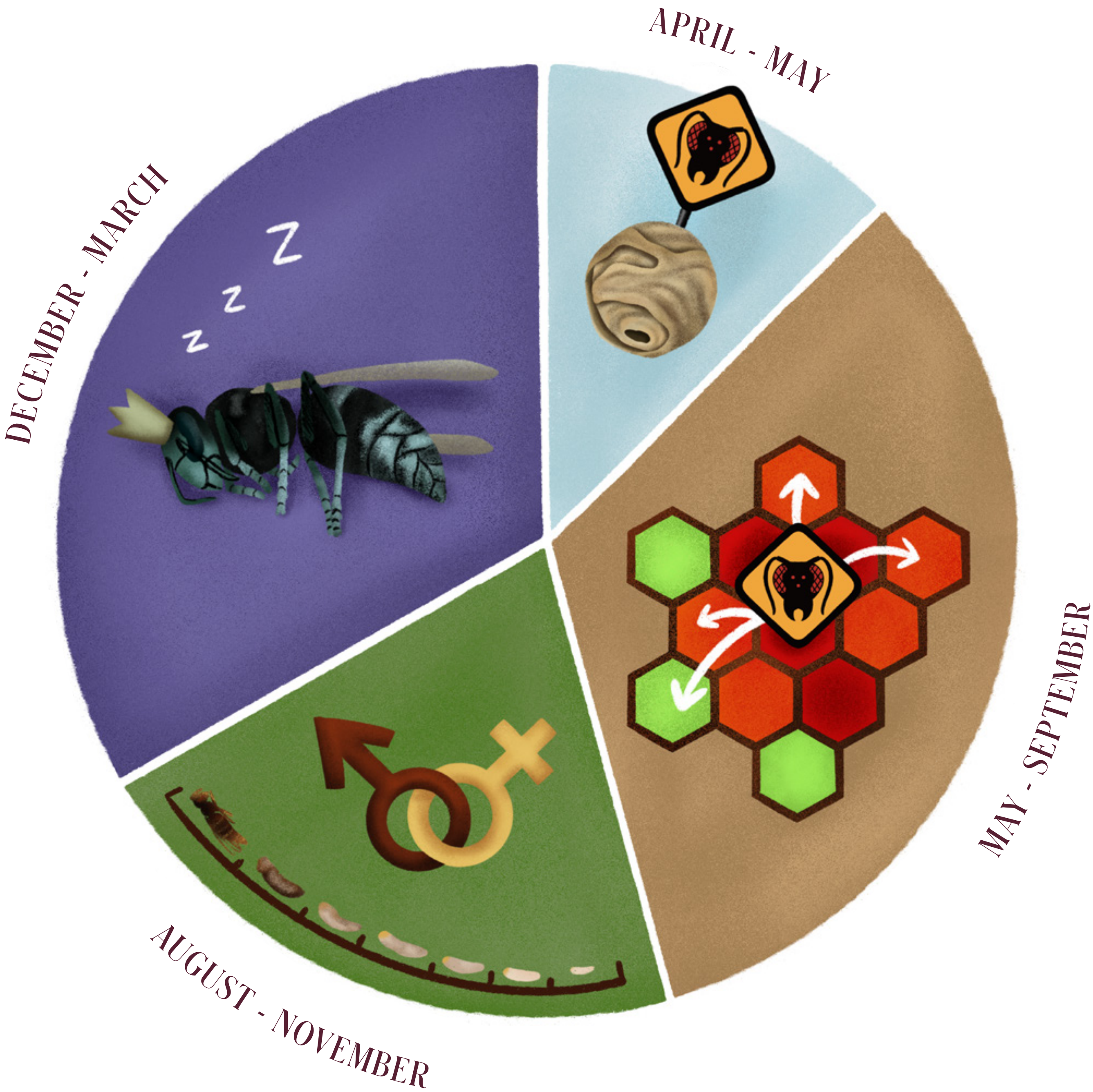
Young tree bark is the material most commonly used by Asian hornets to build their honeycombs and the inner parts of their nests. The workers first chew through the found plant parts, mixing them with saliva, making the bark a well-mouldable material resembling wet paper. The nest is wet and brittle at first, but over time it dries out, hardens, and changes colours. Gradually, the workers add more and more pieces of plant matter to the nest, making it larger and larger. The nest gradually dries out. The outer shell of the nest is made up of several coils that overlap and join together.

At the beginning, the nest is formed by a single female, the queen of the colony. It is about **the size of a tangerine and consists of about 12 cells on one small comb.** The workers constantly expand the nest by adding more and more cells around the edge of the nest, which can be up to 1 metre in length. **Such a nest reaches a size of 1 metre at the end of the year with a diameter of 70 cm and with about 9 to 12 tiers of horizontally arranged combs. Nests may be built in the ground, partly underground on river banks, but more often high up in trees or bushes.**

3 • BIOLOGICAL CYCLE OF THE ASIAN HORNET

3 • 1

Biological cycle of the Asian hornet



Inception

The primary nest building phase takes place in April. The queen and several dozen workers live there.

Development

The nest development phase runs from May to the end of August; many female workers hatch and the nest grows rapidly.

Reproduction

The reproduction phase lasts from the end of August and continues until November, when males and females (queens) hatch and mate with males during December.

Hibernation

The hibernation phase of queens always takes place outside the maternity nest. At the same time, the original maternity nest disappears during this period.

At our altitudes, the vast majority of hymenopterous insects do not overwinter. The nests are emptied, their inhabitants die and are no longer replaced by new individuals. The original queen perishes along with the other workers. This causes the rapid decline of the entire colony. The queen was the only one who laid eggs and could produce workers and new queens. This end applies to the wasps, hornets and bumblebees.

In January, there are no more individuals in the nest. The queens are in hibernation from December till March. They wake up in spring during the first warm days in April and May and build a primary nest with the first twelve or so cells in which they lay their eggs. From May to September, the nest enlarges, many new cells are added and a large number of workers hatch daily. At the end of August and beginning of September, the reproductive period begins. The males hatch first and a few days later the future foundresses of the new colonies hatch. From October to November there are only a few hundred workers in the nest and hundreds to thousands of sexually mature individuals, i.e. males and future queens.

One of the studies conducted in France showed the composition of the nest in autumn. Scientists found an average of 350 future queens and 900 males in the frozen and examined nests.

Once the queens have hatched in the nest, they feed on the vomit of the developing worker larvae to build up their fat bodies. Well-fed queens leave the nest and mate with males outside the nest, usually in the treetops and bushes. They fly even several kilometres from the maternity colony to avoid inbreeding. After the mating act, they never return to the original maternity nest, but seek a suitable shelter to overwinter. They are awakened by warmer weather and the need to replenish their food supply and instinct to establish their own nest and colony. In the original nest, the queen dies after the young queens hatch and larval mortality increases sharply. The workers neglect to feed them and cannibalism occurs and the weather causes the whole colony to extinct.

3 • 2

Nest building and the colony development

Everything begins in spring because the climatic conditions begin to be mild. The female, the nest founder, who has survived the winter, will form a primary nest or sometimes called the basic nest. It is generally hidden from bad weather and predator attacks. The material used to build the nest consists of plant fibres that the queen gathers from trees. She must first grind them up with the pair of teeth and add saliva secretions to them. The primary nest is fragile, moist, about the size of a tennis ball (or a tangerine). The nest looks as if it was made of paper. The queen first establishes the primary structure vertically attached to some support (e.g. the wall of an abandoned nest or under the roof of a house) and then she builds the first 12 or so cells on the innermost parts of the primary nest. The cells are oriented downwards. The female forms an envelope of three coils around the cells. The opening of the nest always faces downwards.

Fig. Primary nest of *Vespa velutina*

The queen lays only one egg in each cell at a time. After four or five days, the white larvae hatch and remain stuck to the bottom of the cell and begin to ask for food from the queen. The queen feeds on malt, collects nectar from plants and hunts insects to feed her hungry offspring. The larvae then go through four stages and grow rapidly. Unlike vertebrates, which present gradual growth, insects grow discontinuously. The moment their cuticle is too small and restricts their growth, they have to get rid of it. Between each moulting, insects go through developmental stages in which their bodies enlarge. The larval stage ends when the larvae fills the entire cell and its body is stuck against the walls of the cell. At the end of the last larval stage, the larvae makes a cap with the help of saliva secretions and closes itself in the cell. Subsequently, a fifth moulting occurs, with the larvae developing into a pupa. At the end of the pupal stage, the individual becomes an adult. Freshly hatched workers rest in the nest for 24 hours, waiting for the cuticle to harden. They then take over the care of the offspring, expanding the nest, ventilating it and guarding it. After 3 to 4 days, they also start flying outside the nest and bring food for the larvae. They use their gnawing mouthparts to bite through the thin cap to get out of the cell. Workers sometimes help the hatchlings to gnaw their way out of the cell. Immediately afterwards, the workers remove any debris at the bottom of the cell so that the queen can lay another egg in it. At the bottom of the cell we can see a tiny dark blob that gradually grows as the larva gets bigger. This is meconium, the remains of the metabolism of the larvae and pupa, which gradually dries.

Nests from the previous year are never reoccupied by queens because they pose a risk and can be a source of disease.

Fig. Primary nest of *Vespa velutina*. Source: Francis Ithurburu

One of the key factors that allows hornets to be very successful predators is their ability to thermoregulate their nests to a constant temperature of around 30°C, even when ambient temperatures are lower. When temperatures peak in the summer months, the workers ventilate their nests. They give the water brought to the nest into the amniotic cells and by vibrating they try to exchange the hot air for a cooler and wet one.

Initially, the queen does all the tasks on her own. Thus, it is impossible for her to build a large nest and keep it at a stable temperature that allows worker hornets to develop from egg to adult. The queen will therefore only build a nest that she is able to heat and defend with her own body and defend it against enemies. The eggs and larvae are at the bottom of the cells in the comb. The queen warms the eggs and larvae with her body and is closest to their needs, which are mainly food and warmth. When the outside temperature rises, the queen regulates the temperature by flapping her wings. Gradually, as the number of workers in the nest increases, so does the nest itself.

3 · 3

Colony foundation – the primary nest

The picture depicts an Asian hornet queen completing her primary nest. Source: Francis ITHURBURU

The period of establishing a new nest takes approximately 30 to 50 days before the first group of workers develop. This colony period is very critical for the continued development of the colony. The queen is on her own to provide all the activities necessary for nest establishment and development. Firstly, it is the building of the primary nest, which includes the collection of natural materials for nest construction, egg laying, nutrition and care of the developing brood, nest cleanliness, control and maintenance of the nest temperature as well as the nest defence. Any event can cause the death of the entire nest. During this period, many colony foundresses get into competition with each other and into fights, which often end with the death of one of the females in order to take over the nest already built by another queen, the founder. In this case we speak of the so-called usurpation of the nest by the queen or intraspecific parasitism. The foreign queen runs a great risk in these attempts, because the workers may kill her while defending their own nest. She therefore tries to disable the oldest workers first to weaken the defence. When the original queen goes to defend the nest, she is attacked and there will be a fight to the death between them.

It is quite common to find the remains of female foundresses on the ground, inside or near the primary nest. **This phenomenon is common in hornet insects, providing natural population control of the number of colonies in a given area.** Other dramatic situations can also cause queen's death. She may be eaten by a bird of prey that is a predator of hornets, she may be struck by a pathogen - bacteria or viruses, or she may be killed by a parasitoid (organisms with a parasitic larval stage that develop in the body of a living host, which they also kill while parasitizing. Parasitoids are only found among insects, most commonly in hymenopterous insects). If the queen survives, her colony may develop during spring and summer.

3 • 4

Nest expansion and colony development – the secondary nest

After some time, when the first workers hatch and can perform the various functions for the survival of the colony, the queen quickly reduces the number of trips out of the nest, thus limiting the risk of her own death and gradually just lays her eggs inside the nest. Like other species of hymenopterous insects, the colony increases in both length and width. It contains only females, some of which are only workers and later future founders of new nests and colonies.

Fig. Secondary nest of the hornet *Vespa velutina*. Source: D. Laurino

3 • 5

Reproduction

The picture displays Asian hornet queen completing her primary nest. Source: Gilles San Martin

From mid-September to early December, the colony enters into the reproductive phase and produces individuals capable of breeding. At the end of November, the nest reaches its peak of development. At first, only the queen, founder of the colony is in the nest, gradually the number of workers unable to reproduce increases. From mid-September onwards, mostly the males hatch and in early October the queens - future foundress females hatch.

During the sexual maturation period, males and females remain in the nest for several days to feed well and build up a fat body that will allow them to overwinter and establish a new nest in the spring. In general, the hymenopterous insects mate well away from their maternal nest to avoid inbreeding.

In the case of the hornet *Vespa crabro* as well as *Vespa velutina aureria*, we know that the males gather in large groups in low bushy trees where they wait and capture the sex pheromones of the queens. Mating of *Vespa crabro* hornets has been observed and it takes place mostly on low bushes or on the ground, and the queen is gradually fertilized by approximately two to three males.

After mating, males quickly die. The future nest founders store the acquired spermatozoa in a spermatheca, they disperse into the surroundings and look for a sheltered place, e.g. in a cellar, in a wall, in a tree cavity, under a lot of branches, in an old building, in a hive, in a garden house, on dry land, and so on. Their only aim is to overwinter in a sheltered hiding place. They put themselves into a typical sleeping position: their wings fall freely down alongside their body to avoid damage. Their tongue and legs are tucked down under their abdomen. The antennae are also tucked under the body. Their body temperature during hibernation is around zero.

3 • 6

Extinction of the colony

As can be seen in the picture on the left, nests of Vespa crabro hornets can also be found side by side, for example in an abandoned house in the attic or in old barns. This is due to the limited number of natural cavities in old trees in the area.

Fig. Nests of *Vespa crabro* in the attic of an abandoned house. Source: Richard Šnìder

The original queen, founder of the colony, dies at the end of autumn (in November at the latest). From this moment, the entire nest begins to decline. It even goes through a certain period of anarchy. The queen dies and the workers start laying only haploid eggs, because they were never fertilized. This behaviour has not yet been observed in the queens. In certain species of hornets, e.g. *Vespa crabro*, the workers stop feeding the larvae and pull them out of the cells to throw them out of the nest. During the season until autumn they clean the nest and pull out the sick or otherwise damaged larvae. In times of food shortage, they behave in the same way. They get rid of larvae that would otherwise be malnourished. It is possible that this type of behaviour also occurs in *Vespa velutina* during December or January, but we do not have scientific evidence for this yet. The nest gets empty and its inhabitants die generally before the Christmas period. In January, the nests are mostly empty and disintegrate due to the bad weather. Depending on climatic conditions, we may also find inhabited nests at the beginning of January. It has been found that in France, the average lifespan of a single colony of *Vespa velutina* is 8-10 months, whereas the lifespan of *Vespa crabro* hornet colonies is shorter. Queens build their nests later in warmer days in April or beginning of May and they die earlier (at the end of September or in October). The biological cycle of the hornets lasts about 6 months.

As it can be seen in the picture below, the nests of *Vespa crabro* hornets can also be found side by side in, for example, an abandoned house in the attic or in old barns. This is due to the limited amount of natural cavities in old trees in the area.

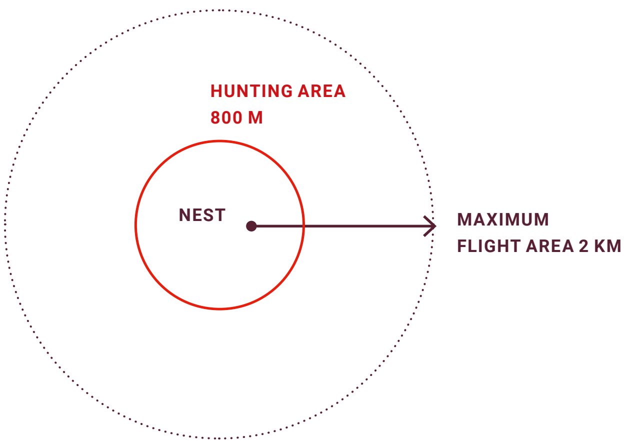
Due to the impact of bad weather, nests completely disintegrate and it is relatively easy to tell whether a nest is active or not. It is enough to look at the inner part of the nest, which is the most sensitive. It is just below the combs, where the larvae, pupae and workers develop, who look after the brood. Anything that can fall out of the nest or what is liquid, such as water in the nest, any liquid substances are potentially aggressive and will accumulate in the inner part of the nest, gradually breaking it down. The nest envelope will completely disintegrate and the nest will break away from its original attachment.

In colonies that are still active, such processes do not occur because workers are constantly cleaning, repairing and maintaining them, including the nest envelope. If the interior of the nest crumbles and falls to the ground, and if we can see the combs with our eyes, it can be assumed that the nest is empty. Unlike *Vespa crabro*, whose colonies are empty long before Christmas, the Asian hornets can survive until the beginning of the new year, even into February of the following year. The most likely theory is that favourable climatic conditions extend the biological cycle of otherwise annual hornet nests. This may also be influenced by the fact that the Asian hornets seek more urban environments, where they are more protected and the outside temperature is slightly higher than is the case in the forest habitats, where the hornets are more common. These are more often found in forested and therefore slightly cooler environments, less protected, than is the case with *Vespa velutina*.

3 • 7

Nest occurrence and its localization

If we see one or more hornets attacking hives or collecting malt, the question is where their nest is located. Is it only a few tens or hundreds of metres or even kilometres away? This question is crucial for beekeepers who have spotted hornets on their apiary. So where is their nest? From what distance are they able to gather food for their colony? What is the hunting speed of the hornets and the method of hunting?



To be able to determine this distance, the scientists used two different techniques. First, a method was tested where a bee colony was placed close to a hornet nest and the worker hornets were equipped with a radio frequency identification, called an RFID tag, to track their daily flight activities. Flights away from the nest took place at different times during the day, with an average (out)flight lasting around 14 minutes. In the case of some females it was as long as 14 hours. Flight abilities were subsequently analysed in the laboratory. Worker females were tethered to the trunk, which allowed them to fly in that direction. The system was connected to a computer that measured the time and speed of flight as well as the distance travelled. This technique made it possible to determine the average flight speed of the workers of *Vespa velutina* which was, 1.56 m s-1. In case of *Vespa crabro*, their speed is slightly higher and reaches approximately 1.8 m s-1.

When the researchers combined the length of time the hornet stayed away from the nest with the average flight speed, taking into account the hornet's return to the nest, they found that the worker Asian hornets fly no further than 1 km from their nest. **Their hunting area is actually smaller and is around 800 m from their nest.** Of course, the workers are capable of flying much further, which they certainly do. However, if they find a suitable food source close to their nest, they have no need to move away from the nest and fly further.

4 • RELATIONS BETWEEN HORNETS AND BEES

4 • 1

Food for the Asian hornet

Some might think that hornets only feed on bees. This is partly true; worker hornets themselves do not eat insects. So who feeds on hunted insects?

Actually, it is only the workers that are responsible for collecting and bringing food, both sugar and protein components. Just as honeybees, the hornets also need sugars and proteins for their life. Predominantly, honeybee brood and maturing young bees take in protein from the pollen they collect and process. The flying bees, in turn, need energy to fly, so they consume more sugars. In both cases, food intake depends on the season as well as the situation the colony is in.

Recall the earlier mentioned biological cycle of the hornet. The colony founder survived the winter. During this period of hibernation, in which her metabolism is slowed down, she has used up all her fat reserves. When she wakes up, she is relatively starved and quickly needs to take in energy, sugars. It extracts nectar from the flowers. After she builds the primary nest and lays a few eggs from which the first larvae hatch, she is forced to collect not only the sugary components of the food she feeds herself but also the protein components she feeds the larvae. The queen has to hunt for insects and brings the processed prey to the nest, where the hungry larvae are already waiting for her. Later, the queen is replaced in this activity by multiple groups of adult workers who provide all the activities the colony needs. The queen just lays eggs. This is the time of year when beekeepers become aware of the problems with hornets invading their bee colonies.

