First records and distribution of the invasive alien hornet *Vespa velutina nigrithorax* du Buysson, 1905 (Hymenoptera: Vespidae) in Luxembourg

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Ries, C., N. Schneider, F. Vitali & A. Weigand, 2021. First records and distribution of the invasive alien hornet *Vespa velutina nigrithorax* du Buysson, 1905 (Hymenoptera: Vespidae) in Luxembourg. *Bulletin de la Société des naturalistes luxembourgeois* 123 : 181–193.

Published online 21 October 2021 (ISSN 2716-750X).

Abstract. The invasive Asian hornet *Vespa velutina nigrithorax* du Buysson, 1905 was first recorded in Luxembourg on 2020-09-02 in Junglinster in the southern part of Luxembourg, where 24 records of the species, including four nests, have been recorded until the end of the year 2020. The species has not yet been recorded in the northern part of the country. Risk assessments were performed following the ISEIA and Harmonia+ protocols, resulting in a high invasion score, medium impact and overall risk scores, and a relatively low environmental impact score.

Keywords. *Vespa velutina nigrithorax*, Vespidae, invertebrates, invasive alien species, IAS of Union concern, risk assessment, ISEIA, Harmonia+, Luxembourg.

1. Introduction

The Asian hornet *Vespa velutina* Lepeletier, 1836 (Hymenoptera: Vespidae) is a species originally widespread in the mountains of Southeast Asia from Kashmir to Malaysia, reaching eastwards to Taiwan and southeastwards to Sulawesi, the Sunda islands and Timor (Vecht 1957, 1959).

This taxon comprises 14 subspecies (Vecht 1957, 1959), which morphologically mainly differ in their body colours and have peculiar geographical distributions (Fig. 1), namely: *V. v. ardens* du Buysson, 1905 (Lombok and Sumbawa), *V. v. auraria* Smith, 1852 (East Himalaya: India, Nepal, South China, North Vietnam), *V. v. celebensis* Pérez, 1910 (Sulawesi), *V. v. divergens* Pérez, 1910 (Malaysian mainland), *V. v. flavitarsis* Sonan, 1939 (Taiwan), *V. v. floresiana* van der Vecht, 1957 (Flores), *V. v. karnyi* van der Vecht, 1957 (Sumatra), *V. v. nigrithorax* du Buysson, 1905 (South China), *V. v. pruthii* van der Vecht, 1959 (Pakistan and Northwest India), *V. v. sumbana* van der Vecht, 1957 (Sumba), *V. v. timorensis* van der Vecht, 1957 (Timor), *V. v. variana* van der Vecht, 1957 (Myanmar, Thailand, Laos and Vietnam) and *V. v. velutina* Lepeletier, 1836 (Java).

Though Carpenter & Kojima (1997) rejected without reasons the validity of these subspecies, subsequent authors (Villemant et al. 2006a, 2006b, Ibáñez-Justicia & Loomans 2011, López et al. 2011, Rome et al. 2011, Villemant et al. 2011, Perrard et al. 2014, Ueno 2014, Goldarazena et al. 2015, Smit et al. 2017, Leza et al. 2018) generally accepted Vecht's systematics.

Vespa velutina is a generalist predator of medium- to large-sized insects and a scavenger of vertebrate carrion. It apparently has large impacts on dipterans and social hyme-

