Journal of Integrated Pest Management, (2024) 15(1): 43; pmae033
https://doi.org/10.1093/jipm/pmae033
Recommendations

Management of honey bee (Hymenoptera: Apidae) colonies under yellow-legged hornet (Hymenoptera: Vespidae) pressure

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Subject Editor: Katelyn Kesheimer

Received on 19 June 2024; revised on 24 September 2024; accepted on 22 October 2024

The yellow-legged hornet, *Vespa velutina nigrithorax* du Buysson, 1905, is a common predator of the honey bee, *Apis mellifera*, Linnaeus. It has become an invasive species in several territories around the world, constituting a major threat to beekeeping in those areas. Management strategies are based on destroying the hornets' nests, trapping adults, or physical interventions to protect honey bee colonies. However, there is a lack of information on how beekeepers should manage their colonies when the yellow-legged hornet is present. Here we present an overview of the life cycle and identification of the yellow-legged hornet, and common control methods used in apiaries. Moreover, we highlight the importance of management techniques for improving honey bee colony survival, including recommendations for beekeepers to achieve better colony health and strength. Essential for such management is close attention to colony food reserves and the provision of extra food when honey bee foraging is stopped by yellow-legged hornets predating foragers in front of the hive. Weak or diseased honey bee colonies succumb easily to the predator; therefore colony strength is key to survival. Although more research is needed to improve control strategies of this invasive species, this manuscript is a useful guide for honey bee colony management in invaded areas.

Key words: apiary management, beekeeping, invasive species, artificial feeding

The yellow-legged hornet, *Vespa velutina nigrithorax*, du Buysson, 1905, is a social insect considered to be an invasive alien species in several areas around the world, and registered in Europe as an invasive alien species of Union concern (EU 2016).

The accidental introduction of the yellow-legged hornet from its native area (northern India, eastern Nepal, Bhutan, and central and eastern China) to new areas occurred through 2 separate routes almost simultaneously. The first was to South Korea, where a nest was discovered on a building in 2003 (Kim et al. 2006). Subsequently, in 2012, the species arrived in the south of Japan, spreading widely (Ueno 2014, Kishi and Goka 2017). The second introduction was to Western Europe, where it was observed for the first time in France in 2004 (Haxaire et al. 2006, Villemant et al. 2006). Since then, several episodes of natural dispersal and accidental introduction have allowed it to colonize the European continent. In addition, a new introduction was reported in Georgia, United States, in 2023 (Georgia Department of Agriculture 2023).

Factors that explain the successful invasion of this species include the survival of a mated queen during transit from one region to another (Keller et al. 2011), and its ability to adapt to the new environment (Arca et al. 2015, Abou-Shaara and Al-Khalaf 2022). Moreover, the potential for males to produce large quantities of sperm, and the existence of polyandry (mating of a queen with several males), may have allowed increased genetic diversity during the early stages of the invasion (Poidatz et al. 2018, Prezoto et al. 2021). The absence of direct enemies and an inexhaustible supply of food have also contributed to its establishment in new territories. In terms of food, the species uses a wide variety of resources, both plant and animal, but a major component of their diet is the honey bee, *Apis mellifera* (Rome et al. 2021).

Here, we compile existing knowledge regarding the biology and life cycle of this invasive species in regions where it has shown the greatest adaptation and has had significant impacts on the beekeeping sector. We focus on strategies for honey bee colony management to mitigate the impact of yellow-legged hornets in apiaries, with a primary focus on ensuring the health and strength of honey bee colonies. To discover such strategies, we reviewed the most effective methods used in apiaries and the most common management practices used by beekeepers.

IPM for Yellow-Legged Hornet Control

Different stakeholders such as governments, citizens, and beekeepers can contribute to the prevention, early detection, eradication, and control of the species once it has become established in a territory (Requier et al. 2020a, Lioy et al. 2022). In terms of prevention, civil administrators, the state, or federal governments should be involved. It is essential to act as quickly as possible, creating regulation and control plans to ameliorate negative impacts on public health (due to stings), the country's economy, and environmental damage to other species with which it competes, or those it predates (Victorian Government 2010, Diagne et al. 2021). Due to multiple factors, including ecology and climate, responses to this invasive species have been customized by local authorities, resulting in different strategic plans in different nations and regions. Most of these strategies include nest destruction and trapping as the main forms of action, as seen in France or Spain (Gobierno de España 2015, Février 2024). A webpage or app for reporting cases is essential in countries where the species is not yet established. For example, the North Carolina Department of Agriculture has a reporting form for yellow-legged hornets (NCDA&CS Plant Industry Division 2024), the National Bee Unit in the United Kingdom has a smartphone app (GOV.UK 2017), and the Xunta de Galicia in Spain uses a chat web (Xunta de Galicia 2024).

By focusing on the life cycle and biology of this insect, it may be possible to identify aspects that could be exploited for the eradication of the species in non-native areas. For example, in order to plan trapping activities, it is vital to know the dates when the foundress queens start to emerge from hibernation to build their embryo nests. Also, there is a possibility of identifying female volatile compounds as sexual attractants for the males when they emerge in autumn, to remove males during the mating period (Cappa et al. 2019).

So far, the integrated pest management (IPM) strategies attempting to control the yellow-legged hornet have proven insufficient: in established areas, populations continue to increase, and sightings are reported in new territories every year (Monceau and Thiéry 2017, Pazos et al. 2022). In territories where the hornet has already established, IPM focuses on a long-term approach based mainly on nest removal and trapping. However, coordinated actions related to pest surveys, pest prevention, action guidelines, or research about management methods are rarely carried out or are done by private entities.