Bees are not the only source of protein food for *Vespa velutina* hornets. Any insect is a potential food source and can easily become prey and food for the hornet larvae. Food the workers bring to the nest also may contain over 150 types of different insects. Hornets are in fact omnivores. It is true that if they find a hive that is available to them and they have thousands and thousands of prey in it, they will take advantage of the situation and attack the hive. One by one they attack one colony after another, regardless of whether it is a sick, weak or strong colony. *Vespa velutina* hornets attack in groups of 20 - 30 or even 50 individuals, communicating with each other as they hunt by the help of the antenna.

Compared to the hornets, the Asian hornet represents a completely new dangerous experience for the honey bees in Europe. Evolution has not taught them to defend themselves against attacking insects that hunt in groups and are much larger than honey bees. Moreover, honey bees in Europe have been bred for gentleness and non-stinging for more than 50 years, which may also be why they are an easy prey for the predatory behaviour of Asian hornets.

The breeding season (September and November), is when most of the individuals capable of breeding hatch. After hatching, they remain in the nest, feeding on larval excretions that contain nutrients. In this way they are able to build up a large fat body for overwintering. It is at this time of the year that the second peak occurs, when bees appear in large numbers on flowers, and the beekeepers record a second period of hornet attacks on their apiaries.

4 • 2

Hunting the prey

Fig. *Vespa velutina* hornet peering into the opening of a honey bee hive. Source: Julien Vallon (ITSAP)

Fig. *Vespa velutina* hornet with its prey. Source: Julien Vallon (ITSAP)

The negative impact of hornets on bee colonies is already widely known. *Vespa velutina* hornets attack bees in groups and relentlessly. They are opportunistic insects that also feed on decomposing vertebrate. They hunt bees very successfully and can kill large numbers of worker bees in a short time. With this intention, they localize the hive. They circle around the flyers and are in the "ready to attack immediately" position. They linger in the air in one spot, waiting for the worker bees to arrive with a load of pollen or nectar. They wait for the flying bees to approach the flyer to pass the food to the bees in the hive and attack them. They catch them while still in flight. In this attack, the bees try to use their faster flight skills to escape the hornets.

Vespa velutina hornets have very good group hunting tactics. The number of hornets in front of the hive is very variable from 1-2 to 20, 30 and even 50 attacking at the same time. Once a bee stops flying, it can no longer take off quickly, which the hornets take advantage of. With the bee captured, the hornet settles on a nearby tree branch, quickly separates its head from its chest, and then begins to gradually quarter the entire bee. It removes all the parts of its body that are not nutritionally important (head, legs, wings and abdomen). The aim is to process the prey in such a way that the worker takes only the chest muscle to the nest in the form of a kind of mush. The hearty "stew" brought in is food for the larvae.

4 · 3

How other bee predators hunt bees

As can be seen in the pictures on the right, the nests of *Vespa velutina* are much larger (about 100 cm) compared to the size of the nests of *Vespa crabro* (from 30 cm to 70 cm).

Fig. Left: Nest of the *Vespa crabro*. Source: Richard Šnídеr. Right: Nest of the *Vespa velutina*. Source: Julien Vallon

In fact, the hornet and the German wasp, or even the common wasp, do exactly the same thing. They capture bees using a different technique. The *Vespa crabro* hornet will stand opposite the hive to catch a bee on the flyer, while the Asian hornet, *Vespa velutina*, tries to catch a bee in flight, before it lands on the flyer. Like *Vespa velutina* workers, also *Vespa crabro* workers decapitate the bee's head, limbs, wings, and abdomen, retaining only the thoracic portion. The main difference in hunting tactics is that both wasps and hornets only capture bees in small numbers in front of the flyer and do not attack in groups. The German wasps hunt weakened and sick worker bees both inside and outside the hive. The German wasp is more of a biological sanitizer that will not kill a healthy bee for the most part in late summer.

The number of larvae that Asian hornet workers have to feed in the nest at the end of the summer is much greater for *Vespa velutina* than it is for *Vespa crabro*. Sexual individuals in Asian hornets develop at the same time as the honey bees are preparing for overwintering. The food supply to the *Vespa velutina* hornet nest is greatly increased between September and November, as the *Vespa velutina* nest is capable of producing up to 500 queens, which need substantial fat reserves to overwinter and establishing a new colony. The bees in the hives are a very easy prey for them.

As can be seen in the picture below, the nests of *Vespa velutina* hornets are much larger (around 100 cm) compared to the size of a *Vespa crabro* nest (from 30 cm to 70 cm).

Another danger to bees is when several different colonies of *Vespa velutina* hornets attack a single colony. French beekeepers record several worker Asian hornets in a hunting position on the apiary, positioned in front of the hive, with mutual contact sometimes seen. The workers either show no particular behaviour or are extremely aggressive with each other. It is highly probable that **in the former case some of the hornets come from the same colony, while in the latter case there is competition between individual workers from different nests attacking the same bee colony. It is not uncommon to see hornets leaving with their prey in different directions, which also tells us that they fly to different nests.** In fact, these mutual attacks only last for a very short time, when the hornets approach each other as if sniffing each other, identifying their mates and analysing the "who's who" situation.

4 · 4

Defence mechanisms of the Asian honeybee against the Asian hornet

Fig. *Vespa velutina* hornets attacking a hive of honey bees. Source: Julien Vallon

In China we can find up to 9 different subspecies of hornets, of which *Vespa velutina* is only one subspecies. *Vespa velutina* is a local species and engages in many interactions with its surroundings, its native habitat, so even the predator-prey relationship has been stabilised for a long time. *Vespa velutina* is also a potential prey for other predator species, including viruses, bacteria and other hornet species, e.g. Vespa mandarina hornets, which also eat *Vespa velutina* hornets.

According to the scientists and beekeepers in China, the eastern bees Apis cerana are able to defend themselves to some extent if they are not attacked by groups of hornets at the same time. Asian honeybees have co-evolved with various species of hornets, including *Vespa velutina* and have built up defensive techniques over many thousands of years that are relatively effective.

The first defensive technique is that a few dozen bees spread out and block the entrance to the hive, then beat their wings regularly and synchronously, and also use their abdomens to create strange movements. With their weight they seem to roll the whole group of bees from the centre to the periphery. Some observers assume that this behaviour disturbs or disorientates the Asian hornet and prevents it from catching a particular bee. Others believe that this movement creates a special vibration that allows the worker bees to be scared off at a great distance so that they do not return to the hive because a predator is present.

Apis cerana workers use also another technique that is slightly less exceptional. A few dozen worker bees are thrown at an attacker and form a so-called thermal sphere, which they use to cover the hornet. The temperature of the thermal sphere must rise to 47° C, which is already a lethal temperature for hornets. Although the high temperature of the thermal sphere will kill even a few bees in close contact with a hornet, the colony as a whole will survive.

Despite some observations of how the bees and hornets behave in French apiaries, there is still no scientific evidence that honey bees of European type are able to defend against these Asian hornets. Rather, they try to kill the aggressor by stinging it to death. Remember that the greatest danger associated with *Vespa velutina* hornet attacks is that they attack in groups. And against such hornet hunting tactics, our much milder honeybees don't have a chance.

It's worth noting that even Apis cerana bees have not developed perfect defensive tactics, as the Asian *Vespa velutina* hornets attack in groups also in China. If the number of attacking hornets exceeds the number of defending bees, even in the case of Apis cerana bees, the colonies cannot defend themselves. In this case, the only effective defender of the colony remains the beekeeper himself. What the beekeeper can do against attacks by *Vespa velutina* will be discussed in a separate chapter.

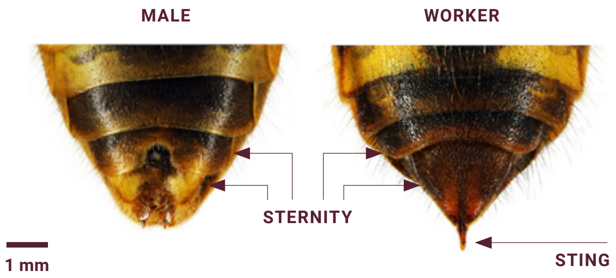
5 • COEXISTENCE OF HORNETS, BEES AND HUMANS

5 • 1

Coexistence of hornets, bees and humans

A nest of the Asian hornet. Source: Père Igor

The worker hornets of the Asian hornet have a sting with which they defend themselves and their colony. Only females have this sting and are able to attack. Males do not have a sting and therefore they are not engaged in any defence.



The sting is located in the elongated part of the abdomen, or at the end of the large venom gland, which is located in the abdominal part of the body. At the moment of the sting, some of the contents of the venom gland is expelled into the victim's body. This venom is a mixture of many molecules that are chemical in nature and have different physiological functions. So far, several studies have been carried out to determine the exact chemical composition of the *Vespa velutina* venom. **All we know is that there are 293 genetic sequences in the venom gland of *Vespa velutina***, which contain neurotoxins, proteases (enzymes that break down proteins), proteins that have antimicrobial effects and various protein peptides. Many other molecules have been found in the Asian hornet venom, such as bioamines (histamine, binamine, catecholamine), ketones, alcohols, carbohydrates and other substances. The composition of its venom is very complex and identifying the exact composition still remains a burden on the shoulders of scientists.

5 • 1

Behaviour of the European hornet

Venom of the Asian hornet is not more dangerous than the venom of German wasps or other hornets. It all depends on the victim and its individual ability to resist the venom that enters the body. A person allergic to the venom of the hymenopterous insects will probably also be allergic to the venom of the Asian hornet. However, it can be said that hornet venom is dangerous for everyone, even without the risk of developing a strong allergic reaction, because it contains a number of toxic molecules. It is not uncommon to find that people who have been stung by the Asian hornet have necrosis or severe swelling in the sting zone. In the case of a bite, it is possible that the body reacts with serious vascular problems such as a small stroke, which suggests that it is not advisable to take an Asian hornet bite lightly. In the case of multiple stings, these effects are compounded by the amount of venom injected.

In Europe, most people are very fearful of hornets. Once upon a time, bee colonies lived in deep forests in the hollows of large trees that were widely separated. In the same forests, even in the same hollow trees, bees lived alongside the hornets. Nowadays, beehives are located in areas that are not very suitable for their breeding and are often located close together. In many European countries, large hollow trees are no longer found at all, so hornets do not have a natural place to build their nests. When there is a lack of natural insects in the environment, for example due to pesticides used in agriculture, forests and gardens, bees are sometimes the only alternative food for hornets, which encourages beekeepers to eradicate them. Howevere, we have to say that the presence of European hornets in the vicinity of beehives has also positive aspects. Hornets, *Vespa crabro*, free the colony of intrusive insects such as wasps and wax moths. Hornets hunt bees only singly and never in groups. The prey are mainly flycatchers, which return to the hive and are saturated with nectar. On the flyer, the bees defend themselves by trying to grab the hornet by their legs and prevent it from escaping to safety. Several bees attack the hornet, biting it or stinging it with stings, resulting in the hornet dying in front of the flyer or at the bottom of the hive.

The public is little aware of the important role for the biological balance that the European hornets play in our conditions. They keep the population of various insects in balance, especially flies, which are harmful to animals but also to certain species of plants. For this reason, some cattle farmers in Germany and Austria are putting up insect wooden boxes for hornets to nest in and to help farmers eradicate the overpopulation of flies that harass cattle. By trapping these flies, the hornets themselves limit the overpopulation of harmful insects on farms and reduce the health risk these flies pose to livestock. Hornets also reduce the amount of pesticides farmers have to spray on their cattle. **The hornet *Vespa crabro* is therefore in some countries considered as a biological tool against parasites of the cattle**.

Vespa crabro hornets also maintain links with other insect species. On the oak trees, they are fond of searching for sap, the sweet juice oozing from the open wounds of the trees. The sap is irresistible to them, and it also contains minerals and nutrients that the tree distributes through its roots into the tree crowns, and the hornets need to receive it. Not all of the trace elements they can procure from the sweet juices and the insects they catch for their larvae. They keep wounds in trees open at all times, providing an important link with hornbills, bearded hornbills and some species of butterflies. The adult hornbill feeds specifically on sap and, thanks to the hornets, has it readily available at all times. Without their help, it would starve to death during its short life. As we can see, everything in nature is connected.

Fig. Hornbill and hornet *Vespa crabro*. Source: Richard Šnídér (SOŠ Pod Bánošom)

Hornets never attack humans without cause. As long as we don't tease them or destroy their nests, they are peaceful and can be approached in close proximity to the nest when moving slowly. It is important not to hinder the hornets in their flying out, not to breathe in the direction of the nest and not to make unnecessary fast movements. The principle applies that if we leave them alone, they will not notice us. Even if they nest in an inappropriate place and disturb people, this does not always have to be dealt with by destroying the nest. If a nest is available, there is also the option of moving the community to a more remote location. In the case of Vespa velutina hornets it is different!

Fig. Nest relocation of *Vespa crabro* hornet. Source: Richard Šnídér

5 · 2

Behaviour of the Asian hornet

***Vespa velutina* hornets have negative impacts on the biodiversity of European countries.** At the peak of the season (September-November), between 1,500 and 2,000 individuals live in the nest, of which up to 500 may be queens that need to be well supplied for overwintering. One colony of *Vespa velutina* consumes more than 1 million of various insects per season. Hornets are well known for their attacks on various species of hymenopterous insects. Studies in France demonstrate that *Vespa velutina* feeds on insects as well as mammal and bird carcasses. The prey spectrum consisted of 59% hymenopterous insects [of which bees (Apidae) represented more than 35%, 32% dipterous insects, and 9% others (orders of Hemiptera, Orthoptera, Lepidoptera, Mecoptera, Trichopetra, Coleoptera, Heteroptera, Neuroptera, Dermaptera, and Blattaria). The prey collected in different areas varied considerably. In urban areas, hornets prey primarily on honey bees, which are abundant due to the trend of urban beekeeping. They sometimes account for up to 70% of hornets' prey. On the contrary, in forest areas the honey bees form only around 30% of hornet´s prey.

***Vespa velutina* hornets have an excellent ability to adapt to new environments.** In addition to insects, hornets also need large quantities of sugars. In summer, when there is a lot of fruit there are also a lot of hornets, when they can do a lot of damage by biting the fruit, which gradually succumbs to monilial rot. Once the damaged fruit has been removed, the hornets find more new fruit, so the damage increases. Fruit growers have found it useful to leave the damaged fruit on the trees so that the hornets do not bite the next ripe fruit, as the fruit ripens quickly. Similarly, working in vineyards and orchards can be dangerous for humans. *Vespa velutina* makes its nests in bushes, in the ground, as well as in trees. **Areas with intensive fruit growing are most at risk.** *Vespa crabro* hornet is mainly confined to forest ecosystems, tree hollows or abandoned barns. *Vespa velutina* hornets prefer warmer places and are not bothered by the proximity of humans, which is why their nests are often found in close proximity to human dwellings, in garden houses, and children's garden houses and climbing frames are no exception.

Stings by *Vespa velutina* hornets are not fatal, but caution is advisable. In terms of potential danger to humans, the *Vespa velutina* is not considered to be more aggressive than the hornet *Vespa crabro*. However, several cases, including fatal ones, are recorded worldwide each year, confirming that the Asian hornet is the more aggressive insect species. Since the hornets arrived in France, the number of *Vespa velutina* hornet stings has increased, but not dramatically. Stings can range from cases that require no hospitalization to very rare cases that end in death. Since the appearance of *Vespa velutina* in France, the media and news have become part of dramatizing the situation and sometimes causing exaggerated fear in people. Serious attacks only occur when colonies are disturbed, and because most *Vespa velutina* nests hang very high in trees, such accidents remain rare. **No study published to date indicates that the number of victims in France has increased.** Deaths only occur if the victim was bitten by many hornets at once or if the persons had a severe allergic reaction. These extreme cases also include stings by species other than the European hornets or wasps. There is some concern about the risk of fruit pickers being stung while picking fruit.

Vespa velutina is also considered a relatively aggressive insect species in Indonesia and Vietnam due to the fact that it builds its nests mainly in houses where there is a high concentration of people. Studies published in 2008 in Vietnam reported that 55% of cases requiring hospitalisation were caused by the sting of *Vespa velutina* hornets.

In China, *Vespa velutina* is not a major problem. The species that the inhabitants of that country are really worried about is Vespa mandarina. Their workers can measure up to 5 cm. In certain years when Vespa mandarina became overpopulated in China, the number of hornet attacks on humans really increased. In 2012, a study was conducted on a sample of 1,640 people who had been stung by this hornet in Shaanxi province (in northwest China). It showed that these people had varying degrees of medical problems. Approximately 40 people out of a total sample of 1,640 died at the end. In Japan, this species of the Vespa mandarina hornet is responsible for about 30 to 50 deaths annually. In Europe, the Vespa mandarina hornet has not appeared or were not identified yet. In 2020, the Vespa mandarina hornet has already been found in North America, in the state of Washington, which has caused great concern about its gradual spread.

A harmless solitary wasp, the giant stinging wasp (Megascolia maculata), living in Europe, measures about 5 cm, and this can also cause in people worries that it is the Vespa mandarina hornet. It may be mistaken, but there is nothing to worry about this insect.

What about the beekeepers themselves when they are working on the apiary, how do they perceive the presence of hornets?

The Apis mellifera bees are the most common prey of the Asian hornet in Europe. The arrival of the non-native hornet *Vespa velutina* in Europe is also harmful to beekeepers themselves. Many have witnessed colony collapses caused by hornet attacks and have given up beekeeping. Society is thus losing pollinators and honey production, not to mention the fact that beekeeping represents not only a livelihood for many, but a lifestyle that they are losing.

Group attacks by *Vespa velutina* hornets on bee colonies can disrupt the dynamics of nectar and pollen collection very significantly. The presence of a predator in front of the hive causes worker bees to remain on the flyer to protect their entrance to the hive. They form the so-called bee beard. Hornets are constantly present in greater numbers in front of the flyer. **During the presence of hornets, the number of bees that dare to fly out to collect food gradually decreases. The queen in the hive stops laying eggs and the number of winter generation of bees decreases. As a consequence of the bees' reduced foraging activity, the bees are paralysed and the colony gradually begins to starve.** In some cases, this behaviour can be extreme and cause a complete **interruption of collecting activities**, resulting in a reduction of the stock in the hive and death of bees. *Vespa velutina* has become another factor in the increased bee mortality mainly in western Europe.

However, we have little economic data on the actual losses to beekeepers. In some areas of France, e.g. near Lyon or the Bordeaux region are more often connected with losses of bee colonies caused by hornets. Colonies rarely die when infested in autumn, but only during the winter due to too few bees in the winter clump, lack of stores due to "foraging paralysis" in autumn.

One questionnaire study on the *Vespa velutina* hornet in France in 2013 focused on the damage caused by the hornets as well as the behaviour of the hornets on the hives. In the first place, the answers showed that hornets caused damage to all bee colonies on the apiary (80% of the observed cases) and not only, as one would expect, to sick individuals. The second thing that emerged was that the increase in the number of bee colony deaths in the three consecutive years following the discovery of the first *Vespa velutina* nests was likely to have had an effect on the increased number of colony deaths in France. Hornet attacks weakened the colonies, which did not survive the winter as a result of stress and poor stocks. Possible explanations that could account for these increased losses of bee colonies due to hornet attacks are:

1

Reduction in the number of worker bees in the bee colony.

2

Reduction in the amount of honey and pollen reserves, even starvation of the entire bee colony.