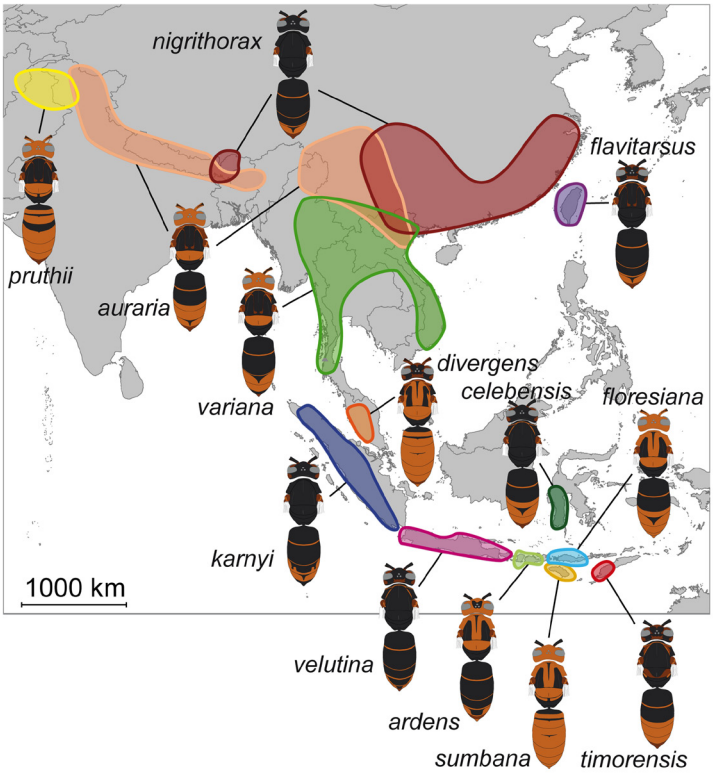

Fig. 1. Known distribution of the different subspecies / colour morphs of *Vespa velutina* across Southeast Asia (Perrard et al. 2014, Wikimedia Commons).

nopterans, including honey bees (*Apis* spp.) (Monceau et al. 2014, Laurino et al. 2020). Yet, while the Oriental *Apis cerana* Fabricius, 1793 evolved efficient anti-predator behaviours, *A. mellifera* Linnaeus, 1758 suffers higher predation rates (Ken et al. 2005; Tan et al. 2007, 2010, 2012a, b, 2013). It has been shown that the presence of *V. velutina* increased oxidative stress in honey bee hives (Leza et al. 2019) and that the hornets can act as vectors for bee viruses (Mazzei et al. 2019). In combination with other stressors such as *Varroa* mites, increased environmental changes and pesticides, *V. velutina* negatively affects the health of honey bee populations. This can lead to a decline of local honey bee densities, and potentially can have negative economic impacts on honey production and overall pollination rates especially in monocultural areas relying upon honey bee hives.

To date, *Vespa velutina nigrithorax* du Buysson, 1905, hereafter abbreviated as *V. v. nigrithorax*, is the only subspecies that has been shown to spread outside its native range (Villemant et al. 2006a, 2006b, Ibáñez-Justicia & Loomans 2011, López et al. 2011, Rome et al. 2011, Villemant et al. 2011, Perrard et al. 2014, Ueno 2014, Goldarazena et al. 2015, Smit et al. 2017, Leza et al. 2018).

V. v. nigrithorax is native to Southern China (Fig. 1). Since the early 2000s, it has been spreading in South Korea (Kim et al. 2006, Choi et al. 2012) and afterwards in Japan (Sakai & Takahashi 2014, Ueno 2014).

It is the same subspecies that has been accidentally introduced to Europe, where it was first recorded from southern France in 2004 (Villemant et al. 2006a, 2006b). Since then, it was found in Spain in 2010 (López et al. 2011), in Portugal in 2011 (Grosso-Silva & Maia 2012), in Belgium in 2011 (Barbier & Renneson 2018), in Italy in 2012 (Demichelis et al. 2013), in Germany in 2014 (Orlow 2014), in the Balearic Islands in 2015 (Leza et al. 2018), in the Channel Islands (States of Guernsey Government 2016) and in the UK in 2016 (Budge et al. 2017), in the

Netherlands in 2017 (Smit et al. 2017), in Switzerland in 2017 (Ebener 2017) and in Luxembourg in 2020 (Ries & Pfeiffenschneider 2020, Renneson et al. 2020).

Concerning the pathways of introduction, it may be introduced and transported accidentally with soil associated with plants, garden furniture and pots, timber, vegetables, camping equipment, etc. (CABI 2020).

In 2016, *V. v. nigrithorax* was added to the list of invasive alien species of Union concern (Anonymous 2016) which implies, in accordance with the EU Directive 1143/2014 on Invasive Alien Species (Anonymous 2014), that member states shall take all necessary steps to prevent its unintentional introduction or spread. Furthermore, pursuant to Article 16(2) of R.1143/2014 (Anonymous 2014), the occurrence/detection of the Invasive Alien Species of Union concern have to be notified to the European Commission and all member states through the EASIN notification system (EC 2021).

2. Methods

2.1. Occurrence records

The present work is based on reports of *V. v. nigrithorax* since the first finding (2020-09-02) and a subsequent press release (2020-09-28). No systematic survey of the species has been done so far in Luxembourg.

2.2. Risk assessments

To assess the risk that this invasive alien hornet species represents to the environment, its invasiveness and its impacts on several targets, we performed risk assessments applying two protocols developed by the Belgian Forum on Invasive Species (BFIS) and widely used in northwestern Europe: ISEIA and Harmonia+.

The ISEIA protocol (Invasive Species Environmental Impact Assessment) enables us to quickly evaluate the potential risk of a species concerning its dispersion potential and its environmental impacts (Branquart 2009). The assessment contains four scores with three levels each (1=low, 2=medium, 3=high): a) dispersal potential, b) colonisation of high conservation value habitats, c) adverse impacts on native species, d) risk of alteration of ecosystem functions.