In this context, the sector most affected by the yellow-legged hornet is beekeeping: European beekeepers have reported colony losses between 30% and 80% and the reduction of beehive products (García-Arias et al. 2023, Laurino et al. 2019). Dealing with this hornet can interrupt routine beekeeping jobs. For example, beekeepers may be expected to take on tasks (such as searching for or removing nests) which are not part of their usual responsibilities. In addition, when beekeepers focus on capturing and killing hornets during the hornet season, they may not keep up with vital colony management. Since the only strategies available to the beekeeping sector are the capture of hornets by trapping, killing hornets by employing electric harps, or protecting hives using physical barriers (Rojas-Nossa et al. 2022, Barandika et al. 2023), it has become necessary to describe the integrated management of honey bee colonies predated by yellow-legged hornets in apiaries, emphasizing honey bee colony management rather than hornet capture. The most relevant goals for beekeepers in combatting this species are to focus on the management of honey bee colonies in terms of strength and health, ensuring that the food reserves available to the colony are adequate according to the season, and utilizing various approaches to diminish or mitigate the presence of yellow-legged hornets in apiaries. Coordinated actions taken by state or governmental entities together with beekeepers' surveys in the apiaries, in terms of surveillance and prevention, when the hornet is not yet in the territory, or coordinated plans in terms of control, if the invasive species is already established, will reduce the negative impact of the hornet on the beekeeping sector as well as on public health, the economy, and biodiversity (Robinet et al. 2019, Requier et al. 2020a) (Fig. 1).

Yellow-Legged Hornet Identification and Life Cycle

Proper identification of pests is essential for efficient eradication while minimizing or completely avoiding impacts on other species. The most significant morphological characteristic is the yellow tips of its brown legs, giving rise to the name yellow-legged hornet. The species has a completely black-brown velvety thorax and brown abdominal segments, each bordered with a thin yellow band. The fourth abdominal segment is almost entirely yellow-orange. The head of the yellow-legged hornet is black with an orange face.

The castes of the species are divided into queen (gynes, which will be the future foundress queens), females (workers), and males (Fig. 2).

The queens can be up to 3.5 cm long. Their function is to generate new adults by laying eggs, producing colony cohesion pheromones, and regulating the activities inside the nest; but queens also take care of the nest before the emergence of the first workers. Queens typically have a lifespan of about 1 yr, starting from their emergence in autumn and ending with their death the following autumn. Males usually reach 3 cm, depending on the size of the cell they develop in. They do not have a sting and have a blunt tip to the abdomen where the sexual organs can be identified. They also have longer and wider antennae than females. Their principal function is reproduction with the gynes. Workers are usually around 1.7–2.5 cm long, at most, and are commonly smaller in primary nests than in secondary nests. They are responsible for supplying food to the colony, distributing food among larvae, providing nest-building material (and remodeling of the nest), carrying water, ventilating to control excess heat and humidity, and defending the nest from predators (Monceau et al. 2014, Galartza 2016, Martin 2017, Bunker 2024). The relative abundance of each of the castes varies throughout the life cycle of the colony (Fig. 3). At the start of the cycle, a single queen starts laying eggs that eventually result in a large number of workers; toward the end of the cycle, new queens and males are produced (Monceau et al. 2014, Martin 2017, Bunker 2024).

When conditions are most favorable, the colony life cycle will start again immediately after the end of the previous cycle, at the end of January or beginning of February. Under less favorable conditions (such as at higher latitudes), the colony life cycle is compressed into a shorter period (e.g., March to November). Understanding the characteristics of local colony life cycles is critical for the use of control strategies such as trapping certain castes. Such trapping can negatively affect biodiversity of the area when not selective (Rodríguez-Flores et al. 2019). A mated queen starts the beginning of the life cycle with the construction of an embryo nest. This nest is characterized by being small and fragile. Inside, it contains a small comb

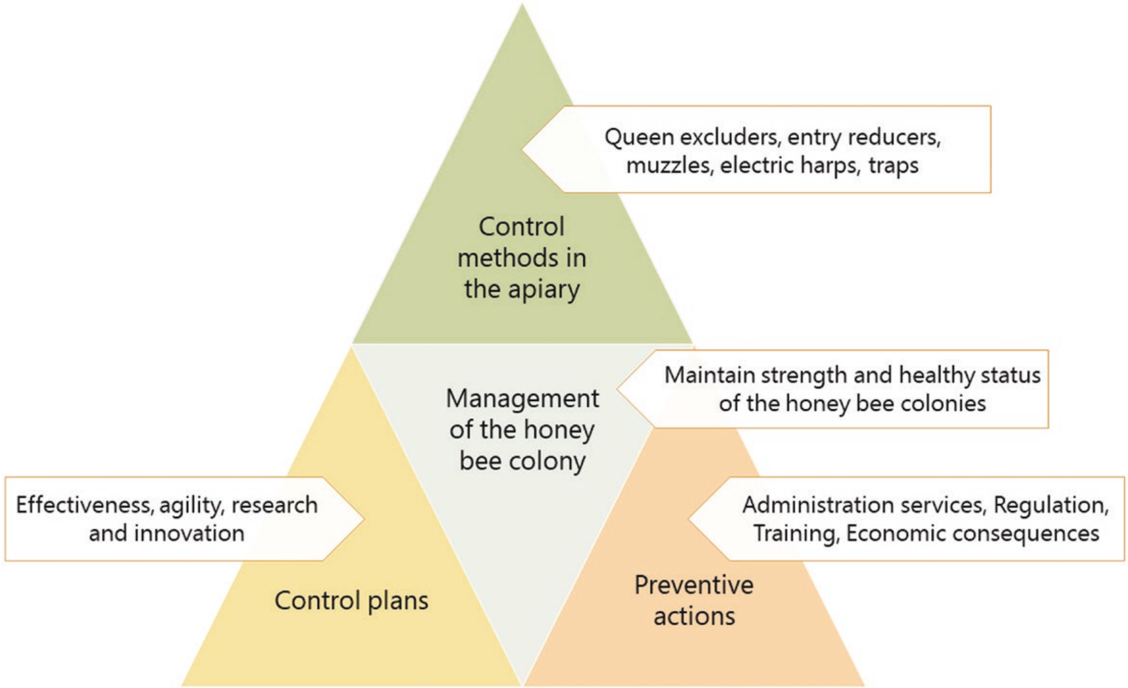

Fig. 1. Pyramid for integrated management of the invasive species yellow-legged hornet in apiaries.

