The yellow-legged hornet, *Vespa velutina nigrithorax*, was accidentally introduced from south-east Asia into France before 2004. Being a stinging insect as well as a predator to bees, this species was rapidly noticed by French people and considered a dangerous insect and major threat to beekeeping. However, the number of people that were stung did not increase in the invaded area. Monitoring the invasion through public warnings showed that the alien hornet spread very rapidly over a large part of the country and has now reached northern Spain. Climatic suitability models suggest that this species could spread over a large part of Europe, as well as in other areas of the world, since the scenario of introduction through international trade could well be repeated. The study of the prey spectrum of the hornet, as well as the huge size of its colonies, have led to the fear of potential threats to the native insect biodiversity, notably pollinators. Honeybees are one of the hornets main preys, so it is expected to have an economic impact on beekeeping activities that are already threatened by a wide panel of adversary factors. Nonetheless, the uncontrolled mass trappings and colony destruction performed every year in France, inside and outside the invaded area, might be more deleterious to entomofauna than the pest problem itself. Until research to develop an effective control method succeeds, recommendations are given to perform control methods limiting the local impact of the hornet on bees and other insects.

**Introduction**

There are 22 hornet species in the world, most of them restricted to Asia. Only two species, *Vespa crabro* and *Vespa orientalis*, naturally reached the European and Middle East areas (Carpenter and Kojima 1997) (Fig. 1).

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*Fig. 1. World distribution of the only three species of *Vespa* that ever reached Europe. Stria corresponds to areas where two species are present and dark brown colour to the variety *nigrithorax* inside the distribution area of *Vespa velutina nigrithorax*
The yellow-legged hornet, *Vespa velutina nigrithorax*, originally distributed in south-east Asia, was accidentally introduced into Korea in the 2000s (Jung et al. 2008; Kim et al. 2006). Its presence was first recorded in France in 2005 (Haxaire et al. 2006) and the species rapidly spread across southwestern France (Rome et al. 2009; Villemant et al. 2006; Villemant et al. 2011a, b), becoming the first successful invasive hornet in Europe (Rasplus et al. 2010). The origin of introduction of *V. v. nigrithorax* remains uncertain. However, locally collected data suggests that hibernating queens could have been accidentally imported from China through the horticultural trade before 2004 (Villemant et al. 2006).

Like many social wasps, *Vespa velutina nigrithorax* produces annual colonies, initiated by a single queen, after overwintering. Only the founders (future queens) survive the overwintering period; after hibernation, each fertilized founder builds a primary nest. Thus, the colony, initiated by a single individual, develops through the warm season by producing, up to, several thousands of workers, finally decreasing and dying in the fall after the sexual generation has emerged. By then, the colony will have raised hundreds of males and new founders able to mate and subsequently produce new colonies. This efficient life cycle initiated by only one individual makes social insects, such as hornets, redoubtable invaders.

**Monitoring the invasion**

**Cartography**

Since 2006 the monitoring of *V. v. nigrithorax* presence in France is made by individual public warning through an online biodiversity database held by the MNHN ([http://inpn.mnhn.fr; INPN 2010](http://inpn.mnhn.fr)). The web page dedicated to *Vespa velutina nigrithorax* provides general information on the invasive hornet and other species with which it can be confused. Articles, fact sheets and a slideshow are also downloadable (INPN 2010). People can report online their observations of nests or individuals occurrences of this species. A spreadsheet to gather nest records at a regional or local scale is also spread throughout naturalists and beekeepers networks, state and regional services, firemen and municipal services and private wasp controllers (Rome et al. 2009). To avoid duplicate reports, only mature nests are recorded and localities are checked. In 2004, only 3 nests were recorded in only one French département (Lot-et-Garonne), while 1,637 nests were reported across 32 départements (160,000 km²) in 2009 (Villemant et al. 2011a). The precise numbers of nests recorded in 2010 is still unknown due to an ongoing verification process. However, 7 new départements have already been colonised during this year in France and the hornet was also reported for the first time from the north of Spain (Basque Country and Navarre) (Castro and Pagola 2010) (Fig. 2).

The invasion spreads at around 100km per year. A few nests have also been recorded more than 200km away from the invasion front, suggesting accidental human transport or migration of founders (Rome et al. 2009; Mulhauser and Vernier 1994).