3

Increased stress of the bees, including the queen, who will inhibit egg laying or stop laying eggs at all.

Beekeepers and scientists in France are outraged by the government's inaction, as they have been left without financial assistance for the destruction of nests, without the necessary legislation, without necessary equipment for the hornet research and also without compensation for damages caused by hornets. In some French regions, coordinated action plans are being set up and municipalities or towns are already allocating funds for the destruction of nests.

Considering the facts and the many problems that some western countries in southern Europe have to deal with in connection with the spread of the Asian hornet nests, it is necessary to prepare in advance for the possible introduction of this Asian insect predator into our territory. The warnings of the French beekeepers and scientists may seem exaggerated, but educating the population, especially beekeepers, fire fighters and other emergency services of the country not only in the biology of the Asian hornet, but also in the different types of measures to monitor, control and eradicate the spread of the Asian hornet in Europe, seems important. A separate chapter of this publication is devoted to this purpose.

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2

A TECHNICAL GUIDE TO MONITOR, CONTROL AND PREVENT THE VESPA VELUTINA NIGRITHORAX IN EUROPE

CONTENT OF PART II

ABBREVIATIONS AND UNITS OF PART II

Artificial Intelligence	AI
Invasive Alien Species	IAS
Black Queen Cell Virus	BQCV
Carbon dioxide	CO_2
Deformed Wing Virus	DWV
European Commission	EU
Kashmir Bee Virus	KBV
Machine Learning	ML
Kilometers	km
Meter per second	m/s

ABOUT PART II

The following technical guide presents an overview and describes selected strategies, measures and techniques to **monitor, control, and prevent the invasive *Vespa velutina*** (Yellow Legged Asian hornet or Asian hornet) in affected countries in Europe. This guide is part of the work of the international ERASMUS+ project **"Education, Training and Capacity-Building in the Field of Beekeeping and Civil Defence Services"**[1], and it is intended for relevant stakeholders, such as beekeepers and their associations, pest control organizations, environmental and health authorities, civilians, and other interest groups; to guide, develop and improve existing coping mechanisms to deal with *Vespa velutina*. In particular this document shall complement trainings during the project duration, targeted to delegates from 4 EU countries and various sectors, especially from apiculture and veterinary as well as from voluntary and professional civil response.

This guide brings together the main results of work conducted from January to July 2022, which included extensive literature and desk research of relevant information from science and practice, as well as the exchange of information with stakeholders and experts from Austria, France, Germany, Ireland, Italy, Spain, and Switzerland. The authors of this work express their gratitude and appreciation to the experts, for their excellent collaboration spirit, and for their valuable contributions with insights, information, graphics and photos for this guide.

The handling of the *Vespa velutina* is, in light of its likely further expansion into more European countries, an ongoing, changing and dynamic challenge, therefore this guide does not claim to be an ultimate compilation of all the information possibly available since the first observation of *Vespa velutina* in Europe in 2004 until today.

The guide is presented as a structured documentation of the available but dispersed information, which has been extracted and summarized with the view to make it accessible in various languages and useful to the project partner and the selected stakeholders mentioned above.

In the context of the ERASMUS+ project, this guide is the second of four information resources, which can be downloaded at international project website[2].

This technical guide contains six chapters, including an additional brief with information targeted to beekeepers. The chapters 2, 3 and 4 cover the core of the information gathered from literature and desk research, and from the exchange with experts and stakeholders. These chapters present an overview on three main themes, for monitoring, control and prevention of the *Vespa velutina*, and focus primarily on existing measures and current initiatives in practice, and to some extent, on ongoing research. The main findings are condensed in a summary chapter, and finally, a brief was elaborated specifically as a guiding document for beekeepers.

This guide is publicly accessible online through the website of the project, in five languages (Czech, English, French, German, and Slovak), and it is a consolidated source of information. This ERASMUS+ project foresees training sessions with beekeepers and civil defense personnel in 2022 and 2023, to prepare for the spread of *Vespa velutina*, for which this guide will be an important content source. Still, as this guide is one of the first project outcomes, and new strategies and measures will likely continue to be developed, this guide is not able to cover the evolution of such measures over time.

Finally, the strategies and measures described and discussed in this guide were selected because there is a certain level of consensus from experts and practitioners on their value, usefulness and practical use. Nevertheless, it is recommended that any measure to be carried out is implemented in compliance with the existing regulatory framework of the specific country. The conditions and provisions of such regulatory frameworks at national, regional and local levels are very extensive, and are not in the scope of this guide.

[1] The ERASMUS+ project grant number is 2021-1-SK01-KA220-VET-000033144.

[2] www.blesabee.online

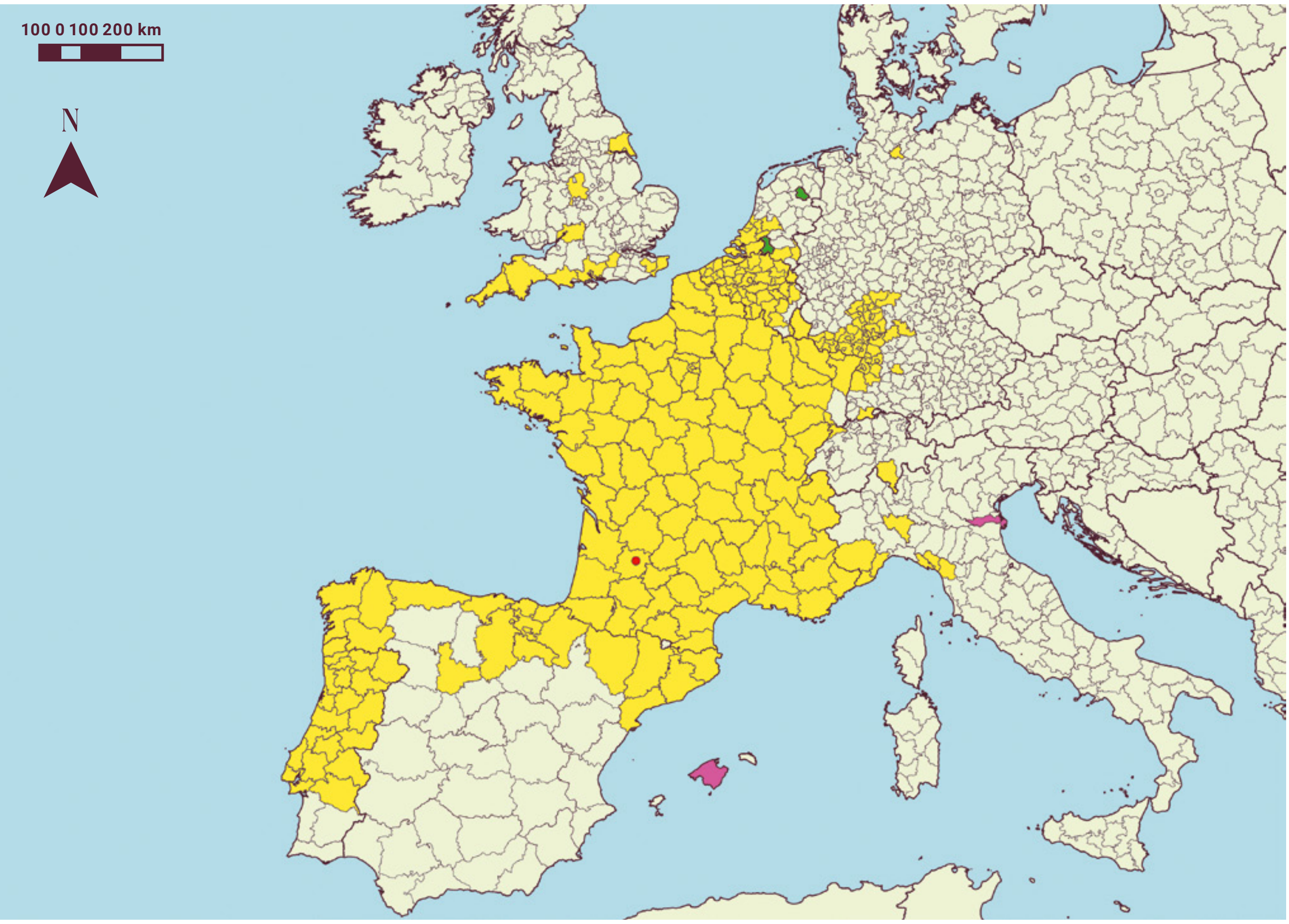
1

Introduction

The Asian hornet Vespa velutina nigrithorax was probably and accidentally introduced to Europe through the import of Chinese pottery. A first nest was found in France in 2004, and now the Vespa velutina has spread within the whole country, and is reaching neighboring countries and beyond. Figure 1 shows the distribution of the Vespa velutina as of January 2022.

Figure 1: Distribution of the *Vespa velutina* as of 26.01.2022

FIRST NEST RECORDED (2004)
FAILED TO ACCLIMATE/ERADICATED
DISTRICTS COLONISED IN 2020
DISTRICTS COLONISED BEFORE 2020
WITHOUT DATA/PROBABLY ABSENT



Source:© Q. Rome - MNHN - INPN http://frelonasiatique.mnhn.fr
© EuroGeographics pour les limites administratives

For a dynamic view of the graph, see https://frelonasiatique.mnhn.fr/biologie/#CarteProgression

The expansion of the *Vespa velutina* throughout Europe will continue, favored by climate change and warmer temperatures, as well as the global trade of goods. In 2016, the European Commission declared the *Vespa velutina* as an Alien Invasive Species (AIS) of concern [3]. Effective control measures, however, can support slowing down the spread, and mitigate the ecological, economic and social risks associated with the *Vespa velutina*. **The *Vespa velutina* presents a serious threat for apiculture**, as the *Vespa velutina* hunts on honeybees to feed its larvae. A weighted estimate of the damage caused by *V. velutina* nigrithorax to European bee colonies in different environments and with different prey availability, derived from several Authors (Ken et al., 2005; Monceau et al., 2013; Monceau et al., 2014) leads to **the assumption that *V. velutina* can be responsible for the loss of 65% of bee colonies in infested areas**, as a result of direct predation and weakening of bee colonies [Fedele et al., 2019]. This has impacts on the honey production and the income of beekeepers. Weakened and lost honeybee colonies show significantly **reduced (crop) pollination performance**. This is mainly because honeybees stop their foraging activities for nectar and pollen when *Vespa velutina* hornets are present at the apiary, a phenomenon called foraging paralysis [Laurino et al., 2020].

The *Vespa velutina* is also a predator for other pollinating insects and wild bees, which amplifies the risk of reduced pollination, with severe consequences on ecosystem services. A study conducted by the European Commission estimates that in affected regions, where the *Vespa velutina* already causes reduced crop pollination, the losses cause an economic damage reaching several million Euros. Only in the Spanish region of Galicia, the annual cost of crops losses is estimated at 4,5 million Euros [Fedele et al., 2019].

The presence of the *Vespa velutina* in rural and urban areas has also raised concerns on its **impacts on public health**, and on the risks that the *Vespa velutina* might represent to human health. As with other species from the Hymenoptera order, the *Vespa velutina* is "not predisposed to attack and sting humans" [Feás et al., 2022], but it shows strong defensive behavior if the (Vespa) colony is at risk. It is therefore advised not to approach their nest closer than 5 meters [BGD, 2021a]. As a result of the increased activity in summer of both, insects and humans doing outdoor activities, the possibility of coming into contact with a stinging insect like the *Vespa velutina* becomes much greater during the late summer (Stinging insect colonies are typically at their maximal size in late summer and/or autumn). Recent work of Feás (2021) documented and characterized the Spanish deaths due to hornet, wasp, and bee stings over a 20-year period (1998 - 2018) at the state and sub-state level. The implication of the invasive species *Vespa velutina* was examined in this study, and based on the findings, the author argues that in Spain there are spots of extremely high exposure to insect stings, mainly due to the *Vespa velutina*. Likewise, occupational anaphylaxis was reported especially for beekeepers. The author also indicated the need to look at health issues as a core part of the impact associated with this invasive alien species [Feás, 2021].

A particular **focus of this guide is the impact on and threats to honeybees posed by the *Vespa velutina*.** European honeybees (Apis mellifera), contrary to other Asian honeybee species which co-evolved with the *Vespa velutina* (such as the Asian honeybee Apis cerana), show inefficient defense mechanisms against *Vespa velutina* [Arca et al., 2014]. **Therefore, preventing damage caused by the Vespa velutina to European honeybees and to the apiculture sector requires human intervention**.

The challenges associated with the presence and the progressive expansion of the Vespa velutina, can be addressed in three ways:

1

Monitoring

2

Controlling

3

Prevention

[3] Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council:: shorturl.at/dhlrx

2

Monitoring Vespa velutina

Monitoring invasive species provides information to better understand the evolution of the population of such species in certain geographical areas, and allows to make estimations of its likely future distribution in new areas. Identifying and monitoring the *Vespa velutina* is a key first step to develop and implement safe and adequate control and prevention strategies and measures.

Monitoring therefore represents a "practical decision-making tool" [Preti et al., 2021] to effectively deal with external risk factors such as diseases, pests, and invasive species. To achieve the objective of monitoring, the **validation of the observations is required**. Although good guiding information materials are available for the identification of the *Vespa velutina*, the confusion of the *Vespa velutina* with other species and insects is common, e.g., in the European project STOPVESPA [4], only 15% of the observations reported by "citizen scientists" [5] were in fact confirmed to be *Vespa velutina*, whereas other species accounted for 85% of the reported observations [Lioy, 2021]. Monitoring is therefore strongly linked to the correct identification, as a basis to ensure a proper data quality for monitoring systems, and to enable appropriate measures. It is also of relevance to validate those observations, to avoid confusions with native wasps and hornets such as the European *Vespa crabro*, which in some countries or regions is a protected species. This is the case in Germany, where the *Vespa crabro* must not be harmed [Umweltbundesamt, 2019].

As the *Vespa velutina* is considered an AIS of concern in Europe, **first discoveries of the species need to be reported to the European Commission** by the responsible National or regional authorities, i.e., environmental ministries or competence centers for invasive species [Hach & Langguth, 2021]. Since 2006 experts in France have run a *Vespa velutina* monitoring system with European scope. Reported observations are validated and mapped, allowing a good overview on the presence of the *Vespa velutina* not only in France but beyond in Europe (see Figure 1) [MNHN, 2022]. This is not the unique ongoing monitoring effort, other regions and countries have their own systems to record validated observations of invasive species, including *Vespa velutina*.

In general, one can distinguish between monitoring of the adult **Asian hornets** and monitoring their **nests**. These activities have different requirements and implications, e.g., those related to the location of the monitoring over time, as the locations might change throughout the life cycle of the *Vespa velutina*.

Classical monitoring techniques mostly focus on the observation and identification of hornets, by installing traps in (infested) areas, and regularly checking these traps. Newer approaches include remote monitoring with different devices such as sensors and cameras, as well as data transfer and recognition technologies by means of artificial intelligence (AI) to reduce labor, time and costs [Preti et al., 2021].

The monitoring approaches in this guide were included considering their practicability and their effectiveness, and are discussed in the following section.

[4] www.vespavelutina.eu/en-us

[5] Non-professional scientists and amateurs that participate in and conduct scientific activities.

2 • 1

Monitoring adult Asian hornets

The monitoring of Asian hornets (adult insects) is not easy because of their speed of flight, the recommended safety distance (5 meters), and their physical characteristics which are similar to those of other wasps and insects. Two types of monitoring of Vespa velutina hornets are discussed below.

2 • 1 • 1

Monitoring at apiaries

This section focuses in particular on the monitoring of Asian hornets around honeybee apiaries. Proteins play an important part in insects' nutrition, especially during periods of population increase. The honeybees, as well as other insects, are a protein rich food source for the larvae of the *Vespa velutina*. The adult Asian hornets hover around apiaries, in front of the entrance of the hives to catch honeybees. Once the *Vespa velutina* catches a honeybee, it removes its head, wings, legs and abdomen, to take to its nest the remaining thorax (rich in muscle and proteins) to feed its larvae [CABI ISC, 2020]. The *Vespa velutina* commonly returns to the apiary to continue the prey [BGD, 2021b]. Steadily hovering in front of the hive entrance is a typical behavior for *Vespa velutina* [6], as opposed to the *Vespa crabro*, which hovers in zig zag motion [7]. Knowing this information, **beekeepers could be trained to observe their hives, and carry out the identification of Vespa velutina adults in their apiaries.**

[6] **As seen in this video footage**
shorturl.at/IQVY4

[7] **As seen in this video footage**
shorturl.at/hzFT4

EXAMPLE

Monitoring of apiaries in the city of Hamburg, Germany

The program **AHlert** aims at monitoring the presence of the *Vespa velutina* in the city of Hamburg (Germany). Participating beekeepers help monitor Asian hornets around their honeybee apiaries. The beekeepers are provided with information guides on *Vespa velutina* and commit to regularly monitor their apiaries for one hour during three specific periods: Mid to end of May, End of July to Begin of August, and end of September [AHlert, 2022].

This approach covers a short timeframe, especially in regions where the *Vespa velutina* density is low, and where there are rather few observations of adult hornets. This is therefore a partial surveillance of the hives and might not be fully effective. Still, the engagement of beekeepers is considered a good strategy to raise awareness, which is why the city of Hamburg continues with this monitoring program during 2022.

While the *Vespa velutina* larvae are fed with proteins deriving from honeybees and other insects, the adult *Vespa velutina* hornet mainly feeds on (sweet) carbohydrates, usually present in ripe fruits and nectar [CABI ISC, 2020]. Therefore, fruit orchards could also be target locations to identify *Vespa velutina* hornets, especially in late summer and autumn, when fruits are ripening[8]. **Farmers and fruit pickers could be another relevant group for monitoring the Vespa velutina hornets**, as they work in locations likely closer to the Asian hornets. On the other side, they are a vulnerable group that possibly suffers from hornet stings during their work. This means that training would also be needed when engaging farmers and/or fruit pickers for monitoring activities.

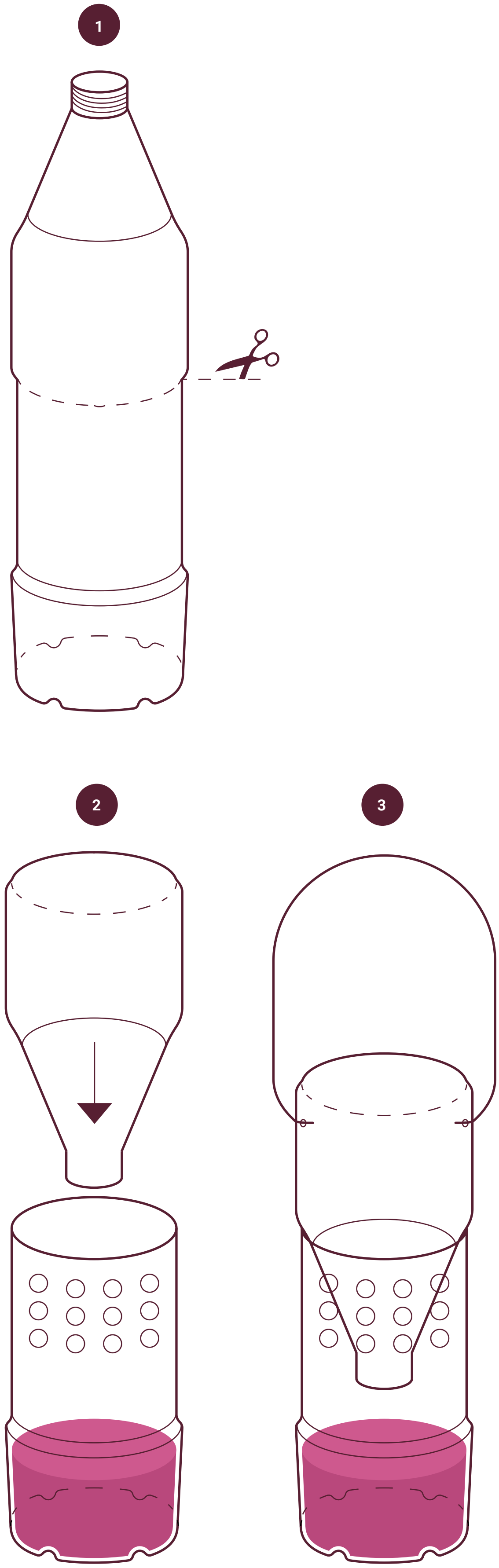
Another option for monitoring Asian hornets at apiaries, orchards and farms is **the use of trapping devices or simply "traps"**. This would not need the presence of beekeepers or other persons. As hornets return to the source of their food i.e., bee protein or ripe fruits, traps can be installed and serve as monitoring tools. These traps are similar to traps used to trap wasps. The principle is to attract the *Vespa velutina* by using an attractant liquid or a bait (e.g., light beer, white wine, or syrup). Once the *Vespa velutina* is inside the trap and cannot escape, it falls and drowns in the liquid, as shown in Figure 2. A variety of such traps are commercially available at low cost[9], and "do-it-yourself" variations are also popular. Figure 3 shows the instructions for making a bottle trap in a quick, easy, and affordable way.