Fig. 2. Characteristics of the head and abdomen of the 3 castes of yellow-legged hornet individuals (photos: Márcia Santos, INIAV).

with a few cells, and at the bottom of the nest, there is a hole that is used as an entrance. These nests are usually found in sheltered places such as buildings, hollows, inside beehives, on the ground, or in bushes, where their fragile structure is protected (Martin 2017, Bunker 2024). Commonly, embryo nests have only 1 queen; however, in several embryo nests located in Galicia, 2 queens were found (Diéguez-Antón et al. 2022a). This finding generates different hypotheses based on competition or cooperation. A queen may use another queen's existing nest to protect herself and make it her own, competing with the original foundress (Kumano and Kasuya 2006). On the other hand, egg-laying by 2 queens may offer a better survival strategy for small nests against predators (Prezoto et al. 2021). At the beginning of the season, the queen lays the first eggs, and the first larvae emerge and develop through 5 larval stages. The final larval stage prepares for pupation, during which there are 4 stages of metamorphosis before the adult emerges. Some primary nests contain both males and females. Because females are present, the queen is known to have mated, but the males may be the result of a loss

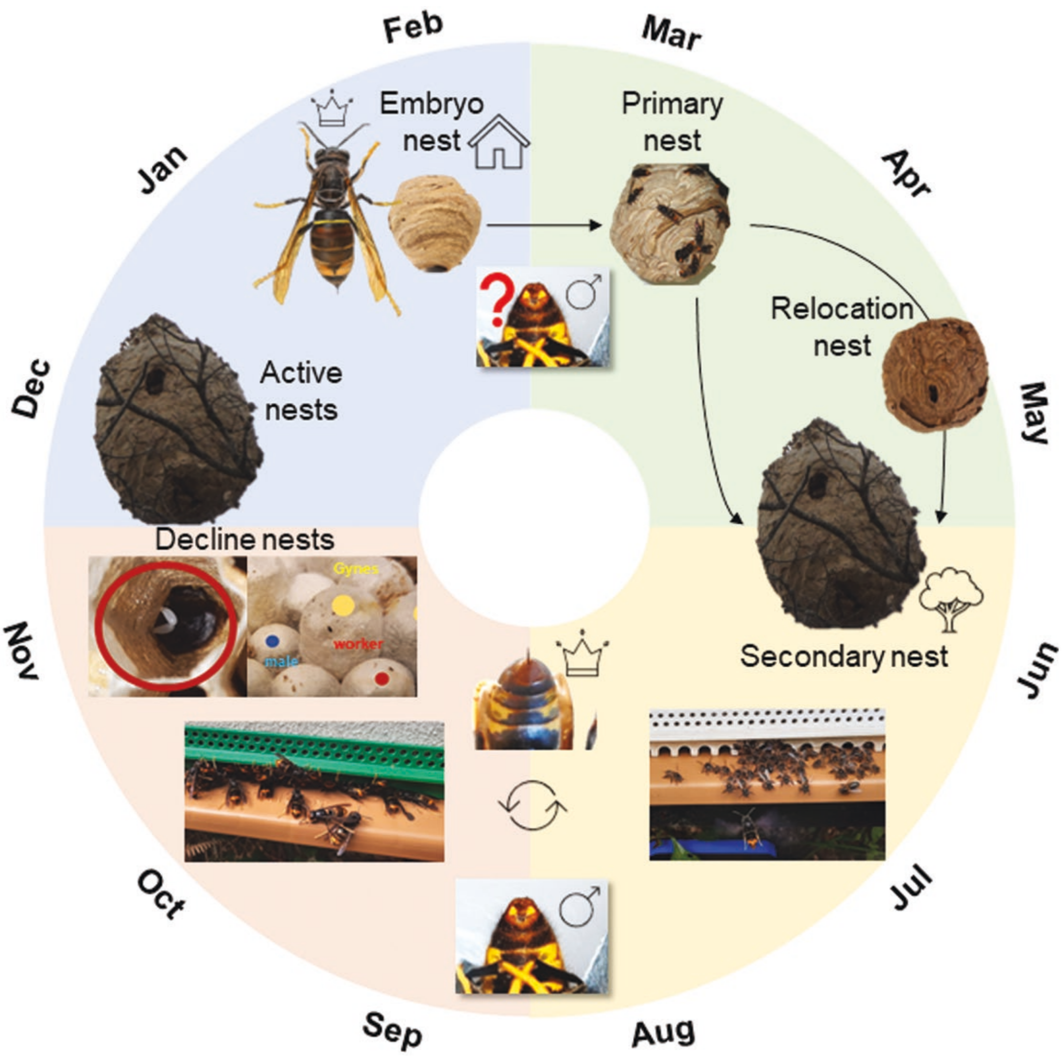

Fig. 3. Yellow-legged hornet life cycle.

of allelic diversity (diploid males) (Darrouzet et al. 2015). There is a hypothesis that normal haploid males produced at this time could possibly mate with overwintered virgin reproductive females.

Once the nest continues to enlarge and more individuals emerge, the nest is known as a primary nest, which can be the size of a football. This nest may be relocated if built in a place where it is not possible to further increase its size (Darrouzet et al. 2015, Diéguez-Antón et al. 2022a). This transition from primary to secondary nest occurs when the population is sufficiently large, in late spring, early summer, or midsummer, depending on weather conditions and latitude, among other factors. At that point, the nest has many larvae that need more protein resources. Secondary nests are often located in treetops, but can also be found in buildings, in the ground, in bushes, or in other locations (Carvalho et al. 2020). The nest continues to increase in size and can exceed sizes of more than 1 m in height and support a population of 30,000 individuals over the season in places where this invasive species is well established (Rome et al. 2015, Diéguez-Antón et al. 2022a).

As the population of a nest increases, the demand for nutrients also increases, leading to more attacks on apiaries. Depending on weather conditions and latitude, yellow-legged workers can be hunting honey bees in apiaries as early as April. Normally, the period of nest decline begins in autumn, when males and gynes are developing. It is also common at this time for brood to be distributed in an irregular pattern, with 2 eggs in many cells. The foundress queen dies and, once the new queens are mated, they look for a place to hibernate. However, where temperatures are not too cold over the winter (such as in coastal areas of Spain or Portugal), it is not known whether mated queens hibernate fully, or undergo some other form of diapause. In such cases, it is not clear when the biological cycle ends, as active secondary nests have been seen at the same time as newly mated queens feeding on nectar (Diéguez-Antón 2023).

Understanding the behavior of the species in the territory is crucial for developing effective management strategies in apiaries. The progression of the different phases of the hornet life cycle determines when the honey bee colonies are most susceptible to attack.