Harmonia+ is a protocol compliant with criteria of the EU regulation (Anonymous 2014) for risk assessments for listing IAS of EU concern and considering, above environmental risks, further criteria like impacts on plants, animals and humans (including their health), impacts on human infrastructure, on ecosystem services and effects of climate change on these risks (D'Hondt et al. 2015, Vanderhoeven et al. 2015). Results are numerical scores between 0 and 1.

3. Results

3.1. First records of *Vespa velutina nigrithorax* in Luxembourg

Vespa v. nigrithorax was first recorded in the wild in Luxembourg on 2020-09-02 by Thierry Helminger, botany curator at the Luxembourg National Museum of Natural History (Fig. 2): a few individuals on grapes from a vine in a garden in the rue du Village in Junglinster (Helminger in litt., MNHNL 2000-). The specimen has been registered as number MNHNL89164 in the zoology collection of the museum (Fig. 3).

Fig. 2. First sighting of *Vespa velutina nigrithorax* in Luxembourg. Photo: Thierry Helminger, 2020-09-02.

Fig. 3. Images of the first recorded specimen. Registration number MNHNL89164. Photos: Alexander Weigand.

On 2020-09-04, a team of experts tried to locate the nest (Renneson & Schneider 2020, Renneson et al. 2020). The search was unsuccessful because the crowns of the trees in question could not be sufficiently inspected due to the dense foliage.

Further observations of the Asian hornet have been reported by citizen scientists from Junglinster: 2020-09-09 in Cité Kremerich, 2020-09-11 in rue Jean-Pierre Ries, 2020-09-16 near CIPA, 2020-09-15 at 4 rue Neuve. On 2020-09-29, the nest was found under the eaves of a house at 21 rue Neuve (Fig. 4), 270 m from the location of the first record.

After this first observation became known in interested circles, reports gradually came in from various regions of the Gutland:

(a) 2020-09-09: south of Ingeldorf, reported near beehives by a beekeeper;
(b) 2020-09-19: Schifflange, north of the school in rue Michel-Rodange;
(c) 2020-09-21: Esch-sur-Alzette, a nest, about 1 m in length, spotted high in a tree in a private garden near the Wobrécken bus station between rue Général G.S. Patton and (d) rue de la Tuilerie. This same nest had already been photographed on 13th September, but reported later on 30th September.
(d) 2020-09-27: Beckerich; a nest was discovered in a garage roof on 2020-12-14;
(e) 2020-09-30: Echternach;
(f) 2020-10-07: Colmar-Berg, next to the town hall on flowering ivy (*Hedera helix*);
(g) 2020-11-24: Colmar-Berg, a huge nest high up in a tree reported by a beekeeper.

Confirmed records came from the following localities: Beckerich (4), Colmar-Berg (2), Echternach (1), Esch-sur-Alzette (3), Ingeldorf (2), Junglinster (11) and Schifflange (1).

In total, four nests were reported: (1) Junglinster: under the eaves of a house (Fig. 4); (2) Esch-sur-Alzette: on a silver birch (*Betula pendula*, Fig. 5a); (3) Colmar-Berg: on *Fraxinus* sp. (Fig. 5b) and (4) Beckerich: under the roof of a garage (Fig. 6).

On 13 January 2021, the nest in Beckerich was removed and examined by Roland Proess. He found 91 females, including 17 alive. All of them had a weight of more than 0.5 g. According to Quentin Rome they were probably all uninseminated and so, even if