Figure 2: Trapped Asian hornets in a commercial bottle trap [Danrok | Wikimedia Commons, 2018].

[8] **As seen in this video footage**
https://bit.ly/3rRILo5

[9] **See for example various Asian hornet traps for gardens and beekeeping (in French)**
https://bit.ly/3ex0I8g

Figure 3: Instructions to build a bottle trap to catch hornets [adapted from Mairie Châteaubriant, 2021].



EXAMPLE

Trapping plan as a regional monitoring strategy in the autonomous province of Asturias, Spain

The Northern part of Spain is heavily impacted by the presence of *Vespa velutina*. The monitoring is carried out using traps with attractant liquids based on sugary or protein substances and odorant products. The Action Plan for the autonomous province of Asturias describes who the authorities involved are and what responsibilities they have, also for the seasonal *Vespa velutina* trapping plan, as follows:

- The spring trapping (February to June) is carried out by surveillance personnel authorized by the General Directorate with competence on biodiversity.
- The spring auxiliary trapping (February to June) is carried out by other members of a surveillance group, beekeepers associations, local organizations, and volunteers, with the participation and engagement of the general public.
- The curative trapping or “baiting” (July to October) takes place mostly in response to an attack by *Vespa velutina* in apiaries and/or plantations.
- The occasional autumn trapping (October to December) focuses on placing traps in places where nests have been detected but could not be removed [Gobierno de Asturias, 2021].

Periodic counting of the of insects found in the traps is carried out, and these counts are registered in a dedicated application called “AvisAp”[10,11]. The trap content is recorded using the following classification: *Vespa velutina* queen, *Vespa velutina* worker, *Vespa crabro*, bees or other wasps, and other insects (Diptera, Lepidoptera, etc.). These counts are recorded by professional agents or by citizens, who have registered their trap in the AvisAp application, and have obtained authorization to use it.

When registering the traps in the AvisAp application, the user commits to respecting the provisions of the Action Plan and the instructions issued by the General Directorate with competences in biodiversity; and in this way the authorization to place traps is only granted to those participants who can ensure correct trap use.

The use of traps for catching adult *Vespa velutina* might have side-effects that need to be considered when using this monitoring option. Trapping single Asian hornets by means of the bottle traps is not considered an effective **control** measure, because one or few single individual hornets lost in the traps does not represent a large impact on the development of a colony of *Vespa velutina* [Turchi & Derijard, 2018].

Apart from the uncertain selectivity of the traps, the dead specimen of *Vespa velutina* cannot be used for tracking and finding their nests, and depending on the principle and the attractants used, the traps are also likely to cause damage to other insects as well.

Another popular conventional trapping method is the use of sticky traps, which attract insects by means of pheromones. The attracted insects will stick to the panel of the trap and die. Studies have shown that the *Vespa velutina* hornets are mostly attracted by olfactory stimuli, in particular, by the honeybee pheromone geraniol, as well as pheromones of honeybee larvae and queens [Couto et al., 2014].

Scientists have also identified sexual pheromones to which *Vespa velutina* drones are highly sensitive. This is the starting point to develop selective pheromones for trapping of drones, thus reducing the reproduction capacity of *Vespa velutina* queens. These pheromone traps though are not yet broadly available, as their effectiveness is still being investigated. For example, the Asian hornet drones not only need the olfactory signal from the sexual pheromones, but also need visual and other stimuli. [Ya-Nan et al., 2022]. Finally, traps are not only used for monitoring but also to control the population of *Vespa velutina*. This is further discussed in Section 3.1 as part of **control measures**.

Hornets can be trapped and tracked alive as they will likely return to their nest after hunting in an apiary, and this is the principle for finding nests by tracking living hornets with remote methods which is further discussed in Section 2. 2.

[10] AVISAP - APPSTORE

[11] AVISAP - GOOGLE PLAY

2·1·2

Remote monitoring

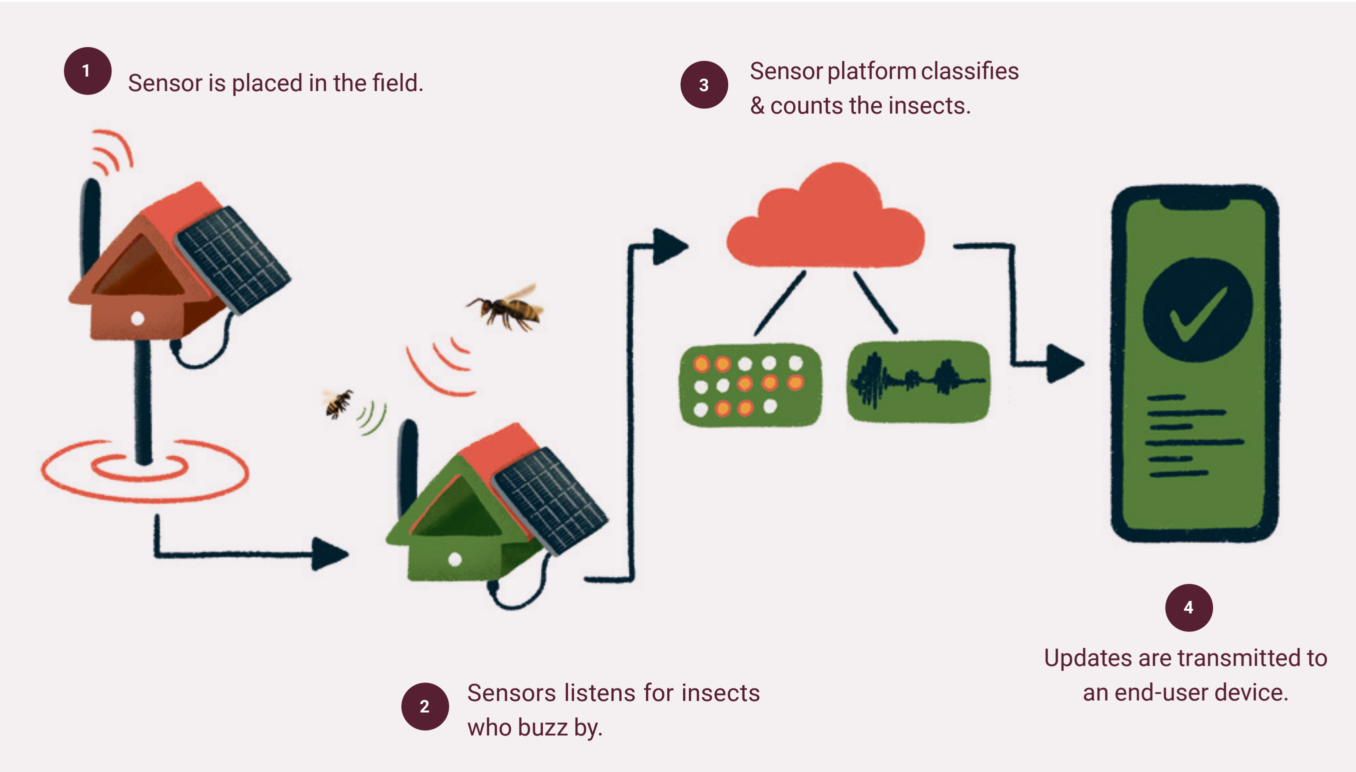


Figure 4: Scheme of a digital (audio) insect monitoring solution [adapted from Farmsense, 2022].

Commercial solutions for remote monitoring of pests are already available and widely used in crop fields and fruit orchards. Often solar-powered and/or battery-powered devices are used for surveillance. The specifications, the functioning principle, and hardware of the products is diverse, but most devices rely on visual detection of pest[12], or detection by means of sound[13]. Visual remote detection usually consists of a trapping mechanism i.e., based on sticky or pheromone-based traps, and image sensors or cameras to provide pictures of the trapped insect(s). Other visual detection for pests includes aerial observation with drones equipped with cameras for covering and surveying larger areas or crop fields. With the technological development of drones, the potential of the use of unmanned drones in agriculture for the anticipation of damage has been described in several papers [Puri et al., 2017].

In principle these technologies could also be adapted to remotely detect the hornets at apiaries and other locations, by using recognition of the Asian hornet sounds. Currently, the use of visual monitoring devices with cameras and AI is investigated for the detection of *Vespa velutina* nests, as explained next in Chapter 2. 2. 2.

[12] See for example iSCOUT by Pessl instruments, see https://metos.at/de/iscout/
[13] See for example Farmsense, www.farmsense.io

2 • 2

Monitoring of nests of Asian hornets

The Vespa velutina colony builds two types of nests during its life cycle. A founder that overwinters will start building a primary nest in spring, to lay the eggs and slowly build up a new colony. In summer, when the population develops to its peak and the primary nest is too small, the colony builds a secondary nest. The primary and the secondary nests are different in terms of their size, shape and possibly location. These different features can be of help in developing strategies for nest monitoring.

2 • 2 • 1

Monitoring primary nests

The primary nests of the *Vespa velutina* are usually overlooked because they are often located in sheltered, undisturbed places, such as abandoned or occasionally used garden sheds. These nests are relatively small in size, approx. 3 to 10 cm in diameter, as shown in Figure 5. Due to their hidden location, modern surveillance technologies used in larger scale monitoring (e.g., by aerial observation with drones) hardly provide any help to detect such primary nests. More effective detection is done by **attentive citizens**, but this requires a certain level of knowledge, as well as a point of contact to report and validate the observation of a *Vespa velutina* primary nests.

It is necessary to regularly monitor the surroundings of water sources, including garden ponds, fountains, wells or natural lakes. Another indicator when monitoring nests is the location of bee hives, as bees are a plentiful food source for Asian hornets. Estimates indicate that workers of one nest of *Vespa velutina* are capable of destroying or severely weakening three productive honeybee colonies.

The French National Museum of Natural History (MNHN) provides a list with habitats and locations where the *Vespa velutina* is likely to build a primary nest [MNHN, 2022], which is based on such reported observations. This information is valuable for informing and training more volunteers and citizens.

Figure 5: Primary nest hanging from a ceiling, with Asian hornets around it [© LIFE STOPVESPA].

2·2·2

Monitoring secondary nests

Figure 6: Detection of a hidden secondary nest [Victoriatell | Wikimedia Commons, 2015].

Figure 7: Detection of a secondary nest in winter [Père Igor | Wikimedia Commons, 2010].

In summer, when the *Vespa velutina* colony is large and strong, the workers leave the primary nest to build a secondary nest, which depending on the surrounding conditions, can be built at the same location or somewhere else. As described in the module Biology of the hornet *Vespa velutina*, secondary nests are found in many different locations, but the majority are built on high trees [Franklin et al., 2017], as shown in Figure 6 and Figure 7. With the dense foliage of the trees in the summer, the secondary nests often remain undiscovered until leaves fall in late autumn and winter. At this point the *Vespa velutina* queen has abandoned the nest to start hibernation, and the nest is inactive.

Although usually hidden under dense vegetation, the secondary nests are much bigger in size and easily call attention, and therefore many observations of secondary nests are just accidental.

A proactive approach for detecting nests is tracking the adult Asian hornets as they fly back to their nests. The *Vespa velutina* can reach a speed of over 6m/s [14] [Lioy et al., 2021], which combined with the high and hidden location of many nests make it almost impossible to visually follow a flying hornet going back to its nest [Roja-Nossa et al., 2022]. The monitoring of nests by tracking hornets relies on using equipment such as harmonic entomological radars and radio telemetry. Other options include triangulation, as well as the regular visual observation tours in targeted areas. These approaches are described next.

[14] An **average** speed of 1,56 m/s for the Vespa velutina is reported in Darrouzet (2019).

2·2·2·1

Harmonic entomological radar

Figure 8: The harmonic radar developed within the STOPVESPA project [©LIFE STOPVESPA].

An essential outcome of the European project STOPVESPA was the development of a prototype of a "harmonic entomological radar" for the detection of Asian hornet nests, shown in Figure 8. The technique works as follows: captured hornets were tagged with a metallic wire and a diode (See Figure 9), which reflect the waves emitted by a harmonic radar, and allows for the real-time tracking of the hornet's flight, and thus the rapid detection of the nest. The operating field of the radar is about 500 meters. During this project this radar showed a nest location efficiency of 75% in new areas of invasion, and 60% in areas of already high *Vespa velutina* density [Lioy et al., 2021]. The early detection of nests with the harmonic entomological radar enables further measures that helped contain new outbreaks of *Vespa velutina*, particularly in the regions of Finale Ligure and La Spezia [LIFE STOPVESPA, 2022].

Figure 9: Tagged *Vespa velutina* hornet [©LIFE STOPVESPA].

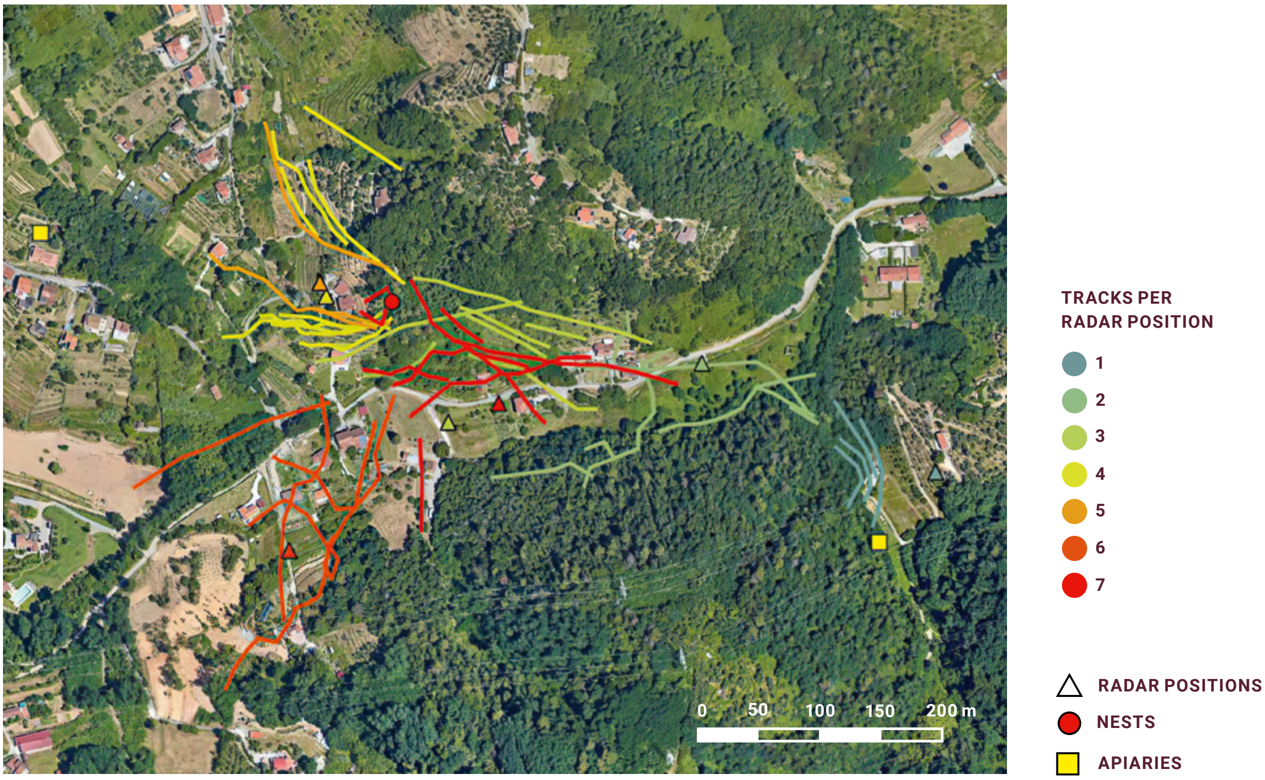
2·2·2·2

Radio telemetry

Radio telemetry has been used to track wildlife for over 50 years [Kennedy et al., 2018] and today is also used e.g., in Switzerland and in Hamburg, for the detection of nests of *Vespa velutina*. The principle is similar to the one previously described for the harmonic radar - a transponder is attached to the Asian hornet, which is then released and tracked using a radio antenna. An operator is in charge of moving the antenna, so that it transmits the radio signals from the transponder to a receiver [Maggiora et al., 2018]. The success rate for detection of flying Asian hornets is 100% in field tests, and around 60% for the detection of Asian hornet nests [Kennedy et al., 2018].

The use of the harmonic entomologic radar and as the radio telemetry have proven to be effective, but they are both **cost and labor intensive**. In areas with a high density of Asian hornet nests and where flight distances are short, the detection of nests through radio telemetry took 90 minutes on average [Kennedy et al., 2018], whereas in areas where the density is low, the expected time for the nest detection is higher, around a couple of hours [Schütte, 2022; Seehausen, 2022]. The costs can be calculated as personnel and equipment costs, and will vary under the different conditions, especially for nests in difficult and/or high locations. The initial equipment cost for radio telemetry (receiver and antenna) is approx. 3000 Euros. The cost for the transponder to attach to the hornets (which is likely to get lost during the operation) is about 200 Euros. Still, these costs are lower than those of the harmonic entomological radar, which is about 100.000 Euros [Lioy et al., 2021]. Figure 10 shows an example of a *V. velutina* tracking session with harmonic radar at the Arcola site (La Spezia, Italy). *V. velutina* workers were tagged (n = 14) at a beehive near the first radar position (easternmost beehive on the map). Subsequently, the harmonic radar was repositioned according to the direction of flight of the Asian hornets in the other six positions (triangles). Different colors highlight the recorded tracks (n= 46) relative to each radar position. The red dot indicates the location of the discovered nest of *V. velutina*.

Figure 10: Example of a tracking session of *Vespa velutina* in Arcola, Italy.
[Lioy et al., 2021; Background map by Google Maps (maps.google.com)].



2·2·2·3

Triangulation

The principle behind triangulation is also visually tracking marked hornets which are released from selected locations. In practice, protein baits placed at three different locations attract the hornets, which are then captured and marked. One can estimate the nest distance and the crossing points of each flight route by recording the flight direction and the time the marked hornets take to return to the bait. This method is mostly successful in areas with low nest density, where there are no other different nests from which the marked hornets could come. A more refined step to determine the precise location of the nest, is to use sugar baits in the vicinity of the potential nest location, and use visible tags attached to the released hornets, to visually follow them to their specific nest. This is a low-cost approach that requires no special equipment, but the time to detect the nests can vary from a few hours to a couple of days [Roja-Nossa et al., 2022].