Yellow-Legged Hornets in Apiaries: Behavior and Damage Caused

The establishment of yellow-legged hornets poses a threat to the beekeeping sector because it endangers honey bee colonies and affects honey production (Table 1).

The yellow-legged hornet predates honey bees at a massive scale and at critical times for the survival of the colony (Fig. 4). The siege of the apiary is the main cause of reduced foraging among worker

Table 1. Effects and consequences of the presence of yellow-legged hornets in apiaries

Effects	Consequences
Honey bee colony siege (Monceau et al. 2014)	Loss of population due to predation (Laurino et al. 2019)
Massive predation of bees (Monceau et al. 2014, Laurino et al. 2019)	Decreased foraging (Monceau et al. 2018)
Vector of disease transmission (Rodríguez-Flores et al. 2022)	Confinement and stress (Diéguez-Antón et al. 2022b)
	Low or no honey production (Tan et al. 2013)
	Lack of pollen (Tan et al. 2013)
	Lack of water (Tan et al. 2013)
	Increased probability of disease (Rodríguez-Flores et al. 2022)
	Increased food consumption (Dong et al. 2023)
	Reduced queen laying (Dong et al. 2023)
	Colony collapse (Dong et al. 2023)

Fig. 4. Yellow-legged hornets entering a beehive.

bees and the reduction in the number of returning honey bees, which are hunted while foraging on flowers or on their arrival back at the hive (Monceau et al. 2013a, Laurino et al. 2019). Reduced foraging leads to decreases in the collection of pollen and nectar, but also of water, which is essential for processes such as ventilation.

When the siege is intense, it causes stress and confinement, reduces cleanliness, and increases susceptibility to infectious diseases. All this causes affected honey bees to consume food stored inside the hive. The queen reduces laying, and the colony population decreases (Büchler et al. 2020). This results in the weakening of, and possibly the collapse of, the honey bee colony (Dong et al. 2023).

The yellow-legged hornet has characteristics and uses techniques that enable it to be very effective as a predator. Firstly, it can hover, which facilitates continuous pressure in front of or under the entrance, depending on the number of bees at the entrance at the time of attack, and the strength of the colony (Monceau et al. 2013b).

If the entrance is full of bees, the hornet will most likely position itself under the hive, waiting for foragers to return. However, if there are few bees at the hive entrance, the yellow-legged hornet will attack the colony directly. If the honey bee colony does not have any bees at the entrance, the yellow-legged hornet will go directly inside, hunting the bees which are protecting the queen (Diéguez-Antón 2023). Weaker colonies have been observed to be attacked more by the yellow-legged hornet (Monceau et al. 2013a).

In places such as Galicia and Portugal, long periods of hornet pressure have been observed, usually starting in April. From then until winter, the presence of the yellow-legged hornet is constant. As the season progresses, the number of hornets increases, with the greatest pressure occurring in July, August, September, and October, depending on the location of the apiary (Diéguez-Antón 2023). Colonies decrease in population, weaken, and are unlikely to survive if the beekeeper does not manage them adequately and apply different control methods. The impacts of the

Table 2. Impacts of yellow-legged hornets on beekeeping, divided into direct and indirect effects

Direct	Indirect
Honey bee colony losses	Lower overwintering success
Need to provide external feed	Slow colony development
Low or no honey production	Difficulties in controlling diseases
Increased production costs	No productive colonies
Increased costs of hornet control methods	Abandonment of the activity
Discouragement of beekeepers	
Increased workload	

yellow-legged hornet on beekeeping can be classified as direct or indirect (Table 2).

Predation of honey bees in the summer and autumn months weakens colonies, many of which will not survive the winter without the beekeeper's intervention, as they have not built up necessary food reserves. To this must be added the increased fuel and labor costs for beekeepers arising from extra work, including setting and managing queen excluders, entry reducers, muzzles, etc. In fact, between February and April (depending on the region) it becomes necessary to set yellow-legged hornet queen traps; the purchase (or manufacture) of the traps and the attractants used in them represents a low investment compared with the increase in visits in order to set and maintain traps. During the peak period, catching foundresses in traps requires emptying the traps and resupplying attractants. This investment can increase the indirect costs of beekeeping by 10% (García-Arias et al. 2023, Requier et al. 2023).

The impact on honey production must also be considered, but is difficult to assess. Colonies with insufficient stores will not survive the winter without supplementary feeding, and even with food supplementation, many colonies that survive the winter do not develop sufficiently in the spring to be able to take advantage of seasonal resources, because they are weakened, resulting in a loss of honey production (Laurino et al. 2019). In any case, weather conditions are a determining factor, both in terms of the production capacity of apiaries, and their resilience to the impact of the yellow-legged hornet.

Honey Bee Colony Management

In addition to pathogens that threaten the survival of honey bee colonies, climate change and the presence of invasive species like the yellow-legged hornet are critical factors for colony losses.

It has been found that colony survival is closely related to the number of hornets hovering in front of the colony (Monceau et al. 2014, Laurino et al. 2019). Moreover, the number of hornets predating in front of the hives depends on the honey bee colony status (Diéguez-Antón et al. 2022b). The best preventive strategy to reduce the impact of the yellow-legged hornet is based on ensuring that honey bee colonies have plenty of individuals, good health, and enough food reserves (pollen and honey) (Fig. 5).

Control of Colony Health Status

Different factors are potentially responsible for colony weakening and colony losses and can be grouped into 3 categories: biotic factors (including pathogens, parasites, and predators), abiotic factors (agrochemicals, habitat disturbance, climate change), and those that depend on hive management (intensive production, poor training, international trade, human activity) (Walsh and Simone-Finstrom 2024). Among the pest and diseases, the one which represents the greatest problem for beekeeping is the ectoparasite *Varroa destructor*, a mite that increases the mortality rate of honey bee colonies, either directly or in association with other microorganisms such as viruses (Hristov et al. 2020, Traynor et al. 2020, FAO et al. 2021, Lin et al. 2023).

Yellow-legged hornets attack some hives more than others (Diéguez-Antón et al. 2022b). Field observations indicate that hornet pressure is higher on weak hives and, particularly, occurs in those with a high *Varroa* infestation rate, a low population, or a combination of several risk factors (Diéguez-Antón et al. 2022b).