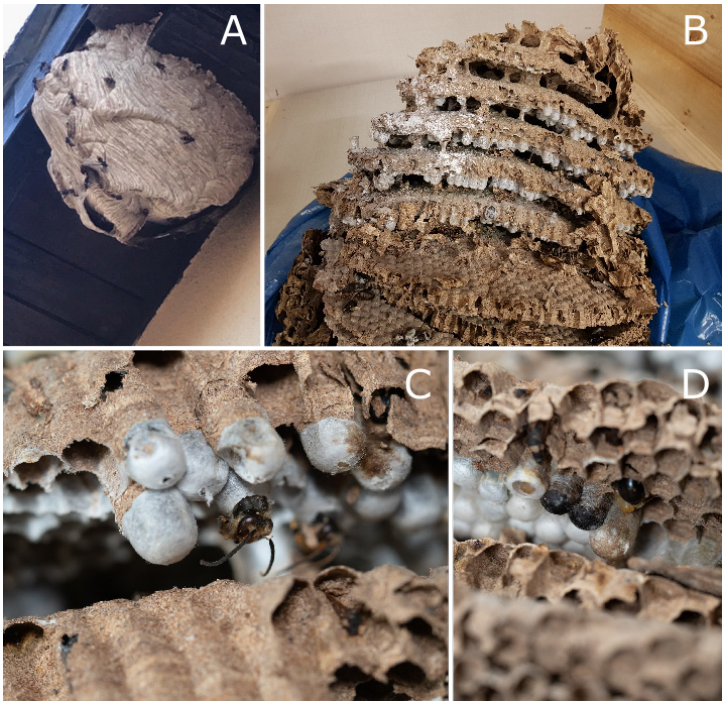

Fig. 4. A) Nest of *Vespa velutina nigrithorax* under the eaves of a house in Junglinster, with some specimens sitting on the nest (approximate measures: height 60 cm, width 35 cm, depth 40 cm). Photo: Josiane Trierweiler, 2020-09-29. B) Collected nest with its various levels after treatment with the insecticide Permas®-D. Photo: Alexander Weigand. C & D) Close-ups of a hatching specimen, empty cells, pupae and larvae within the nest. Photos: Paul Braun.

they would have left the nest in spring, they would not have been able to found a new colony (R. Proess in litt.).

Individuals were sometimes observed at greater distances from the nest: Beckerich 568 m, Colmar-Berg 210 m, Esch-sur-Alzette 650 m and Junglinster 695 m (Fig. 7). If the individual observed in Schifflange came from the nest in Esch-sur-Alzette, it would have been observed at >3 km distance from its nest.

As far as the removal of the nests is concerned, they were firstly treated with the insecticide Permas®-D by the company Lux Pest Control, and removed only after a waiting period of several weeks: Junglinster 2020-10-08 & 2020-11-10, Colmar-Berg 2020-12-23 (no more activity detected in the nest, direct removal of the nest), Beckerich 2020-12-29 & 2021-01-13. The nest of Junglinster was removed by a team of the Administration de la nature et des forêts and transferred on 2020-11-11 to the Museum collections. The nest in Esch-sur-Alzette could neither be treated nor removed because of its location high in a birch tree in a back garden.

Being listed in the list of invasive alien species of Union concern and pursuant to article 16(2) of R.1143/2014 (Anonymous 2014), the occurrence/detection of *V. v. nigrithorax* since its first record on 2020-09-02 has been notified six times (2020-09-03, 2020-09-10; 4 x 2020-10-30) through the EASIN notification system by the Luxembourg authorities (Tiago de Sousa in litt., EC 2021).

A presumed first observation of *V. v. nigrithorax* in Luxembourg was published in August 2012 in a daily newspaper. It turned out to be wrong, as the article contained photos of the Eurasian hornet *Vespa crabro* (Back 2012b). 11 days before, the same journalist had already published an article about the Asian hornet in Belgium (Back 2012a).

3.2. Distribution of *Vespa velutina nigrithorax* in Luxembourg

As of 2020-12-04, 24 records of *V. v. nigrithorax* in Luxembourg are accessible through the MNHNL-mdata portal (MNHNL, iNaturalist & GBIF 2020). Until then, the species has only been observed in the Gutland, the

Fig. 5. Nests of *Vespa velutina nigrithorax* high up in trees: on *Betula pendula* in Esch-sur-Alzette (a) and on *Fraxinus* sp. in Colmar-Berg (b). Photos: (a) Monique Rippinger, 2020-09-13, (b) Christian Ries, 2020-11-26.

southern part of the country, while the species has so far not been recorded from the Oesling, the northern part of the country, part of the Ardennes.

In less than three months, *V. v. nigrithorax* was recorded in three different cantons of Luxembourg (Diekirch, Grevenmacher and Esch-sur-Alzette) (Fig. 8).

Fig. 6. Nest of *Vespa velutina nigrithorax* under the roof of a garage in Beckerich. Photo: Nicolas Schweicher, 2021-01-13.