2·2·2·4

Thermal imaging

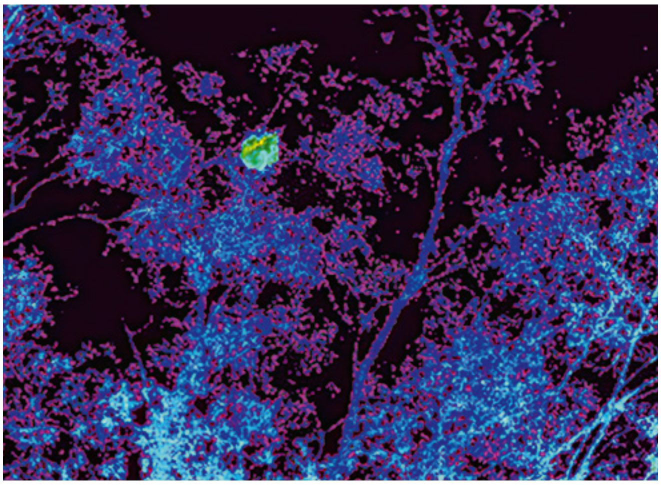


Figure 11: Example of thermal imaging of *Vespa velutina* nest located up in the crown of a tree. [Lioy et al., 2021].

Since the *Vespa velutina* hornets are able to regulate the temperature of their nest, these are detectable by cameras and thermal imaging. This has also proven to be an effective method, tested in Portugal, the UK and Italy [Laurino et al., 2019]. Field tests indicate that thermal imaging works up to 30 meters away, and could be an additional, effective technique to support other nest detection measures [Lioy et al., 2021]. Figure 11 shows an example of thermal imaging for nest detection.

Other experiences however show that the temperature difference between the inside of the nest and the foliage is low, so that thermal imaging equipment would not be fully reliable for nest detection in all conditions and locations [Thiéry, D., Lacombrade, M., 2021].

2·2·2·5

Aerial observation with drones

Drones allow observing Asian hornet nests safely and precisely, as they can be approached without risk of attacks or stings. This also enables accurate measurements of the size of the nest, to estimate the strength of the colony and better plan the possible removal of the nest. The use of drones can also facilitate the regular observations, as it allows a more distant approach and remote work [La Voz de Galicia, 2015]. The need for monitoring methods that do not rely on human effort is stressed by the Portuguese funded project CONTROLVESPA. This project is about developing a new type of drone together with machine learning to correctly locate and identify *Vespa velutina* nests [Capela, 2021].

2·2·2·6

Regular observation tours

Regular observation tours are common e.g., in protected areas and natural reservoirs, with the objective to monitor the population of animals and/or plants, to identify irregularities, etc. These tours are not punctually triggered by a reported incident or by random observations, and might be also effective to monitor *Vespa velutina* in areas with higher nest densities. The Rangers Europe, with national units in Italy, Belgium, and France[15] carry out such regular observation tours.

Despite its ease to adapt to different surroundings, there seems to be favorable geographical conditions and pathways for the expansion of the *Vespa velutina* (later described in Chapter 4.2). The information on such locations as well as on the typical features of the secondary nests could be integrated to the regular observation tours and monitoring protocols. The tours could be complemented with detection equipment as those described before.

2·3

Citizen scientists

The engagement of "citizen scientists" represents a less strategic approach for monitoring, and can complement other strategies, and help raise awareness on the expansion of the *Vespa velutina*. To seize this potential, certain knowledge amongst the citizen scientists is required to ensure that the right observations are reported for monitoring purposes. Many programs for monitoring *Vespa velutina* include capacity building and dissemination, as well as establishing appropriate communication channels to collect and validate observations reported by citizen scientists. Examples include the Belgian program Vespawatch[16] and the Spanish program VESPAPP [17]. These communication channels for reporting observations are discussed in Section 2. 5.

2·4

Sentinel hives

Sentinel hives are honeybee colonies placed in specific locations, and are closely monitored to serve as early warning systems to detect pests, diseases, and other potential problems. As the *Vespa velutina* largely feeds on honeybees, sentinel hives can be used to attract and monitor *Vespa velutina* hornets in a given area. Two examples of monitoring programs making use of sentinel hives are presented next.

EXAMPLE

Sentinel Apiary Program of the Department for Agriculture, Food and the Marine (DAFM), Ireland:

In 2021, the Irish Department for Agriculture, Food and the Marine (DAFM) established a Sentinel Apiary Program to detect three exotic honeybee pests: the Tropilaelaps mite, the Small Hive Beetle (SHB) and the *Vespa velutina*. None of them have been reported so far in Ireland at the time the program was established.

Volunteer beekeepers were selected across the country, focusing on those with apiaries located closer to the main airports and ports. Each beekeeper was given a bottle trap and specific instructions to set the trap, and to perform the sampling at the right timing. Surveillance traps were also strategically placed in Dublin, where the first *Vespa velutina* was ever found in Ireland. No *Vespa velutina* was reported in the course of the DAFM Sentinel Program in 2021 [DAFM, 2021].

EXAMPLE

Sentinel hives within the project "Bee Warned", Bavarian State Institute for Viticulture and Horticulture, Germany

The *Vespa velutina* was first observed in 2014 in Baden-Wurttemberg (South-west Germany), and later also was found in the neighboring state of Rhineland-Palatinate. The Institute for Apiculture of the Bavarian State Institute for Viticulture and Horticulture ran a research program between 2017 and 2020, to establish sentinel hives for the detection of *Vespa velutina* in Bavaria, because this is a state with a large number of beekeepers, and is next located to Baden-Wurttemberg. This program involved, on the one hand the training for beekeepers, and on the other hand, the provision of educational material to carry out the monitoring. A wide monitoring system was established in the seven administrative districts of Bavaria, setting observation areas inside squares along the state, and engaging an evenly distributed number of participants, as shown in Figure 12. The green dots indicate the registered monitoring apiaries, the blue dots show the institute-owned apiaries, and the purple dots are the volunteer "wasp and hornet advisors", involved in monitoring the Asian hornet. The participating beekeepers were instructed to observe their apiaries three times a year, in April-May, June-July, and August-September, following the life cycle of the *Vespa velutina*. No *Vespa velutina* was reported during the monitoring between 2019 and 2020 [Höcherl & Berg, 2020].

This approach is in part similar to that of the monitoring program AHlert of Hamburg (Northern Germany).

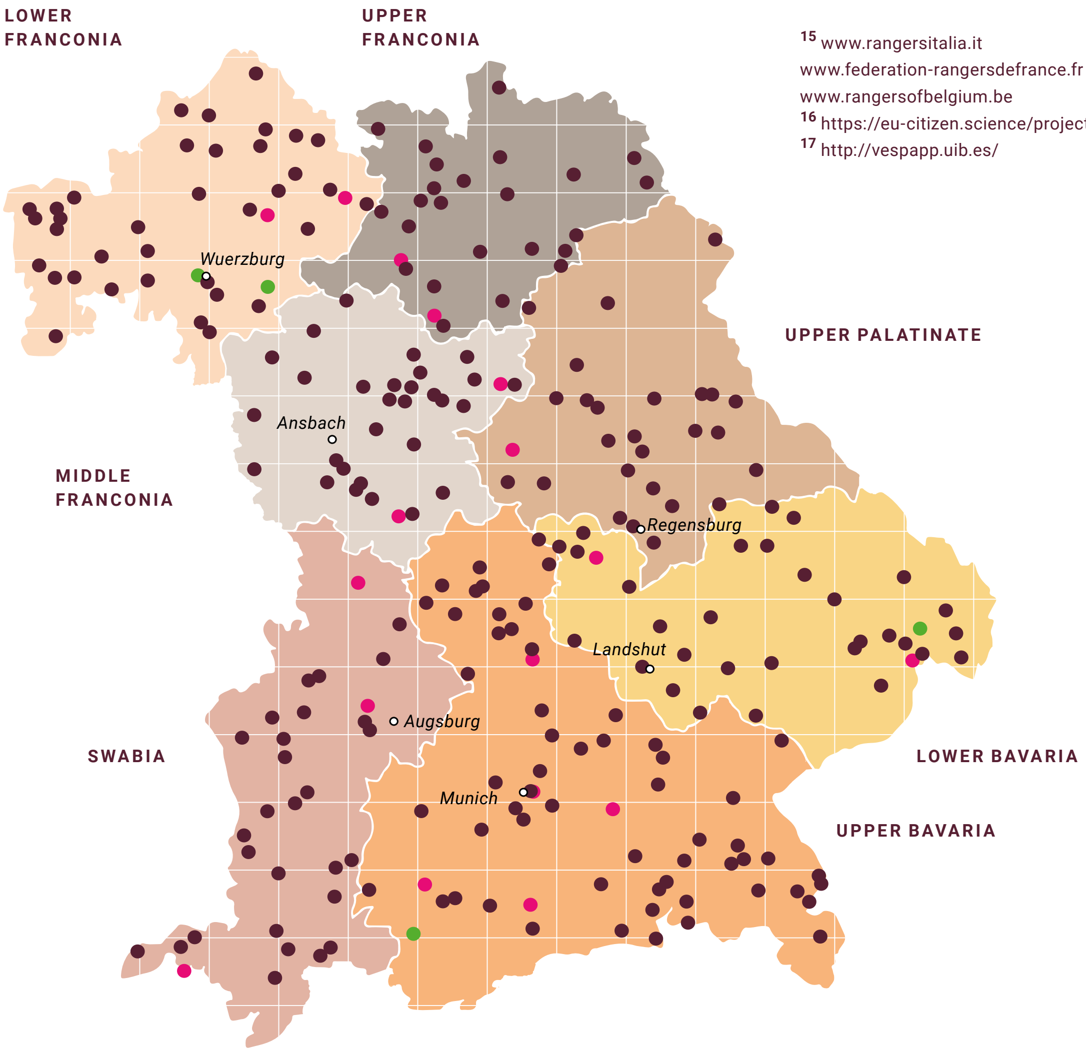


Figure 12: Monitoring locations of the project Bee Warned in the State of Bavaria [adapted from Höcherl, N., Berg, S., 2020].

15 www.rangersitalia.it
www.federation-rangersdefrance.fr
www.rangersofbelgium.be
16 https://eu-citizen.science/project/184
17 http://vespapp.uib.es/

2·5

Reporting observations of Vespa velutina

As the *Vespa velutina* falls under the EU Regulation on Invasive Alien Species (IAS) (1143/2014), its presence and expansion in Europe is closely monitored., The "Member States must notify the [European] Commission of the appearance of IAS of Union concern whose presence was previously unknown or of the re-appearance of IAS of Union concern after they have been reported as eradicated" [European Commission, 2021]. Reporting to the authorities in charge the first observations, but also the more frequent observations in areas where the *Vespa velutina* is already established, is needed for:

- Verifying the observations, to ensure proper identification from and to avoid possible confusion with other insects or hornet species. Verifiable evidence, e.g., photos or the insect itself, and the location and time of observations are necessary.
- Taking appropriate control measures, according to action plans and/or response systems
- Collecting data to better follow the expansion of the *Vespa velutina*

In European countries where federal or other similar governance systems are common, the competencies and responsibilities are widely spread amongst various authorities, and therefore, there might be different channels to report observations, as seen in Table 1.

Especially in those areas where the *Vespa velutina* is established, the easy access of user-friendly tools promotes the collaboration with observers, and can help to a faster deployment of control measures. In the beekeeping community, the informal and social media communication channels, such as WhatsApp and Facebook, are popular and widely used, and these might be further exploited regarding reporting of *Vespa velutina* in apiaries and their vicinities.

Table 1: Examples of channels for reporting *Vespa velutina* observations.

COUNTRY	AUTRHORITY	CHANNEL
Austria	Federal Ministry of Environment	**Online:** https://secure.umweltbundesamt.at/neobiota
	Agency for Health and Food Safety (AGES)	**E-mail:** bienen@ages.at
Ireland	National Parks & Wildlife Service	**Online reporting tool:** https://records.biodiversityireland.ie/record/invasives
Spain (Province of Asturias)	Principality of Asturias	**E-mail:** info@avisap.es **Mobile application:** https://apps.apple.com/es/app/avisap/id1569625433 **Phone:** +34 984249165 **WhatsApp:** +34 610255111

3

Controlling the Vespa velutina

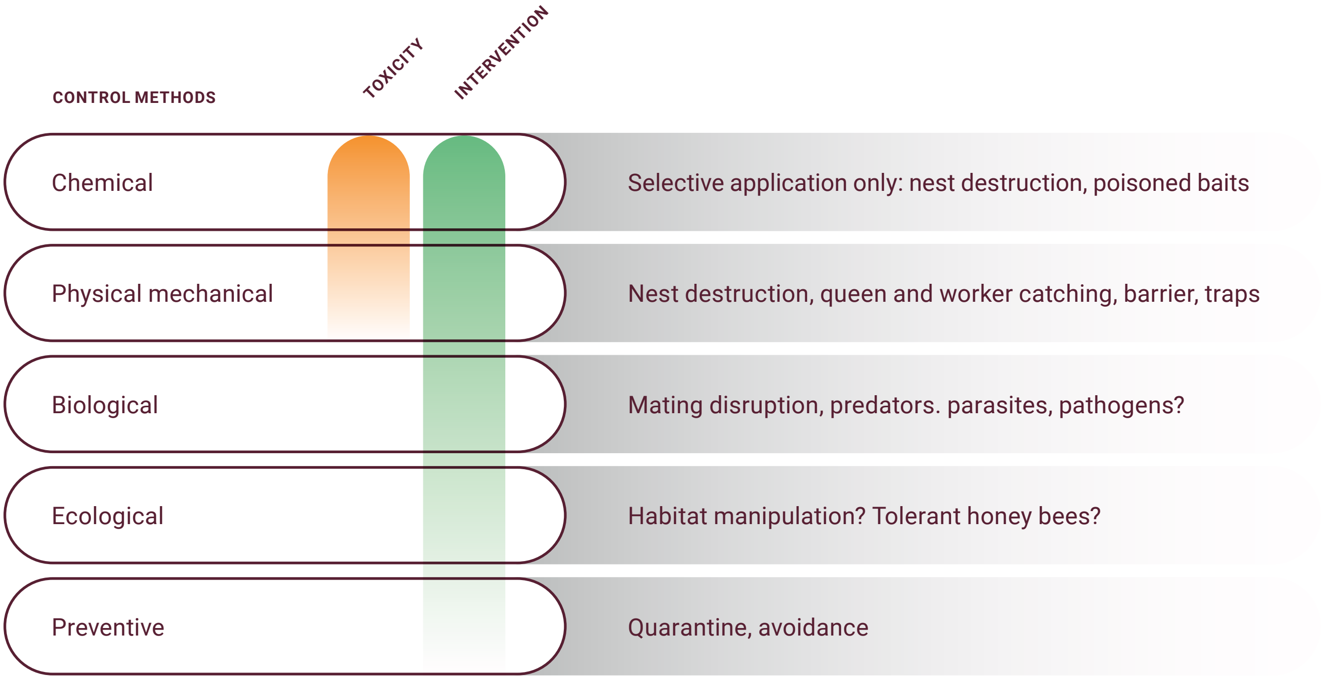


Figure 13: *Vespa velutina* control methods [adapted from Laurino et al., 2019]. Source of file: "*Vespa velutina*: An Alien Driver of Honey Bee Colony Losses" Laurino et al., 2019 (https://doi.org/10.3390/d12010005). CC-BY 4.0.

As the *Vespa velutina* continues to expand, its control is an emerging challenge for more European countries and regions. The hierarchy of available methods for the control of *Vespa velutina* is presented in Figure 13. The bottom represents non-toxic methods that require low intervention, whereas the top of the pyramid stands for high impact methods, which often involve the use of toxic insecticides.

More concretely, commonly applied control measures are summarized in Table 2.

The control measures available to date are limited, "they are sometimes effective but not eco-friendly" [Ruiz et al., 2020], and no single control measure has proven to be fully effective against the *Vespa velutina*. Once present, the eradication of the *Vespa velutina* seems illusory, yet the coordinated use of several methods as part of an integrated pest management approach has the potential to reduce its impact, i.e., on honeybees and on the environment [Laurino et al., 2019].

This chapter gives an overview of selected control methods, based on three main criteria: selectiveness, effectiveness, and compliance with existing regulations. This chapter also describes the current efforts in research and practice, and draws conclusions with a medium to a long-term perspective, about the most promising methods to control the *Vespa velutina*.

Table 2: Commonly used control measures for *Vespa velutina* [adapted from USC & Ecoagrarsoc, 2022].

1.	Destruction of *Vespa velutina* nests	Further described in Section 3.2
2.	Trapping of queens and workers.	Further described in Section 3.3
3.	Protection of apiaries by means of electric harps, muzzles and nets.	Further described in Section 3.4
4.	Supporting the defensive mechanism of honeybees through artificial feeding and reducing the hive entrance.	
5.	Moving of apiaries to other places.	

3 • 1

Criteria for assessing control measures

This chapter gives an overview of selected control methods, based on three main criteria: selectiveness, effectiveness, and compliance with regulations.

3 • 1 • 1

Selectiveness

As an invasive species, the Asian Hornet *Vespa velutina* can be directly detrimental to European biodiversity, and at the same time some measures to control its spread, such as using available insect traps, might also put pressure on biodiversity (as discussed in Chapter 2. 1. 1). Therefore, it is important to apply **selective** methods which are specifically targeted at controlling only the Asian hornet *Vespa velutina*.

Figure 14: Beekeeper Denis Jaffré shows the selective trap he developed to control Asian hornets [©REUTERS/Manuel Ausloos].

A simple assessment of the selectiveness of e.g., insect traps, is to calculate the ratio between the *Vespa velutina* and insect specimen trapped [Renoux et al., 2020]. However, the assessment becomes more complicated when secondary and long-term effects are considered, especially for control measures based on the use of pesticides. The premise should be to apply pesticides in a targeted and specific way, so that no releases and/or damages are caused to the environment. Birds, such as green woodpeckers *(Picus viridis)*, jays *(Garrulus glandarius)*, and tits *(Paridae)*, feed on dead larvae in the pre-winter period[18]. The impact of potentially contaminated larvae with pesticides on the feeding birds has not yet been assessed in the case of *Vespa velutina*, but other cases show that residues of pesticides and insecticides can indeed move through the food chain, causing harm to other species not originally targeted with these pesticides [Auburn University, 2020].

[18] Other birds that act as natural enemies to the *Vespa velutina* include the European honey buzzard *(Pernis apivorus)* and the European bee-eater *(Merops apiaster)*. However, none of the listed birds is able to handle large and active *Vespa velutina* colonies to this point, and therefore, the impact of the natural enemies on the *Vespa velutina* population is considered negligible [CABI ISC, 2020]. The impact of natural enemies is further discussed in Chapter 3.5.

3 • 1 • 2

Effectiveness

To ensure a long-term, sustainable control of the *Vespa velutina*, the control measures should be **effective** at reducing the expansion as well as its impacts. The biology of the *Vespa velutina* needs to be well understood, including its lifecycle, behavior and reaction mechanisms to stress factors, to develop effective control measures. One example of a commonly used, yet mostly deemed as ineffective control measures is the bottle trap, which shows no "protective effect (…) nor on the foraging activity nor on the development nor on the survival of the (honeybee) colonies" [Turchi & Derijard, 2018]. To this date the use of stand-alone strategies has not proven to be effective, and it seems unrealistic to aim at the complete eradication of the Asian hornet in Europe. Instead, the **combination** of different methods and tools might increase the effectiveness in controlling the impacts of this species e.g., protecting bee hives against hornet attacks might limit the impact on single apiaries, but would not impede the reproduction of *Vespa velutina* populations in one region.