Therefore, strong healthy colonies are vital when managing beehives in the presence of *V. velutina* pressure. The goal is to reach the period of high yellow-legged hornet pressure with low *Varroa* infestation.

There are several key indicators that serve as alerts when monitoring the health status of hives, using observations at the entrance and inside the hive (EFSA 2016) (Table 3). It is important to point out that both disease diagnosis and decisions on possible treatments should be advised by the veterinary service or beekeeping technicians, among others, and according to the national bee health program, if there is one. It is also essential to monitor the effectiveness of the measures adopted.

Influence of Yellow-Legged Hornet Pressure on *Varroa* Mite Treatments

High yellow-legged hornet pressure affects both the biology and the behavior of the honey bee colony, and such changes can be used as an opportunity when it comes to *Varroa* treatment.

On the one hand, the honey bees reduce foraging and form a kind of winter cluster to protect the queen from hornet attacks, reducing their movement inside the hive (Requier et al. 2019), which negatively affects the distribution of contact-dependent formulations against *Varroa* mites. In the case of these contact-dependent formulations against *Varroa* mites, it is essential for honey bees to touch the substrate: when honey bees become less active, this necessary contact will decrease, making these treatments less effective. In this situation, it is helpful to use a queen excluder placed between the brood chamber and the floor. This prevents hornets from entering the hive, making the brood chamber into a more secure environment for the bees, and allowing them to move around and come into contact with the treatment. In the case of evaporation treatments, ventilation must be facilitated.

On the other hand, under high hornet pressure, the queen lays fewer and fewer eggs, resulting in a rapidly reduced brood. Although this situation is terrible for the colony, it does afford the opportunity for treating against *Varroa* mites (Büchler et al. 2020, Dong et al. 2023).

Control of Colony Nutritional Status

The yellow-legged hornet causes a prolonged confinement of honey bee colonies, which results in a reduction of nectar and pollen to feed any brood, resulting in poor nutrition (Tan et al. 2013). This causes several sublethal effects such as compromised immune function and increased susceptibility to diseases and agrochemicals (Nicholls et al. 2021, Bocquet and Tosi 2022). Therefore, honey bee nutrition influences honey bee health at both individual and colony levels. At the individual level, the microbiota plays a key role in honey bee physiology (Motta and Moran 2024). At the colony level, the availability of food sources, such as nectar and pollen, improves resilience, and the availability of varied nutrients influences social immunity and

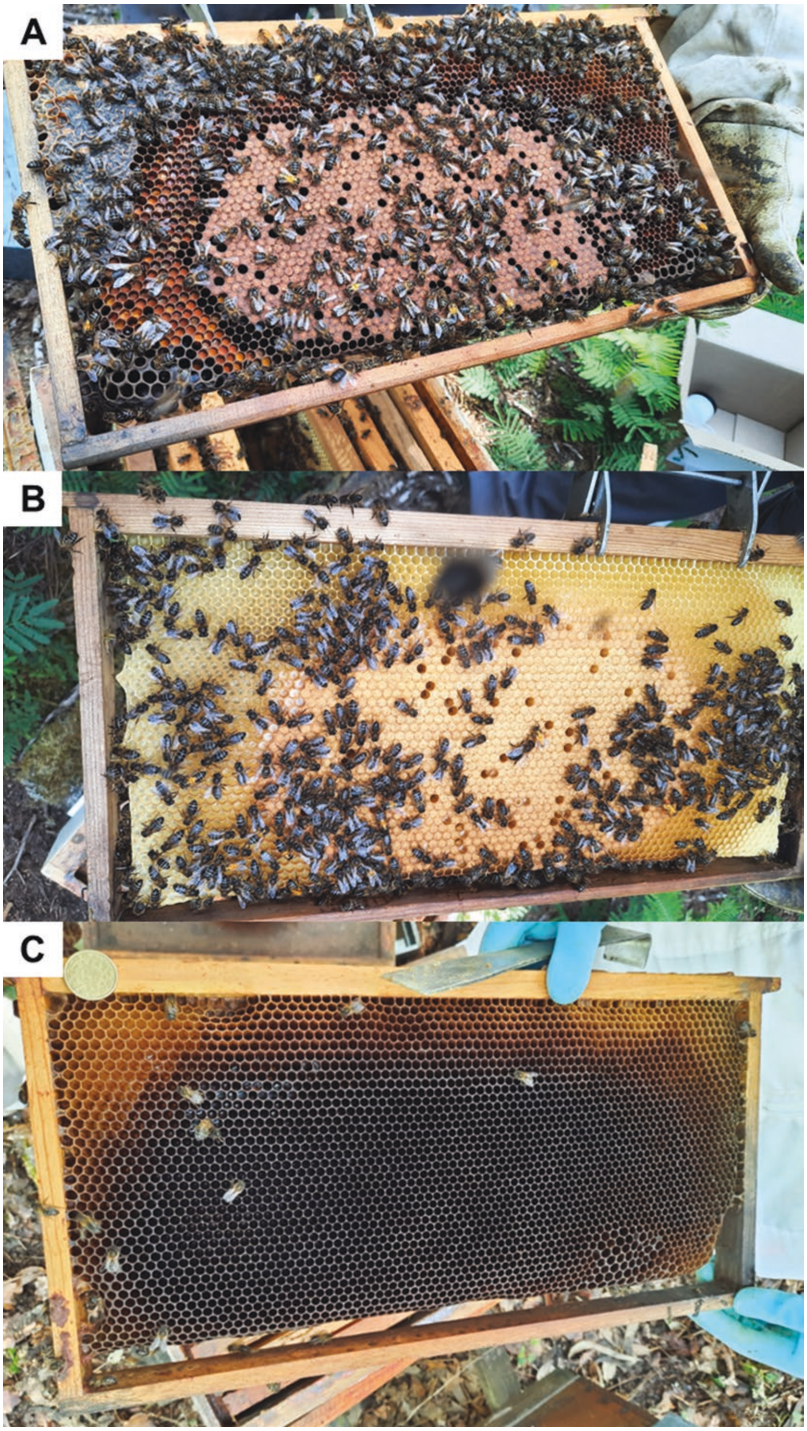

Fig. 5. Frames with different honey and bee bread reserves. (A) A good frame with honey and bee pollen next to the brood; (B) a frame with brood and low food reserves; and (C) an almost empty frame.

behavior (Simone-Finstrom 2017). The diversity and abundance of botanical resources are crucial for brood production, immune function, and overwintering honey bee survival (DeGrandi-Hoffman et al. 2016). Nectar serves as a source of carbohydrates, while pollen is the major source of protein, lipids, and micronutrients. Pollen is of particular interest as it stimulates colony growth and increases resistance to environmental stressors by allowing the colony to replace bees that may be dying at an accelerated rate (Di Pasquale et al. 2013).