**Avoiding wrong records**

Most of the data allowing this monitoring is supplied by the participative work of the public, which can lead to a major bias: despite the distinctive coloration of *V. v. nigrithorax* (Fig. 2) among European insect fauna and its numerous illustrations in descriptive spreadsheets and online contents, almost 30% of public identifications are wrong (Fig. 3). Misidentifications mainly concern Vespids (*Vespa crabro, Dolichovespula media*), other Hymenoptera (*Megascolia maculata, Urocerus gigas, Xylocopa violacea*) and insects that look like hornets (*Mileia crabroniformis, Volucella zonaria*). Confusions are also made between mature nests of *V. crabro, Vespu* spp. or *Dolichovespula* spp. and those of *V. v. nigrithorax* (Fig. 3). The latter are round or pear shaped, from 50 to 80 cm in diameter, and with a small circular entrance on the lateral side (Fig. 2). They are generally located at more than 10m above the ground, hidden in tree crowns, but they can also be found in hedges or eave in more sheltered places such as bramble bushes or ground holes. Due to such confusion risks, a photo of the nest or its inhabitants must be added to each report of the invasive species (a dead hornet can also be sent by mail) in order to control the identification and avoid overestimation of the species population densities and invasion range (Fig. 3).

**Invasion risk modelling**

Eight climatic suitability models have been used to predict the potential invasion risk of *V. v. nigrithorax* (Villemant et al. 2011a) based on eight climatic data from WorldClim at 5 arc-minutes grid (Hijmans et al. 2005). We used occurrence data in the models from the invaded range as well as from the native range of this particular variety, gathering information from museum collections, published records and recent field sampling in its native range. The consensus map obtained from the models shows that *V. v. nigrithorax* could successfully invade many other parts of the world (Fig. 4) since the scenario of introductions through international trade - as it occurred in France - could well be repeated (Villemant et al. 2011a). The potential worldwide distribution of the hornet significantly matches the current distribution of another invasive social wasp, the German yellow jacket, *Vespu* spp. (Villemant et al. 2011a).

In Europe, the potential extent of *V. v. nigrithorax*
concerns almost all European countries, with reduced risks in the dryer southern regions (Fig. 5a). Without excluding incorrect records, the potential extent map would have been strongly overvalued, expending more in eastern continental and Mediterranean regions (Fig. 5b).

**Potential impacts of the invasive hornet in Europe**

_A new threat to honeybees_

The main threat due to _V. v. nigrithorax_ on human activities concerns beekeeping activities. The hornet is a well known predator of _honeybees_ in Asia (Van der Vecht 1957; Shah and Shah 1991). Workers fly in front of the hives, facing bees that fly back to the nest. They catch their prey while flying, land nearby to transform them into pellets, and bring them back to the nest to feed to the larvae. This predation can be intense during late summer, when the

Fig. 2. Adult and nest of _Vespa velutina nigrithorax_ and its distribution in its invaded range. Photos of _Vespa velutina nigrithorax_ Quentin Rome, photo of nest Michel Duret

Fig. 3. Distribution of the wrong records of _Vespa velutina nigrithorax_ nests/individuals sent by the public and examples of nests/individuals of other species commonly confused with this hornet. Photos Quentin Rome.
worker population reaches its maximum and while the sexual brood has to be fed. During this period, several hornets can be seen flying together in front of a hive repeatedly capturing honeybees. Asian bees are able to resist these attacks by making heat-balling (Abrol 2006; Tan et al. 2007; Villemant 2008). A similar behaviour has been very occasionally observed in some French honeybees, but this is still very rare.

While beekeeping is already suffering a noteworthy decline under the pressure of multiple factors (VanEngelsdorp and Meixner 2010; Ellis et al. 2010), reports of devastated apiaries by the invasive hornet causes great concern among beekeepers (Fig. 6) and V. v. nigrithorax appears to be a new factor of honeybee decline in France (Jourdain 2010).

**Potential threat to native insect preys**

V. v. nigrithorax diet is not restricted to honeybees. During the high season, the hornet preys intensively on various insects and spiders, indicating that vulnerable prey species may become threatened by this new predator. To analyse the prey spectrum, we collected prey pellets since 2007 by catching the hornets that brought their prey back to the nest (Perrard et al. 2009) (Fig. 7).

The identification of about 2,500 pellets collected between 2007 and 2009 allowed us to compare the hornets’ prey spectrum in relation to the environment (urbanised, agricultural or forestry) of their nests (Villemant et al. 2011b) (Fig. 8).

While its prey spectrum is much diversified, V. v. nigrithorax shows a real preference for social Hymenoptera: honeybees (37%), common wasps (18%) as well as other pollinators such as hoverflies (Syrphidae) and necrophagous Diptera, such as carrion and house flies (Calliphoridae, Muscidae) (34%). The hornet has a clear impact on bees but, even if hardly visible, its threatening impact on wild insect species may be even more deleterious knowing that large colonies can produce up to 10,000 individuals in a season (Villemant et al. 2011b).
Sting risk for humans

Its large size, painful sting and noisy flight make these hornets one of the most frightening stinging insects. Moreover, the discovery after leaf fall of an enormous nest in the crown of a tree often leads people to be concerned, even if, at that time of the year, the colony has most often already died. Stings can occasionally cause a life threatening allergic reaction (Golden et al. 2006), but as long as the colonies remain undisturbed, hornets will not attack. Nonetheless, the increase and spread of *V. v. nigrithorax* in France, notably in urbanized areas, raises the question of an increasing number of sting accidents. However, probably because its nests generally hang very high in the trees (Perrard et al. 2009; Rome et al. 2009; Rortais et al. 2010), the presence of *V. v. nigrithorax* did not induce an increasing rate of Hymenoptera (bees, wasps and hornets) stings in the colonized regions (De Haro et al. 2010).