3 • 1 • 3

Compliance with regulations

With the declaration of the *Vespa velutina* as Alien Invasive Species of Union concern in 2016, *"Member States [of the European Union] are required to take action on pathways of unintentional introduction, to take measures for the early detection and **rapid eradication** of these species, and to manage species that are already widely spread in their territory"* [European Union, 2019]. The trapping of Asian hornets does not require special authorization, as it is the case with other protected insects such as the European hornet (*Vespa crabro*) [Ruiz-Cristi et al., 2020]. The implementation of control strategies might be subject to National or regional regulations under the responsibility of specific authorities, as discussed in the following examples of measures:

- **Asian hornet nest destruction**: In Switzerland, the authority to remove and destroy *Vespa velutina* nests is set differently in each Canton; e.g., in Geneva a nest will be removed by the fire brigade, whereas in the Canton of Jura, the nests are removed by a private pest management company commissioned by this Canton. In the city of Vienna, the Fire Department is currently responsible for the removal of insect nests in public spaces (honeybee swarms and wasp nests), and **firefighters need to complete a special training**, which provides them a solid understanding on the biology and behavior of insects which is crucial for effective nest removal [Feiler, 2022].

- **Unmanned drones for observation or nest destruction**: The use of unmanned drones, might be regulated and/or restricted in terms of the flight height, the distance to the pilot, and the areas where it is allowed to fly.

- **Chemicals for nest destruction**: one way of destroying the nests of *Vespa velutina* involves the use of highly effective chemicals such as Chlordane, Tetrachlorvinphos, and Diazinon [Kishi & Goka, 2017], but these currently are banned from use in the EU. More detailed aspects of nest destruction are discussed next.

3・2

Nest removal and destruction

It is estimated that increasing the nest destruction from 30% to 60% could reduce the spread of the *Vespa velutina* by 17% and nest density by 29%. It is estimated that the spread could decline by 43% by destroying 95% of the nests [Robinet et al., 2017]. These figures seem promising, but suggest that the nest destruction needs complementary strategies and right timing, to ensure that the destruction of the nest actually contains the colony development. In this strategy the right timing for nest destruction before the young queens fly out to mate is key [BGD, 2021b], and should therefore be carried out at the beginning of spring and during the summer, when the colony begins to grow. Depending on the colony development, the nest removal and destruction may be extended until November, but going beyond into the winter season is no longer effective because the nests are not active anymore. Next to these seasonal implications, it is important to note the high labor and equipment costs that are needed to detect and destroy the *Vespa velutina* nests. Only in France, Italy and the UK, the annual cost of nest destruction is now exceeding 29 million EUR [Quaresma et al., 2022].

In additional to the equipment for the chemical and mechanical removal and destruction of nests, there are other materials needed. For example, the Vienna Fire Department has dedicated vehicles with special equipment, and carry protection gear (e.g., overalls, gloves and veils) and information and reference documentation for identifying the nest and insects, as well as to share with citizens for educational and information purposes [Feiler, 2022]. Special protection gear with thicker and more resistant fabric is required for safe *Vespa velutina* nest removal, because the *Vespa velutina* has a longer and stronger sting than honeybees. This also results in higher costs[19].

Mechanical and chemical approaches to remove and destroy nests are used, and in general, it is recommended to perform these operations at night or at dawn or dusk, when most of the adult hornets are inside the nests, to ensure an effective elimination of the colony.

[19] An example for a protective suit that has been tested for *Vespa velutina* attacks can be found in this French online shop: shorturl.at/pFL59 (access 15. 6. 2022)

3・2・1

Mechanical methods

Primary nest can be removed and destroyed in a non-invasive manner when they are easy to reach. The nest destruction should be done at dusk when the queen is in the nest with a few workers. The steps are as follows [MAGRAMA, 2015]: 1 Cover the entrance to the *Vespa velutina* nest. 2 Wrap the nest in a container e.g., a container of sufficient strength to prevent the Asian hornets from piercing it. 3 Detach the nest from its anchor. 4 Finally, destroy the nest.

Secondary nests, up to approximately 2.5 m above the ground, if accessible, are most efficiently destroyed using a special battery-powered vacuum cleaner with a transparent collection container that can be conveniently placed on the back of the person so that both hands are free to manipulate the vacuum cleaner hose or the vacuum cleaner hose extension handle. The foragers (so-called colony guards) at the edge of the entrance from the nest should be vacuumed first, followed by vacuuming the other individuals, and also parts of the nest cover.

Only the individual combs with larvae will remain inside the nest, which must then be manually removed and placed into a collection bag. It is necessary to place a trap (e.g., made of a plastic bottle filled with sweet fruit syrup) on the site of the removed nest, to trap Asian hornet workers that have been outside the nest at time of removal. After about a week, the trap should be removed. The hornets died after 10 minutes exposure at the sun. They can be given to the birds, burned or composted.

Prolonged freezing (minimum 48 hours) is also recommended to destroy nests. The incineration or the shooting might be performed when no other method is possible, should be authorized by the competent authority, and should be done avoiding the dispersion of *Vespa velutina* workers that could form new nests. Other approaches include the sedation of Asian hornets inside the nest by using CO_2 for a safer nest removal, e.g., as applied within the frame of AHlert by the authorized personnel of the City of Hamburg[20].

[20] The removal and destruction steps are documented in this video: https://bit.ly/3TkEoNN

3·2·2

Chemical methods

If the secondary nest is high in the tree crown, it can be eradicated with the application of Sulfur dioxide (SO_2). Once the gaseous substance enters the Asian hornet nest, the hornets suffocate within 3 seconds. The larvae remain alive and the portion of the workers that was outside the nest will try to rebuild the nest. It is therefore necessary to install a plastic bottle with liquid syrup to trap the workers which escaped the Sulphur dioxide treatment. The treated nest needs to be removed completely, and should either be composted or the larvae could be further used as feed (Zoos or ornithological societies could be contacted, as the larvae are a high-protein feed for poultry or even fish farming).

Other destruction method involves the injection of an authorized biocide (most often natural or synthetic pyrethroids) to cause the death of the Asian hornets inside the nest, according to the following steps: ① Close the nest exit. ② Inject the authorized biocide using application (e.g., injection poles) and protection equipment. ③ After not later than 48 hours, unhook the nest from its anchor and collect the remaining of the nest, as it might contaminate the ecosystem if not removed.

The use of chemicals poses a risk of dispersion and contamination, therefore, in all cases the indicated conditions of use provided by the competent authority and the manufacturer of the product must be strictly followed. The conditions of each area, the priority habitats and protected species should be evaluated, since in many cases the biocides contain *cypermethrins* or *tetramethrins*, which are considered to be dangerous for the environment. Normally the nest with biocide will be removed in a few days, so that the Asian hornets returning to the nest after application will be poisoned too. If the nest is difficult to access the inactivated nest might eventually never be removed.

To avoid the dispersion of chemical agents into the environment, recent approaches are looking into the use of heat, mimicking the defensive mechanism by honeybees when forming a heated "bee ball" around the predator when under attack. The temperature can reach 45,7°C to 52°C, causing the death of the predator [Ken et al., 2004]. In the case of the Asian hornets, studies show that the lethal temperature for hornets is 45,7°C. This principle allows to destroy the nests and kill the hornets by e-g., heating the nest with **steam injections**. A gradual increase in humid temperature seems more effective for killing the hornets inside the nest, but more studies are needed to develop an effective and safe thermal (steam-based) nest destruction method for *Vespa velutina* [Ruiz-Cristi, 2020].

3·3

Trapping of queens and workers

The effectiveness of trapping is still a matter of controversy between experts, because the efficacy is considered in general low; and traps might even generate adverse side effects on the entomofauna, by trapping native insects and thus reducing biodiversity. For a trap to be truly effective and selective, an attractive bait, only to the Asian hornet, is required, which at the same time is not attracting or is ineffective to other insects. At the beginning of the season (around March) honey and beeswax can be placed in a bait box. This is very attractive to Asian hornet queens looking for food. Very saturated sugar syrup or very ripe fruit are also very effective, and mixes of various types of bait can be used. It is important to be very generous on the quantity of bait because the more odor this generates, the greater the radius of action of the trap. Thus, filling the entire bait box to a height of about 1.5 centimeters is ideal. In the summer the Asian hornets search for protein, so dried fish is additionally recommended as bait to attract them to the trap. Research efforts are underway to develop a pheromone-based trap [Ya-Nan et al., 2022].

The eventual damage to biodiversity by installing traps is also the reason why some countries, amongst others Switzerland, prohibits the use of insect traps without special authorization. The use of traps is allowed in France, but in other countries or regions certain conditions must be met.

Trapping can limit the local damage caused by the *Vespa v.* when used, for example, as a specific measure to protect apiaries located in highly invaded areas. The key principle for a strategic and effective trapping strategy is to align it to the phases in the life cycle of the *Vespa velutina*. The example in Figure 14 shows the calendar recommended by the Spanish Ministry for Agriculture, Fishing and Alimentation (MAGRAMA) for the trapping activities.

The trapping calendar indicates phases along a timeline of a year. Starting with the winter phase, the installation of trapping devices is not recommended, because the overwintered *Vespa velutina* queens are not active, and the traps would attract other untargeted insect species.

In **early spring**, the first *Vespa velutina* foundresses appear. At this time traps shall be installed only in a radius of maximum 10 km from previously identified nests. A selective trap, shown in Figure 15, was developed in France by the beekeeper and *Vespa velutina* specialist Mr. Denis Jaffré[21].

Towards late spring, the foundresses are searching for food to build up their colonies, and at this time traps shall be placed within a radius of 30 km from areas where the *Vespa velutina* is present. Aside from trapping, the focus of seasonal controlling shall be to localize and destroy the primary nests.

In **summer** the colony starts building the second nest and the hornets feed mostly on proteins. In France during the month of August, even before the presence of Asian hornet workers is noticed, can meat baits such as fish bones, barbecue leftovers, and salmon cat food are used as bait. It is important that the bait smells strongly, so that the hornets will find it. From time to time, pouring a few centiliters of beer (e.g., a sweet beer, red fruit beer, etc.) in the bait box is recommended, as the yeast will create a fermentation of the bait and this will also increase its smell. The hornets take time to get used to the baits. Some baits can work well in one region and less well in locations few hundred kilometers away, because in some those areas there might be more prey and feed options for the hornets.

In France beekeepers work to divert the attention of the Asian hornets, which have become accustomed to feeding on the bees from the apiary. To do this, they place meat bait in the open air, in the spot where the trap (Preventive and Autonomous Capture Tank - in French BCPA) shall be placed. After a day or two, the Asian hornets will be used to feed there. Then the trap (BCPA) can de installed, keeping the same bait and even adding honey. The dead hornets are left inside the trap, as they will continue to release pheromones, which will continue to attract their fellow hornets.

In the fall the *Vespa velutina* is again feeding on sugar-based foods, e.g., from fruits or honey. Opinions vary on the effectiveness of baits. Old beeswax, light beer, currant or blueberry syrup are considered good attractants [MAGRAMA, 2015], however, recent studies have indicated a decreasing effectiveness of beer-based baits in fall. The reasons for this could be a change in the olfactive profile of the bait, as a consequence of changing environmental temperatures [Lioy et al., 2020].

The traps for reducing the damage to orchards and apiaries are installed as follows:

1 trap for every 10 hives
2 traps for every 25 hives
3 traps for every 30 hives
4 traps for more than 50 hives

[21] See: https://www.jabeprode.fr/fr.

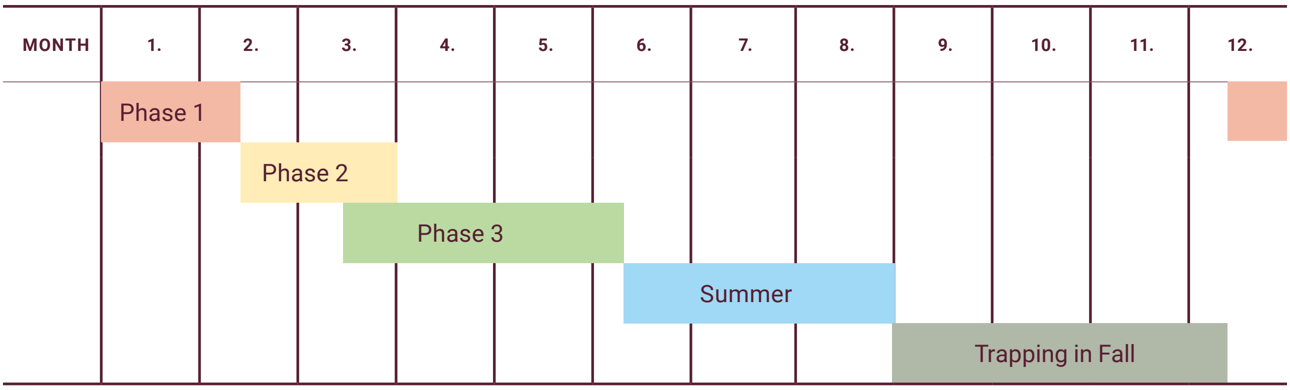


Figure 15: Trapping calendar as recommended by MAGRAMA, Spain [adapted from MAGRAMA, 2015].

3 • 4

Control measures at apiaries

A study conducted by USC and Ecoagrasoc (2022) describes the control measures that are commonly used at apiaries, which can be grouped into the following actions:

1. Using traps according to a specific trapping plan as discussed before.
2. Using apiary protective equipment, such as electric harps and nets.
3. Supporting the defense mechanism of honeybees, e.g., by reducing the entrance to the hives and/or installing apiaries at new locations.
4. Maintaining apiaries clean from residues, possible attractants to Vespa velutina.

3 • 4 • 1

Use of protective netting

Due to the size of the holes in the nets, they serve as a method of protecting the hives, since they allow the bees to pass through while blocking the passage of *Vespa velutina*. They can be used to cover the entire hive or as a muzzle by placing the netting only at the entrance of the hive. The muzzle generally consists of two boards placed on the sides of the hive on which a lattice with a 6 mm × 6 mm mesh is fastened. This system prevents *Vespa velutina* from entering the hives, but shifts the predation to a perimeter further away from the bees' entrance to the hive. The muzzle has the advantage of being a very cheap method, and one that honeybees get used to very quickly [Turchi, L., Derijard, B., 2018].

3 • 4 • 2

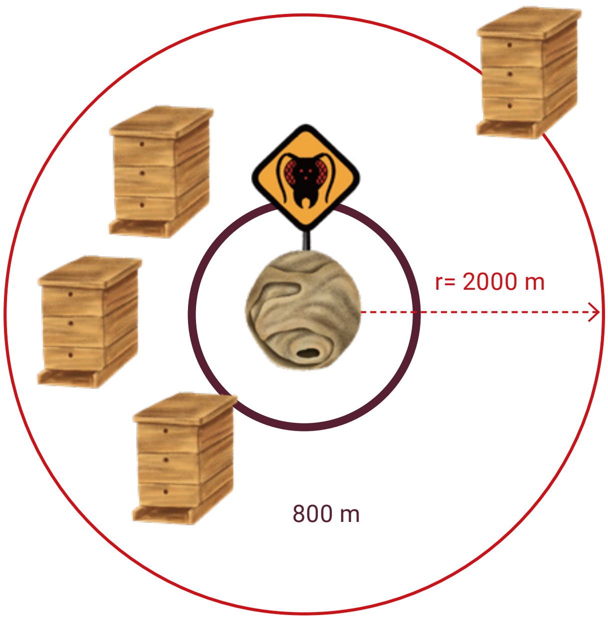
Electric harps

The electric harp is intended to electrocute *Vespa velutina* hornets passing through an armature of wires powered by a current generator. The separation of the conducting wires is such that the bees can fly past without touching them, while the *Vespa velutina* hornets inevitably touch the wires and are electrocuted [Turchi & Derijard, 2018]. Optionally, a container with water can be placed just below the trap so that these wasps drown once they fall electrocuted, but it is not strictly necessary.
The electric harp is placed between two hives because the *Vespa velutina* usually circles between the hives before stopping at the bee entrance. There are commercial electric harps available on the market, but there is also the possibility of making these devices homemade [Turchi, L., Derijard, B., 2018].

3·4·3

Support defense mechanism of honeybees

Strong bee colonies can withstand attacks from the *Vespa velutina* and endure bee losses [BGD, 2021a]. It is therefore recommended to take actions which support the overall strength of the colony, including artificial feeding, to sustain potential *Vespa velutina* attacks. Beekeepers can also take actions to avoid the exposure of honeybee colonies to *Vespa velutina* hornets. One possible action would be to narrow the hive entrance to 5,5 mm so that the hornets cannot penetrate the hive. Another less handy option, which requires much more consideration and planning is to move the hives to locations where the *Vespa velutina* has not yet been detected, or where there are no favorable conditions for her distribution or expansion. Based on the observation of the expansion of the *Vespa velutina* throughout Europe, certain conditions in the environment provide more ease to its distribution than others, e. g. river flows, the presence of high trees, and a large density of honeybee hives. The density of beehives and hence the abundance of foods are considered decisive in terms of the chances that *Vespa velutina* nests are built; although the flying radius of the *Vespa velutina* is considered 2 km, studies have shown that usually 600 m are enough for the *Vespa velutina* to find enough quantities of food [BGD, 2021b].



3·4·4

Maintenance of apiaries clean of residues

Good beekeeping practices involve maintaining clean apiaries and working spaces, to avoid the spread of diseases and potential attractants for predators of honeybees and honeybee products. As such, it is highly recommended to remove frames with honey remains in the vicinity of apiaries.

3 • 5

Biological control methods

The control methods described in this chapter require essential human effort: existing policies need to be assessed and evaluated, investments for tools and equipment are required, and a considerable amount of time to perform targeted actions is also needed. And even if given indications are thoroughly followed, there is no guarantee to be in full control of the situation. This is also because the learning about the *Vespa velutina* is on-going and dynamic, and hence, different coping mechanisms are yet to be implemented and assessed.

To lower the effort in relation to the described control strategies, much effort has therefore been dedicated to more "passive" strategies; such as the use of biological enemies that parasitize or that prey on the *Vespa velutina*. One limiting factor is that the use of biological agents might damage other (native) species. This is for example the case with the *Hymenopteran* called *Bareogonalos jezoensis*, which parasitizes the *Vespa velutina* in Eastern Asia. Since its distribution is limited to Eastern Asia, the potential impacts on the species native to Europe when using this biological agent remains unknown.

In France, a number of species parasiting *Vespa velutina* have been identified. A research group found larvae of *Conops vesicularis* (Diptera Conopidae) inside the abdomen of some individuals of *Vespa velutina*, and this has caused their death. However, the efficacy of *Conops vesicularis* as a biological agent to control *Vespa velutina* seems limited. Another potential parasite of *Vespa velutina* is the nematode *Pheromermis vesparum* (Nematoda Mermithidae), which was also found in adult specimens. The high potential of two entomopathogenic fungi (native French strains of *Beauveria* and *Metharizium*) as potential biological control agents against *Vespa velutina* invasion has also been described [Turchi, L., Derijard, B., 2018].

Some species of mammals (such as *Meles meles*) and birds (such as *Garrulus glandarius, Merops apiaster, Parus major, Pica pica, Sitta europaea* and *Gallus gallus domesticus*) can prey on *V. velutina*, but their predatory activity is sporadic and therefore do not have an effect on limiting the expansion of *Vespa velutina* populations [Laurino et al., 2020].

To this date, other hornet species (i.e., *Vespa crabro*, as well as the invasive species *Vespa orientalis*) show no competitive behavior towards the *Vespa velutina* [Thiéry, 2021a]. The large nest density of *Vespa velutina* in France[22], as well as lab studies conducted by French scientists, indicate that there is no competitive behavior between the species and queens of different colonies [Thiéry, 2022b].