Supplementary feeding should be adapted to the needs of the hive, depending on location, season, honey bee population dynamics, and colony growth state, to ensure successful overwintering and protect honey bees from food deficits (Brodschneider and Crailsheim 2010). The appropriate type of feed requires careful consideration of seasonal weather conditions and the circumstances of each colony, including food reserves and brood (Manning 2016, Paray et al. 2021, Vicente et al. 2024). To determine whether a colony has food stocks, the hive must be opened, and frames examined. Depending

Table 3. External and internal indicators for monitoring honey bee colony health status under yellow-legged hornet pressure

	Observation	Meaning	Actions to be implemented (1)
External indicators	A lot of hornets at the hive entrance	Possible health problems in the colony, check interior and/or bottom of the brood chamber for *Varroa* or poor population.	If *Varroa* infestation is present, implement treatment against it If there is a low population: determine the reason, reduce the space for the entrance and/or adapt the space to the bee population
	No honey bees at the entrance	This could be due to few bees in the colony, or could be related to external factors such as low temperature	Place a queen excluder between the brood chamber and the floor to avoid yellow-legged hornets gaining entrance to the hive[a]
	Hornets going into the honey bee colony	This could be due to a weak colony with a low population	Adapt the space and put a queen excluder between the floor and the brood chamber to prevent hornets from entering[a]
Internal indicators	*Varroa* on the honey bees or brood and honey bees with deformed wings	High *Varroa* and/or associated viruses	Mite treatment If the virus persists, use feed supplements
	Low population	Old/bad queen, imbalance between adult honey bees and brood	Reduce/adapt the space of the hive to the population Decide if any treatment is necessary Insert queen excluder between the floor and the brood chamber to avoid the entry of hornets[a]
	Spotty brood	Brood diseases: *Varroa*, American/European foulbrood, chalkbrood, or old/bad queen	(1) for the application of treatments, diagnosis of diseases, and supply of feed supplements

(1) Consult the veterinary service, beekeeping technicians, or technicians from associations for the application of treatments, diagnosis of diseases, and supply of feed supplements.

[a]Be careful when installing a queen excluder because if drones and dead honey bees cannot be expelled, it is possible to asphyxiate the colony.

on the food stocks, the nutritional status of the colony will range from good to critical (starvation) when bees can be seen with their heads stuck in empty cells.

When yellow-legged hornets attack colonies, external indicators of food input, such as pollen on bees, are difficult to assess because the bees are not foraging. For example, in the coastal areas of Galicia (NW Spain), colonies often have deficiencies in pollen that are exacerbated by the pressure exerted by the yellow-legged hornet. Consequently, protein reserves are very poor or even nonexistent and need to be supplemented. Thus, food supplementation becomes necessary for honey bee colonies when there is a high incidence of hornets in the apiary and the honey bees are unable to forage. There could be low food resources inside the colony, so it is important to check inside (Table 4).

Control Methods in the Apiary

As mentioned before, beekeepers should focus on managing their colonies if they are to survive under yellow-legged hornet attacks. If beekeepers do not manage their colonies, all the control methods they use to reduce the number of yellow-legged hornets in the apiary are useless, as their colonies will not survive. Once management is in place, control of hornets can be considered. There are different control methods for the hive or apiary to prevent hornets from entering the hive, and to reduce the number of hornets in the apiary, respectively.

Entrance Reducers and Queen Excluders

Entrance reducers (5- to 6-mm gaps) are used to decrease the entrance aperture size of the hive, limit heat loss of the colony, and facilitate defense of the colony by bees. Entrance reducers are essential to stop mass entry of hornets into the weakest honey bee colonies. Such reducers can also protect the hive from other enemies, such as small rodents (Al-Fattah et al. 2014, Breece et al. 2018). However, it should be noted that some yellow-legged hornet workers are small and can get through such a barrier, killing the honey bees within, and leading to colony collapse (Papachristoforou et al. 2011).

The queen excluder (4.3-mm gaps) is a hive component designed to prevent the queen, who has a larger abdomen than the workers, from going up to the honey supers to lay eggs. It normally separates the brood chamber, where the queen lays eggs and larvae are reared, from the honey supers where the bees keep honey. Therefore, a queen excluder can be placed between the brood chamber and the floor of the hive, or at the entrance to the hive, to stop yellow-legged hornets entering the hive: even small hornets will not be able to enter through this barrier. This allows the bees to be protected inside the hive, even if they cannot forage. Such security allows the bees to move throughout the brood chamber without being crowded together.

The queen excluder prevents hornets from entering but also prevents drones and the queen from leaving. Therefore, once the period of high hornet pressure is over, this excluder should be removed to avoid problems with the expulsion of drones or dead bees, and with swarming in spring, because the queen will not be able to leave. If the lower queen excluder or entry reducer is not removed, the colony could asphyxiate due to lack of ventilation because drones and dead bees cannot be fully expelled from the hive.

Queen excluders and entrance reducers are both low-cost components, and do not have environmental impacts.

Muzzles

These are devices placed around the hive entrance during the months of higher yellow-legged hornet pressure. There are several types of muzzles available for protecting hives: they are usually homemade and some also capture hornets.