Control and its by-side effects

Trapping

The use of baited traps is generally regarded as the best means to control wasps, although it is not always the case. Despite scientific advice, this control method remains the most commonly used while uncontrolled mass trapping induces side effects on non target species. As observed by Thomas (1960) for invasive yellow-jackets, mass destruction of founder queens in spring seems to have virtually no effect on nest density for the following summer months (Villemant et al. 2011b; Beggs et al. in press). Indeed, a successful *Vespa velutina nigrithorax* colony may produce more than 400 founder queens, but only a few survive (Villemant et al. 2011b). Competition for nesting sites and the hard living conditions each queen undergoes before emergence of its first workers cause most of the young colonies to be abandoned. However, the survival of only few colonies is sufficient for the population to sustain and multiply (Haxaire and Villemant 2010).
In the very same way, trapping of workers is not a good method to control Vespidae populations. Indeed, removing 50 to 75% of adults in a Polistes nest induces only a reduction by 29% to 34% of the colony size (Toft and Harris 2004). Trapping should only be used to limit the impact of Vespa velutina nigrithorax predation on apiaries (Rome et al. 2011). Furthermore, none of the traps currently being used show selectivity for Vespa velutina nigrithorax. The most used traps baited with sweet beer kill a huge number of non-target insects, versus only few V. v. nigrithorax (about 1% of the captures in average) (Dauphin and Thomas 2009; Rome et al. 2011) (Fig. 9). To maximise captures of V. v. nigrithorax and minimise the number of non-target insects, trapping must be done with traps combining mechanical selection (with holes allowing small insects to escape) with bait made of fermented honeycomb juice. These traps, placed from July to November close to beehives in apiaries attacked by V. v. nigrithorax, captured about 40% of V. v. nigrithorax (Rome et al. 2011). Research to develop an effective control method for V. v. nigrithorax by using specific bait is still under investigation (Maher et al. unpubl. data).

Colony destruction
V. v. nigrithorax nests are difficult to find and one colony could potentially produce a sufficient number of new founders to colonise an entire French département (about 10 000 km²). Therefore, manual destruction of nests cannot be intensive enough to control vespid populations in wide areas (Beggs et al. in press). However, destruction of nests could locally and temporarily reduce predation. V. v. nigrithorax is a diurnal hornet, so destruction must
be done at nightfall or sunrise and always with adapted protection.

Fig. 10. Vespa velutina nigrithorax. Photo: Quentin Rome

Destroying nests with a shotgun (as used by many people in France) does not kill all the individuals, increases the risk of accident and does not prevent a new nest to be reconstructed. If the queen is killed, brood development and predation could be continued by workers that begin to lay eggs instead of the queen (but they produce only males). The most effective method for colony destruction is the injection into the nest of a poison (cypermethrin or SO₂) with a telescopic perch. Destroyed nests (with dead hornets inside) must be removed to avoid other animals, such as birds, to be intoxicated by eating poisoned brood and hornets. The use of toxic-bait which is taken back to the nest by workers to feed larvae and other adults could result in the destruction of the whole colony but such bait is attractive for all vespid species and the problem remains for the removal of the poisoned nest (Beggs et al. in press).

Recommendations

In the present state of scientific knowledge, we recommend limiting trapping to the proximity of attacked beehives by using traps as selectively as possible. Preventive trapping must be avoided, or performed only punctually to survey V. v. nigrithorax arrival in a given region and warn beekeepers as soon as possible that they should increase their vigilance. Although they are difficult to find before leaf fall, destruction of colonies remains the best way to limit locally the impact of this hornet on bees and other insects.

Conclusion

Probably introduced through international trade from China, Vespa velutina nigrithorax appears to be an effective invader in France that could potentially spread across a large part of Europe. Even if this species is not a direct threat to people, its predation on honeybees add a new component to the decline of honeybee populations in Europe and its big colonies and large prey spectrum suggest that it could have a noticeable impact on local insects biodiversity, including many wild pollinators.

Moreover, inconsiderate trials of control of this invasive species such as massive trapping by the general public also have a negative impact. While they have already proven to be poorly efficient against social insect invasions, they’re also considered to have a great impact on the local insect biodiversity. Thus, until more selective and efficient traps and baits are made available, the only solution that could reduce the impact of this species on beekeeping activity is to only trap V. v. nigrithorax in apiaries during the high predation period.

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