In addition to parasites, fungi, and other animals, viruses have also been considered in recent studies as possible agents for combating the *Vespa velutina*. These include the Deformed Wing Virus (DWV), the Black Queen Cell Virus (BQCV) and the Kashmir Bee Virus (KBV), which are also found in honeybees. In fact, it is likely that the DWV has spread from prey (honeybee) to predator (*Vespa velutina*), but the transmission path remains subject of further research. The actual potential of viruses for combating *Vespa velutina* populations therefore needs to be better understood, and the potential impact on other species also needs to be evaluated [Marzoli et al., 2021].

In summary, biological control methods are still associated with uncertainty. Extensive and holistic research on the effectiveness and potential side effects (e.g., impacts on other species and biodiversity) need to be further conducted. Although some approaches show potential, the delivery of mature and effective biological agents against the *Vespa velutina* are not likely to be available in the short term.

[22] e. g., in the department of Bouliac, more than 50 nests in an area covering 7,5 km² were counted. It is likely that not all nests were recorded, i.e., the density could be even higher.

4

Preventing Vespa velutina

Climate change and rising temperatures, as well as mobility and the transportation of goods are favoring the expansion of invasive species worldwide. In the case of the *Vespa velutina*, its expansion in Europe is estimated at approx. 78 km per year, without considering possible human-mediated dispersal [Robinet et al., 2017]. Other studies indicate an expansion speed of 100 km per year. Even with the use of short-term controlling mechanisms, the progression of the *Vespa velutina* populations to other European countries is certain. The *Vespa velutina* can now be considered an established species in some European countries, and hence its complete eradication is illusory. The strategies presented can therefore reduce the impacts associated with the *Vespa velutina*, and potentially limit its expansion through Europe.

As indicated, the ongoing research to better understand the *Vespa velutina* and to evaluate potential strategies to limit its expansion is a dynamic field, and new approaches and research projects are emerging throughout Europe. A selection of measures has been described in this guide. To this date, no single strategy or measure has proven to be fully effective, which stresses the need for an integrated management approach, both related to an overall strategy (e.g., on a national or regional level) as well as for the apiaries.

Based on the identified strategies and measures, further actions to limit the expansion of the *Vespa velutina* mainly include:

1. The development and implementation of targeted strategies and Action Plans at different levels (international, national, regional, local), which shall define the responsibilities, authorities and roles to encounter the presence and control of the Vespa velutina.

2. The support to research activities for closing the knowledge gaps and for developing a better understanding of the biology and behavior of the Vespa velutina, as the basis for further developing effective control strategies.

These actions rely on each other: research findings need to be integrated into strategies, and the findings from practice and practical implementation should flow back to the research community.

Lastly, continuous **education and dissemination** are considered essential to prevent the *Vespa velutina*. As discussed in this guide, monitoring and control strategies rely on several competences and stakeholders. It is important to reach those stakeholders with relevant information, to ensure the collaboration and the effectiveness of defined Action Plans. Figure 16 shows examples with information about the *Vespa velutina*, targeted to beekeepers. Next to a variety of documents, videos are available online. Internet, social media and digital Apps enable a great opportunity for reaching various stakeholders in different locations, and offer formats for interaction and exchange. Moreover, funded research consortia usually carry out many dissemination activities such as presenting in conferences, recording webinars, and publishing their new insights and results in the form of academic papers and reports. Connecting and networking with such research projects is important to spread state of the art information.

This chapter further focusses on the strategies and Action plans as well as on research, as the main field of activities for the further prevention of the *Vespa velutina* in Europe.

4 • 1

Strategies and Actions Plans

As indicated, the *Vespa velutina* is declared an Alien Invasive Species of concern, and hence, the European Commission specifies: "Member States are required to take action on pathways of unintentional introduction, to take measures for the early detection and rapid eradication of these species, and to manage species that are already widely spread in their territory." [European Commission, 2019]. The management of invasive species and the responsibilities vary in each country assessed.

Likewise, most European countries have a federal system comprising several states, in which the responsibilities are again commissioned to different authorities: only in Switzerland, a country with 8.6 mil inhabitants, there are 26 cantons which means that in principle, 26 different authorities are in charge of managing observations and taking actions against the *Vespa velutina*. E. g., in the Canton of Geneva, the fire department is responsible for the nest destruction, whereas in the Canton of Jura, this task has been assigned to a private pest management company. Efforts to harmonize control strategies and to provide consolidated recommendations for beekeepers are currently on-going.

As the initial presence of the *Vespa velutina* in a certain region is usually considered a local outbreak, quick actions are required. With the continuous expansion to other regions, this might result in parallel ongoing initiatives, often without exchange of information. The dispersion of responsibilities, strategies and recommendations provided by local, regional, national or even European authorities can provoke misinformation or confusion amongst stakeholders which needs to be worked on. Therefore, there is a need for consolidation and harmonization, which is challenging because:

- The continuous research on the *Vespa velutina* is constantly providing new insights on the biology and the behavior of the species.

- The ongoing dynamics and developments, especially climate change, increase in temperatures and the global trade of goods might result in sudden and new conditions which affects the presence of the *Vespa velutina*.

The lack of financial resources as well as other events (e.g., the dynamics of Covid-19 pandemic) influence the work of researchers and authorities, possibly shifting the focus and resources to address other topics.

It is important to note that this harmonized strategy needs to be regularly evaluated, and it shall consider structural aspects that influence the expansion of *Vespa velutina*. These include, for example, geographical factors, abundance of food, density of honeybee colonies, and the opportunity to build primary and secondary nests.

To provide support to stakeholders, a consolidated *Vespa velutina* strategy shall cover the following aspects, and provide answers to a number of questions:

Scope

Which geographical areas does the plan cover and what is its temporal validity?

Background information

What is the Vespa velutina and what is its impact?

Guide for identifi ation

What are the identification marks of the Vespa velutina?

Definition of responsibilities

Who is responsible for the management of the Vespa velutina population?

Actions and recommendations

E. g. for specific target groups such as beekeepers

Measeres of success

How are actions evaluated and serving for the development of new actions?

Figure 17 shows an example of a regional action plan. It clearly defines the actions to be taken and the responsible authorities, and it also indicates the path for the generation of data, which shall serve as a basis for updating distribution and environmental maps.

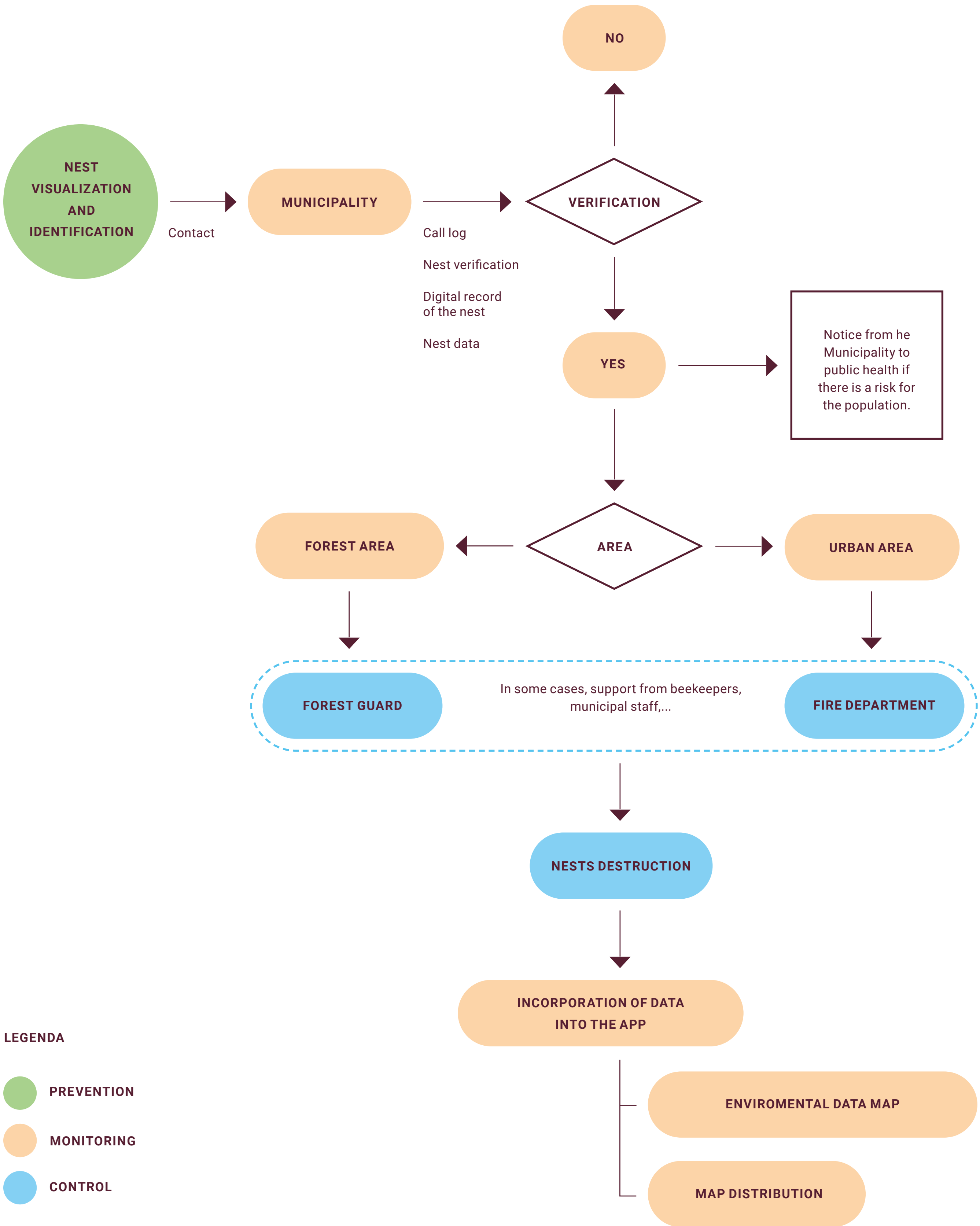


Figure 17: Action plan of the Basque Country, Spain [adapted from MAGRAMA, 2015 and Bizkaia, n.d.]

4 · 2

Research activities

Although the combination and thoughtful implementation of strategies can help control *Vespa velutina* populations, it is not expected that these strategies will completely eradicate this invasive species, at least not in the short to medium term. The *Vespa velutina* will continue to expand throughout Europe, due to the favorable environmental conditions and to the human-mediated movement of goods by transportation. Research has accelerated after the introduction of the *Vespa velutina* in Europe in 2004. This is key to understanding its behavior and impact on apiculture, biodiversity and public health, as well as to develop strategies to limit its further expansion and for sharing good practices. However, the lack and the reduction of financial resources present a major barrier to perform continuous research.

As presented in this guide, much work has been focusing on the development and assessment of different control approaches. These activities helped understand the negative impacts and low effectivity (e.g., of bottle traps), and have also revealed the potential of other measures, including more specific traps (e.g., pheromone traps), biological agents (e.g., fungi) and more environmentally sound nest destruction methods (e.g., using steam injection).

Another area of current research is focusing on understanding the risk of invasion of *Vespa velutina* in the future. A deeper knowledge about its spreading can support the development of strategies to control it, and it is also relevant to estimate possible impacts and costs in the future. This research hence considers in two aspects, one is retrospectively understanding the expansion and the other is, describing the potential scenarios in the future, to anticipate and apply suitable control mechanisms.

Geographical approaches based on modelling of climatic conditions are helpful in understanding which situations and topography are favorable for the establishment of the *Vespa velutina*. A 2011 study shows that each continent has suitable conditions for the establishment of the *Vespa velutina*, as seen in Figure 18.

Figure 18: Predicted global invasion risk of the *Vespa velutina* [adapted from Rome et al., 2011].

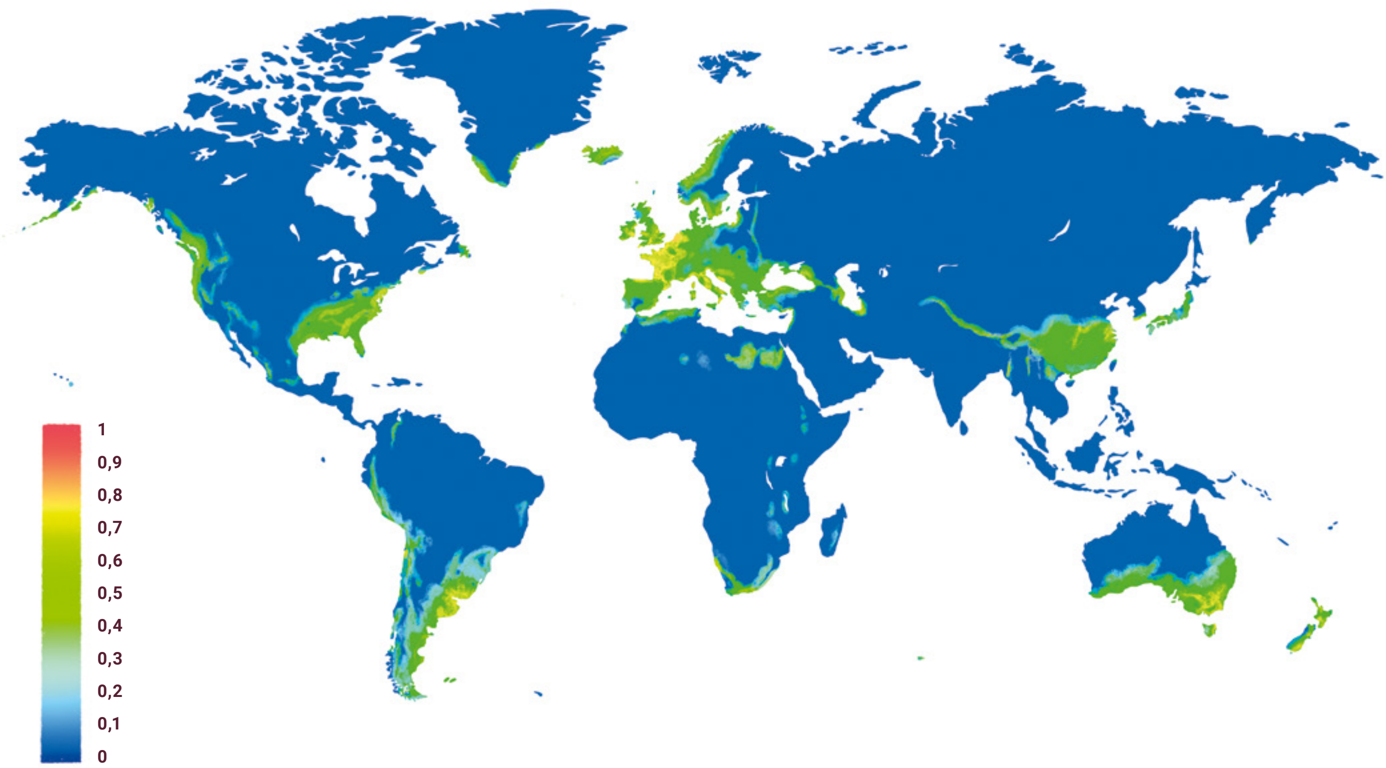
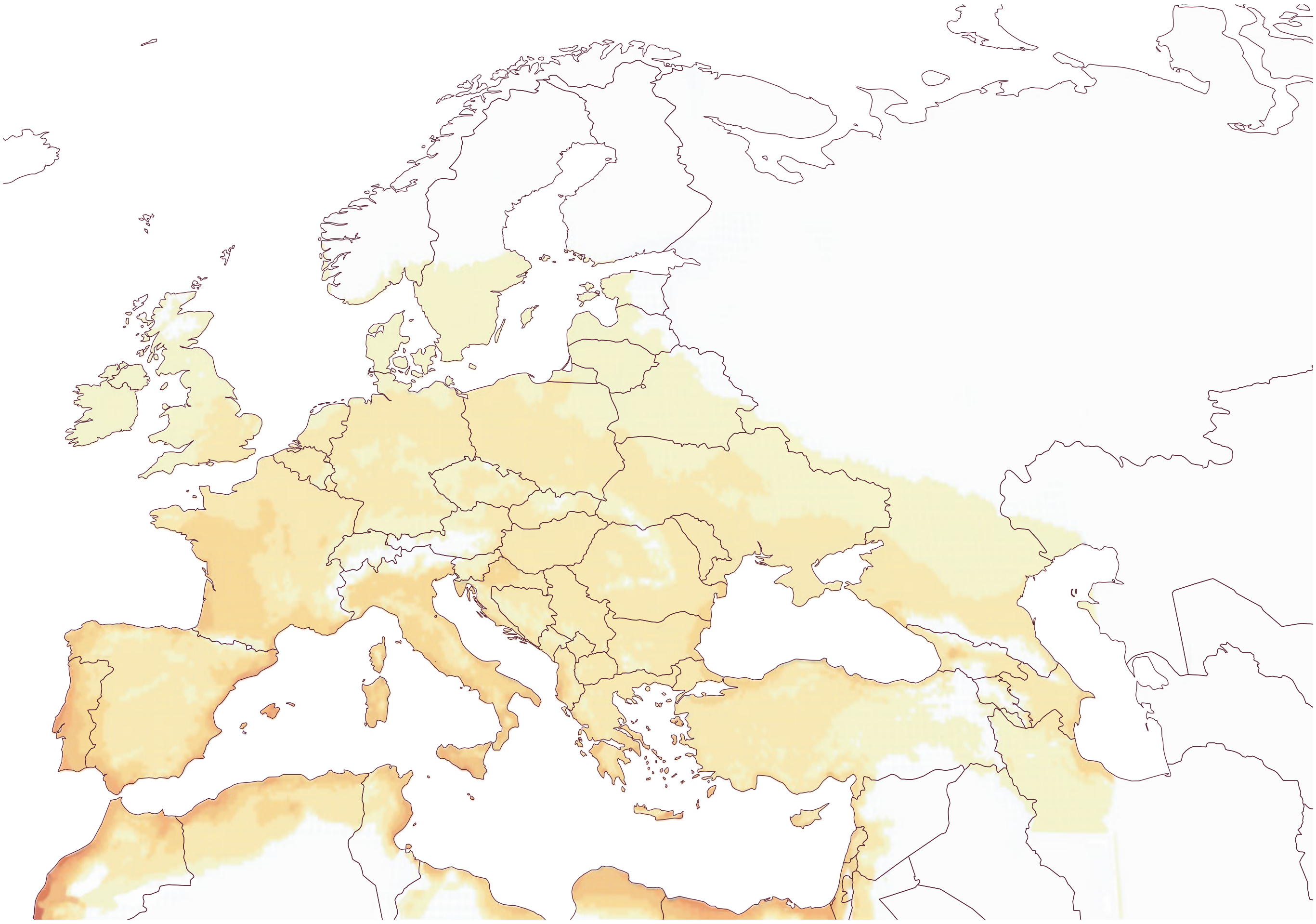


Figure 19: Potential distribution of *Vespa velutina* nigrithorax in Europe [L. Seehausen|CABI, 2022].



ECOCLIMATIC INDEX

0 | 0 – 10 | 10 – 20 | 20 – 30 | 30 – 40 | 40 – 50 | 50 – 60 | 60 – 70 | 70 – 80 | 80 – 90 | 90 – 99

Figure 19 shows the results of an ecological niche modelling, a method applied to predict the distribution of a species over geographic areas and time periods, by using environmental data. The red dots represent the recent distribution of the *Vespa velutina* (until 2019). White colored areas show that an establishment of the *Vespa velutina* there is very unlikely, due to unfavorable environmental conditions, e.g., because it is too cold or too dry. These maps are developed with large average distances; hence, the entire Alpine region is shown in white. Higher resolution maps show that settlement of the *Vespa* in the Alpine valleys is possible. The darker (yellow, orange) areas show a higher probability of an establishment of the *Vespa velutina* in many regions.