One type of muzzle has a small mesh of 6 × 6 mm (Turchi and Derijard 2018). Depending on the version, a plastic tube may be installed at one end, covered with a plastic mesh, to capture hornets. This type of muzzle works because yellow-legged hornets tend to

Table 4. Internal indicators for monitoring honey bee colony nutritional status under yellow-legged hornet pressure

	Observation	Meaning	Feed?
Early poor nutritional status	Low amounts of honey and pollen	Possible nutritional problems	Supply protein and carbohydrates
	Headless pupae in cells	Protein needed	Revision of food stocks especially pollen. Provide protein
	Low population	Insufficient population for hibernation	Feed to breed a strong and healthy population for overwintering.*
Nutritional stress	Low honey stocks next to the brood and no bee bread	First sign that the colony is consuming its food stocks. If there is no pollen, there will be no brood.	Depends on honey and pollen stock. Move the frames with food stocks next the brood.
	Dried larvae	When food reserves decrease, the amount of royal jelly given to the larvae by nurse bees decreases.	Feed the colony with protein and maybe carbohydrates.
	Reduction of brood	When the food decreases, the brood decreases.	Feed the colony with protein and carbohydrates.
Critical nutritional status	No sealed brood. Cannibalism.	When the colony is in this critical nutritional state, the adults bees begin to eat their brood. Frames with no brood and eggs will be observed, or if brood is present, it will follow an irregular pattern.	Feeding is essential. Replace empty frames with pollen and honey stocks and feed with carbohydrate and protein.
	Dead pupae and young bees are found dead on the floor.	Colony is starving and has no capacity to feed brood. Dead bees are found with their proboscises out and in empty cells. Many dead bees will be found on the floor.	Colony could not have solution.
	There are dead bees with their heads in empty cells.	Sign that the colony has collapsed. The colony died of starvation.	Too late to save the colony, colony will die.

*Uniting colonies would be another solution.

ascend once enclosed. The muzzle has an entrance at the level of the hive entrance that allows the bees to enter and exit. When yellow-legged hornets access the muzzle and feel enclosed, they try to escape by climbing up the mesh toward the "chimney" and become captured (Fig. 6).

Another type of muzzle stops the entrance of yellow-legged hornets into the hive, using a similar mechanism to the entrance reducer and queen excluder. In this case, the muzzle should be located more than 25 cm away from the entrance to avoid bees getting stressed by the hornet (Requier et al. 2020b, Bonnefond et al. 2021) and allow them to expel drones or dead bees without causing the colony to asphyxiate.

All these types of muzzles are low-cost, and do not lead to any environmental impacts.

Traps

The purpose of yellow-legged hornet traps is to capture queen foundresses in spring, future queens at the end of the life cycle, and workers in apiaries when there is high pressure.

Foundress queens hibernate close to the secondary nests they came from the previous year. They build their nests in early spring in protected locations and feed on sugary liquids. Therefore, the emphasis should be on locating foundress traps close to previous nest sites.

There are different trap designs, both in construction and in the characteristics of the attractant liquids. The attractant liquid must contain a sugary component and some type of alcoholic liquid to reduce the attraction of other insects such as bees.

In general, the traps are not very selective and capture a wide variety of organisms, which interferes with the balance of biodiversity. Some studies mention the negative consequences of this control method and question its effectiveness in reducing yellow-legged hornet populations in areas where traps are placed (Rojas-Nossa et al. 2018, Rodríguez-Flores et al. 2019, Rome et al. 2021). Improved trap efficacy and higher specificity of attraction are relevant objectives to avoid biodiversity losses (Lioy et al. 2020). In the case of traps installed in apiaries with high yellow-legged hornet pressure, it is evident that they capture many hornets, compared with other types of insects, so they do help to reduce pressure on colonies, although they do not solve the problem. Traps are low-cost interventions.

Electric harps

These devices are placed between hives to electrocute hornets. They are installed when the first hornets appear in the apiary and should remain in place if there is pressure, usually in the summer and autumn months. Electric harps consist of a series of fine vertical wires that are electrified. The gap between the wires allows a honey bee to fly through it, while larger insects such as the yellow-legged hornet touch 2 wires simultaneously and are electrocuted.

Some studies report good results with the use of electric harps, controlling the pressure effectively, while in other cases the results seem worse (Turchi and Derijard 2018, Rojas-Nossa et al. 2022, Pérez-Granados et al. 2023, Thiéry et al. 2023). Harps allow bees to forage and therefore obtain food in the field, but they do not eliminate the presence of all hornets in the vicinity of the apiary, because the hornets learn to avoid the electric harps. The effectiveness of the harps depends largely on their placement. They should be installed in front of the hives, between and perpendicular to them, in order to intercept hornets as they circle around the hive. The harps should be located between every 2 or 3 hives (Fig. 7A).

These devices need continuous attention, both for repositioning, because the hornets learn their position and avoid them, and to reactivate them, because they frequently become deactivated. Also, the use of direct electric current has risks. This is one of the most expensive control methods and, if relying on photovoltaic panels for power, it may be difficult to obtain enough electricity if the apiary is in a shady place. Other types of nontarget

Fig. 6. Muzzle with the chimney located in front of the beehive entrance.

insects such as honey bees can be affected by harps (Rojas-Nossa et al. 2022) (Fig. 7B). In addition, birds were found in electric harps in Galicia.

Suggestions for Implementing Different Control Methods in Apiaries

Here we look at the main tasks, by season, for beekeepers wanting to improve the health and strength of honey bee colonies, decrease the number of hornets in the apiary, and stop them entering hives.

Spring

In most areas, this is when the honey bee colony starts to develop. The quality of the queen, the availability of adequate food reserves, and the absence of diseases are essential for good colony development. It is important to check that the colonies have a low *Varroa* mite load. We recommend:

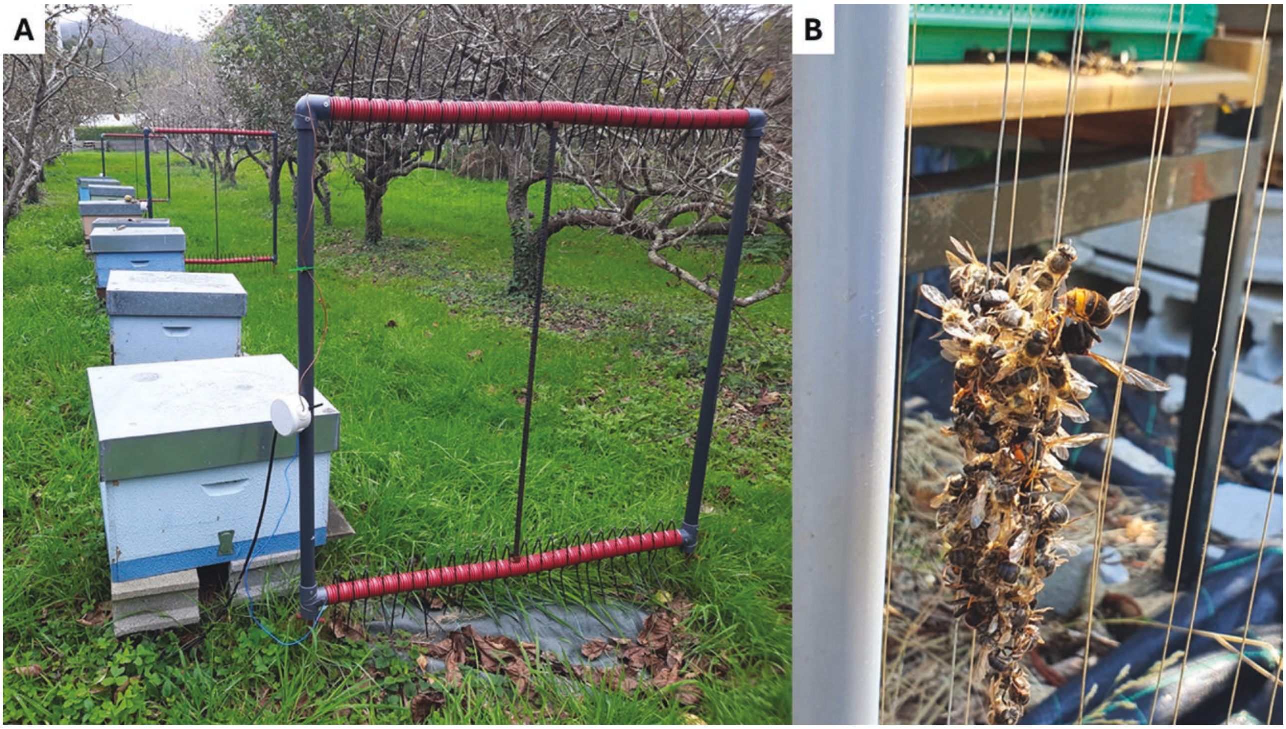

Fig. 7. Electric harps located in an apiary (A) and honey bees electrocuted around a wire of the electric harps (B).

- Checking the colonies after winter: general condition, queen activity, quality of laying, food reserves, population estimate.
- *Varroa* load counting. If necessary, implement spring *Varroa* mite treatment.
- If yellow-legged hornets are observed, follow the premises of colony management (health and nutrition) and apply physical protection methods if necessary.

Summer

At the beginning of this season, the first hornets start to hunt honey bees in apiaries. Among the activities to consider are:

- Maintain strong and healthy honey bee colonies.
- Harvest the honey before the highest pressure of yellow-legged hornets.
- Use *Varroa* mite treatment as soon as the honey is harvested (check the section: Influence of Yellow-Legged Hornet Pressure on *Varroa* Mite Treatments).
- Install physical methods to protect the colonies and to control yellow-legged hornets if necessary.

For the weakest colonies, it is time to install a queen excluder or entry reducer, but consider removing it if there are drones or dead honey bees in the colony, to avoid asphyxiation in the hive. The beekeeper can install muzzles, electric harps, or traps: it is important for the bees to get used to such obstacles as quickly as possible.

Autumn

This season and the summer months are the seasons with the highest number of yellow-legged hornets in apiaries, and honey bee colonies may be weak, due to foraging effort and *Varroa* mite load. It is important to check the amount of food reserves available inside the hive. The activities to consider are:

- *Varroa* mite treatment (if not done before).
- If food reserves are low, provide liquid and protein, depending on the colony status (Table 4).
- Reduce the entrance size if the colony is weak and has a small population, using an entrance reducer or closing the entrance down to 1 bee width. Do not reduce the entrance if the colony has a big enough population, it would be counterproductive.
- If there are no drones inside the colony, place a queen excluder between the floor of the hive and the brood chamber, or at the entrance to the hive.

Feed the colony to renew the population and to have young and healthy honey bees for the winter. Be careful with robbing. If yellow-legged hornet pressure is high, traps can be placed to decrease the number of hornets, since at this time only yellow-legged hornets will be captured in the traps. In addition, the capture of these yellow-legged hornet workers will result in less food reaching hornet larvae in the nest and will cause an eventual decrease in the size of emerging hornets. The beekeeper can install electric harps or muzzles.

Winter

Honey bees overwinter in regions with low temperatures. However, in some places, such as the coastal margins of Galicia and Portugal, it is time for honey bees to forage for nectar and pollen.

- Feed with solid food and keep colonies supplied with good stocks of food if the colony is going to overwinter.
- Deactivate harps, remove muzzles, and remove traps.

Conclusions

Vespa velutina nigrithorax is a public health problem, damages the biodiversity of the environment and causes great economic losses to both the public and private sectors, with the beekeeping sector being the most affected. We present an IPM program for beekeeping. The best preventive strategy to reduce the impact of the yellow-legged hornet is based on ensuring that honey bee colonies are strong, which means good-quality bees with a substantial population, in good health, and with enough food reserves, both pollen and honey. Complementary feeding is essential for those honey bee colonies that do not have enough food reserves, are not strong enough to defend themselves from hornet attacks, and cannot forage. The feeding should be adapted to the needs of the colony, and it will depend on the location and the conditions of the season and year. Adapting our recommendations to the needs of each colony is the main task for the beekeeper. Although none of the control strategies for this invasive species alone guarantee the total protection of honey bee colonies against this threat, there are different options that can help to reduce stress in honey bee colonies, lower the numbers of yellow-legged hornets in the apiary, and reduce the damage it causes to honey bee colonies.

Acknowledgments

The authors want to thank the Agrupación Apícola de Galicia and Federação Nacional dos Apicultores de Portugal (FNAP) for their collaboration in this study. Special thanks to the beekeepers for their time and help. Funding for open access charge: Universidade de Vigo/CISUG.

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Funding

This research was funded by the Interreg Atlantic Area Program (European Regional Development Fund, European Union): EAPA_800/2018-Atlantic-POSitive. A.N. is supported by National Funds from FCT—Portuguese Foundation for Science and Technology, under the project UIDB/04033/2020.

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