5

Lessons learned

This chapter summarizes the main lessons learned in relation to the Vespa velutina. These are presented for the three topics in this technical guide: Monitoring, Controlling and Preventing.

MONITORING

- According to the EU Regulation on Invasive Alien Species (IAS) (EU 1143/2014), the first observation of a *Vespa velutina* in a member country needs to be reported to the European Commission.
- The timely identification and monitoring of nests and hornets builds the foundation for developing strategies and actions for controlling the *Vespa velutina*
- Different monitoring strategies are commonly applied in Europe, which vary in cost, labor effort, effectiveness and selectiveness. The main monitoring strategies discussed in this guide are:
  - Observation of hives.
  - Traps with various designs, baits and attractants.
  - Remote observation with unmanned drones.
  - Hornet tracking for nest identification.
  - Sentinel hives.
- In areas where the *Vespa velutina* is already established, easy and self-made monitoring (bottle) traps are commonly used. However, these traps have a low selectivity and could be harmful for local biodiversity, including damaging protected insects such as the European hornet *Vespa crabro*. The use of such traps is, in some instances and areas, forbidden.
- The observation of hives and the use of sentinel hives is deployed in areas with very low density of *Vespa velutina*, or where it has been observed only sporadically (e.g., Ireland, Hamburg, Bavaria). On the other hand, given the low probability that precisely these hives are attacked by the Asian hornet implies that the effectiveness of these measures might be also low and even questionable considering the efforts required.
- Many *Vespa velutina* nests are found accidentally, therefore engaging and training citizens could support the monitoring efforts.
- The regular monitoring of nests seems very effective when combined with further actions such as nest removal and destruction, especially targeting primary nests.
- However, the identification needed prior to the destruction of nests might be quite intensive in cost and labor, e.g., due to the efforts to find and identify these nests.
- Research is underway for developing more selective traps, e.g., traps that use sexual pheromones to attract *Vespa velutina* drones. These traps could help interrupt the reproduction of *Vespa velutina*.

CONTROLLING

- The complete eradication of the Asian hornet *Vespa velutina* is unlikely at this point, because the species is already considered as established in selected EU countries, and its expansion (70 to 100 km per year) continues despite the intended human intervention to control it.

- No single control strategy so far (from those covered in this technical guide) has been proven to be fully effective. Moreover, the changing climatic conditions and the extensive trade of goods might further accelerate the expansion of the *Vespa velutina* in Europe.

- An integrated management approach and action plan is required, combining different monitoring actions and control options, in alignment with the lifecycle of the *Vespa velutina*. Ideally these plans shall also involve key stakeholders and actors.

- The life cycle of the *Vespa velutina* indicates that destroying the nests before the young mated *Vespa velutina* queens fly out seems to be a very effective measure, because it reduces the viability of new colonies to emerge in other areas.

- The destruction of nests using e.g., chemical agents or fire might involve risks for the environment. Other options to destroy the nests possibly involving less risks are under investigation, such as using CO_2, suction and heat/steam injection.

- Current efforts in research and in practice strongly focus on developing technologies to enhance the monitoring and destruction of primary and secondary nests, e.g., using unmanned drones, imaging with thermal cameras, and Artificial Intelligence recognition algorithms.

- The potential of using biological control methods, by means of different species that parasitize or prey on *Vespa velutina* is being studied. Species ranging from viruses and other microorganisms, to birds and mammals, are investigated and evaluated for their positive and negative impacts, especially concerning damages to other species and changes in ecosystems.

PREVENTING

- As the *Vespa velutina* is well established in certain regions in Europe the strategies discussed so far for the control and prevention primarily aim at reducing its impacts, as well as at limiting its further expansion in Europe.

- Barriers to the effective prevention of the *Vespa velutina* include the lack of sufficient knowledge (both at academic and research level as well as amongst target groups such as beekeepers), the lack of harmonized strategies and action plans, and lack of resources.

- Various action plans and strategies exist in regions severely affected by the *Vespa velutina*, with set responsibilities for actors and stakeholders together with specific actions.

- Also important are suitable information channels to promote trust and facilitate cooperation with the responsible authorities.

- Current efforts to prevent the *Vespa velutina* include the harmonization of strategies and recommendations (e.g., in Switzerland), as well as the dissemination of information and capacity building.

- A deeper understanding on the life cycle and the behavior patterns of the *Vespa velutina* is needed to assess possible expansion scenarios and evaluate potential impacts. In this context, the data from monitoring and observations needs to be integrated with data and maps of its distribution. Researchers are working with climatic and geographic models to identify environmental conditions that are favorable for the expansion of *Vespa velutina*. These would be areas targeted for more regular monitoring.

- Conducting genetic studies also helps to understand the development of populations as well as the reproduction behavior of *Vespa velutina*.

6

Insights for beekeepers

The Vespa velutina is considered a major threat to European apiculture, as honeybees represent a significant share in its diet. It is therefore responsible for honeybee colony losses. Beekeepers can therefore be considered the main stakeholder group impacted by the presence of the Vespa velutina. This chapter extracts the information presented in the work that are most relevant for beekeepers. In general, this chapter is based on two areas shown in Figure 20: suggestions for possible beekeeping practices, and the active contribution in dissemination through engagement and collaboration with other stakeholder groups.

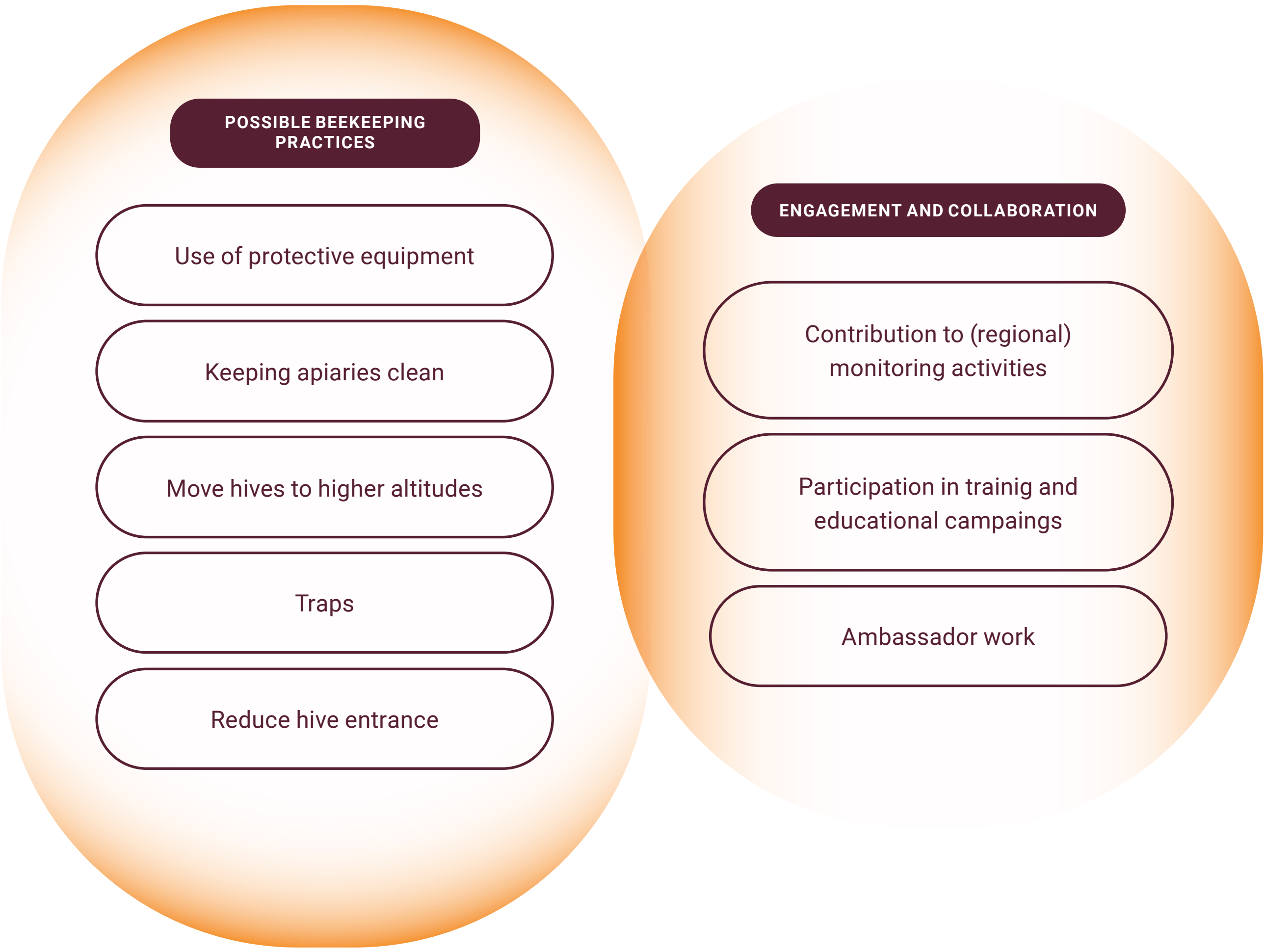


Figure 20: Areas of work for beekeepers to monitor, control and prevent the *Vespa velutina* [own figure, 2022].

6 • 1

Beekeeping practices

As described in this work, current strategies to effectively and safely combat the *Vespa velutina* are mostly targeting the destruction of nests, a practice that does not lay in the responsibility of beekeepers. The analysis in this work also suggests that the use of bottle and sticky traps does not effectively impact the *Vespa velutina* populations, and that the use of such traps might even cause more damage to biodiversity, given the fact that selective baits are yet under development. More research on this topic is required, so waiting for commercially available solutions is not an option. Meanwhile, the *Vespa velutina* continues to expand, and in certain regions the pressure on bee colonies due to the attacks is becoming higher.

With this baseline in mind, the question is more than justified: What can I do to actively protect my apiaries against the *Vespa velutina*?

The presented measures could support beekeepers to develop individual strategies to deal with *Vespa velutina* challenges in their own apiaries. It is unlikely that the presented measures can hinder the expansion of the *Vespa velutina*, but they can support the effectiveness of larger scale control mechanisms described in regional, local, or national Action plans and strategies. The application of these measures as part of good beekeeping practices also brings positive impacts on managing other risks and challenges, such as diseases and predators.

USE OF PROTECTIVE

e.g. electric harps, nets

The use of protection equipment for the hives is one essential measure for beekeepers. The protection with a mesh at the hives allows honeybees to move inside and out, but blocks the larger *Vespa velutina* hornets from entering the colony. These nets can be placed around entire hives or even for the whole apiary, though more commonly the smaller nets or muzzles are placed right at the hive entrance, as seen in. These muzzles drastically reduce the foraging paralysis and hence honey bee colonies maintain their foraging activity even in the presence of the predator [Requier et al., 2019]. Commonly 6x6 mm squared meshes are used, and it is recommended to place them in late summer, when the *Vespa velutina* begins their preying on honeybees. The muzzles can be removed in spring, as they can also block other larger insects or mammals from attacking honeybee hives in winter time. The costs vary from 15 Euros for home-made, to around 100 Euros for commercially available devices [Requier et al., 2019].

Another option is the use of electric harps placed at the apiaries along the hives, as shown in Figure 22. These consist of a frame that holds charged metal wires connected to a power supply. When the *Vespa velutina* flies through the charged wires, they are electrocuted and fall to the ground or in some cases, into a container with water placed below the harp. The gap between the wires is large enough for the bees to fly through without being electrocuted. The use of electric harps can mitigate the impact of *Vespa velutina* at apiaries [Pérez-Granados et al., 2021].

Figure 21: Examples of muzzles to protect the honeybee hive entrance [Left: André Lavignotte, n. d. Right: Núria Roura-Pascual, 2021].

Figure 22: Examples of electric harps installed in apiaries [Núria Roura-Pascual | Pérez-Granados et al., 2021].

REDUCE HIVE ENTRANCE

In the absence of measures that hinder the *Vespa velutina* from reaching the hive entrance (the muzzle or the electric harp), another option is reducing the size of the hive entrance to support the bees defense mechanism. This technique is usually applied by beekeepers during periods of robbery (in late summer) of weak colonies by strong colonies, and can also help protect hives against attacks from the Asian hornets.

KEEPING APIARIES CLEAN

Keeping the apiaries clean, and making sure that dirt, waste and residues from hive products are regularly cleaned and removed. This is a good beekeeping practice to prevent the spread of diseases and other pressure factors, and avoids attracting the *Vespa velutina* hornets to the apiaries.

MOVE HIVES TO HIGHER ALTITUDES

Research on the expansion of the *Vespa velutina* populations indicates that geographical features such as mountains seem to hinder the establishment of hornet colonies, and thus locating apiaries at higher altitudes, so far this is possible, might mitigate the exposure to *Vespa velutina*. The Alpine region seems so far to work as a geographical barrier for the expansion of the *Vespa velutina* in Europe [Bertolino et al., 2016]. However, the intense transport and movement of goods could promote the *Vespa velutina* expansion, despite the natural barriers.

TRAPS

From the available traps investigated (home-made and commercial) none can be fully recommended for their use in individual apiaries. The use of traps for monitoring and/or controlling the *Vespa velutina* always needs to be in accordance with the existing regulations, and must follow the recommendations and strategies in line with National, regional or local action plans as described in Chapter 3. 3. However, the use of traps could support the mitigation of *Vespa velutina* pressure at apiaries in the future, as selective baits and trapping mechanisms become available.

6 • 2

Engagement and collaboration

The majority of European beekeepers are members of a beekeeping association or bee related organization, and get their information from this exchange and participation. The current lack of education and knowledge is an important barrier to overcome when dealing with the challenge of Vespa velutina expanding in Europe. Therefore, the engagement and collaboration of beekeepers in their different organizations shall be promoted and supported. These could be through selected activities, discussed next.

CONTRIBUTION TO (REGIONAL) MONITORING ACTIVITIES

Monitoring hornets and nests, as this is key especially in areas not yet showing *Vespa velutina* populations and enables taking immediate actions, to quickly limit regional outbreaks and hence prevent the further expansion. In areas already affected beekeepers can help with reporting of observations and with validation as a starting point for authorized nest removal and destruction. They can also help to provide data into larger scale monitoring systems.

PARTICIPATION IN TRAININGS AND EDUCATIONAL CAMPAINGS

The participation of beekeepers in training and educational campaigns aims at transforming European apiculture into a professional and resilient sector. In the context of the *Vespa velutina*, training shall address both, building-up theoretical knowledge, but also gaining practical experience in tasks such as tracking hornets and eventually even on destruction of Asian hornet nests. Especially in countries and regions where the *Vespa velutina* is not yet present and poses a threat, capacity building is highly recommended, not only as part of the activities of beekeeper associations, but also at a larger international level through the collaborations with existing initiatives and projects, such as the BLESABEE[23] and COLOSS [24].

AMBASSADOR WORK

Experiences of regions in Europe which were able to contain the expansion of regional outbreaks of *Vespa velutina*, such as in the Italian Province of Liguria [STOPVESPA, 2022], show that a tight network of stakeholders and collaborators enables effective results. Beekeepers can actively participate in such regional/local networks, by providing monitoring data), and by contributing to the dissemination of information and creating awareness amongst other audiences and stakeholders.

[23] See the webpage of the international network for sustainable beekeeping BLESABEE: https://blesabee.online/

[24] See the webpage of the international honeybee research association COLOSS: https://coloss.org/

6 • 3

Overview of implementation

Combining the knowledge on the biology of the *Vespa velutina* with the measures presented in this chapter and considering their suitability, an implementation over the different phases in the lifecycle of the *Vespa velutina* could follow the sequence presented in Figure 23. This graphic shows a distinction between the measures which are focusing on the protection of the apiaries (in blue) and the measures that are more long-term oriented, with a local, regional and/or national scope (in green). Another differentiation refers to trapping, which might become a helpful method to prevent the *Vespa velutina* and associated impacts in the future, especially when more effective and selective traps are developed, tested and placed in the market.

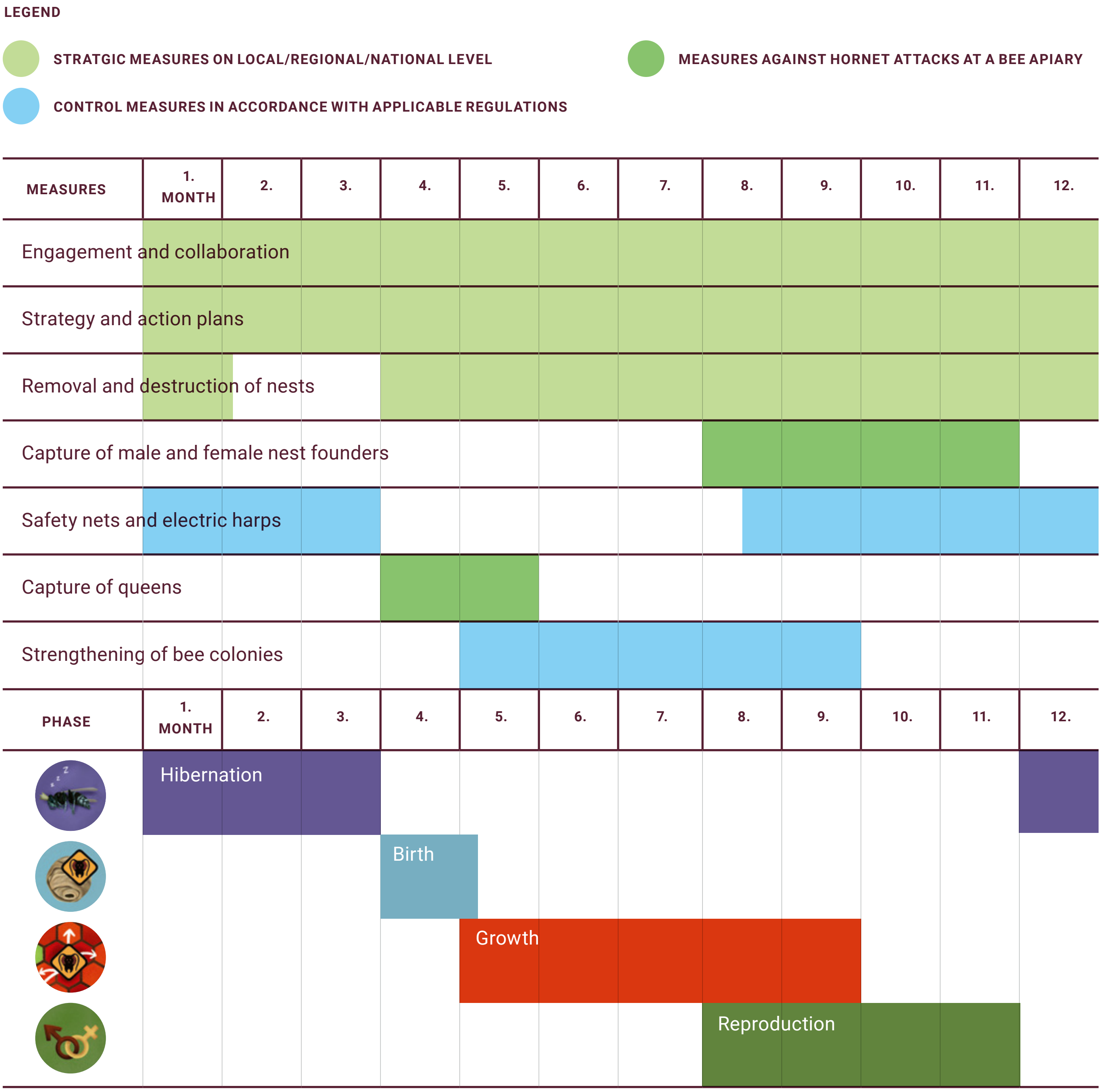


Figure 23: Alignment of various types of measures with the different phases of the lifecycle of the *Vespa velutina* [own figure, 2022].

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