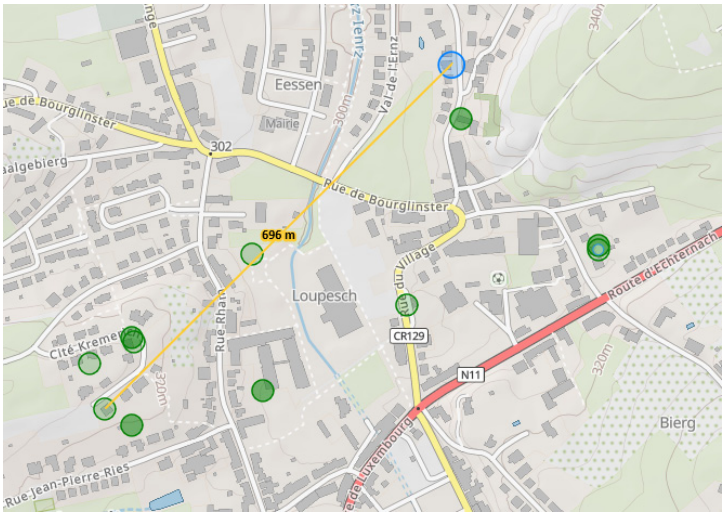

Fig. 7. Eleven reports of *V. v. nigrithorax* in Junglinster. Green: observations. Blue: nest. Map: geoportail.lu.

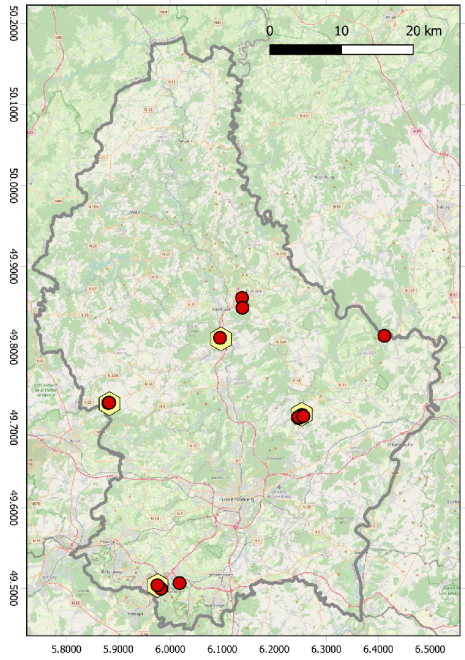

Fig. 8. Distribution of *V. v. nigrithorax* in Luxembourg as of 2020-12-14. Yellow hexagons = nests, red dots = records of individuals.

3.3. Risk assessments of *V. v. nigrithorax*

3.3.1. ISEIA protocol

In 2015, a first assessment of the Asian hornet was performed based on the ISEIA protocol. The resulting index value [C0] (scores 3+1+1+1) reflects that the assessors did not consider the species to be a threat for native biodiversity and ecosystems [C] and that it was absent from the area covered by the assessment [0] (Ries et al. 2017: 68).

An update of this assessment in September 2020 resulted in the same scores (3+1+1+1), and thus left the species in the same category [C] (no threat for native biodiversity and ecosystems), with a distribution of isolated populations [1] = [C1] (Ries & Pfeiffenschneider 2020). The four scores (1=low, 2=medium, 3=high) mean that the species shows [a=3] a high dispersal potential, [b=1] a low risk of colonisation of high conservation value habitats, [c=1] a low risk of adverse impacts on native species, and [d=1] a low risk of alteration of ecosystem functions.

3.3.2. Harmonia+ protocol

The resulting scores of the assessment of *V. v. nigrithorax* with the internet-based Harmonia+ protocol (D'Hondt et al. 2015, Vanderhoeven et al. 2015) are presented in Table 1.

After a detailed risk assessment applying the Harmonia+ protocol, the overall invasion score for *V. v. nigrithorax* is quite high with 0.72 being the arithmetic mean of the scores for introduction, establishment and spread. Indeed, the species can actively colonise new

Table 1. Risk assessment of *V. v. nigrithorax* for Luxembourg according to the Harmonia+ protocol, performed by 5 assessors. Default operations used, all module and question weights considered equal.

	Invasion				Impact						
	Introduction	Establishment	Spread	Invasion score	Environment	Plants	Animals	Humans	Others	Impact score	Overall risk score
Arithmetic mean (average)	0.57	0.95	0.72	0.72	0.23	0.23	0.48	0.33	0.05	0.55	0.39
Median (middle value)	0.50	1.00	0.75	0.72	0.25	0.00	0.50	0.25	0.00	0.50	0.36
Sample standard deviation	0.09	0.11	0.16	0.07	0.17	0.34	0.04	0.16	0.11	0.11	0.05
Coefficient of variation	0.16	0.12	0.22	0.10	0.74	1.49	0.08	0.47	2.24	0.20	0.13
Minimum	0.50	0.75	0.50	0.63	0.04	0.00	0.42	0.17	0.00	0.50	0.35
Maximum	0.67	1.00	0.88	0.84	0.46	0.75	0.50	0.50	0.25	0.75	0.47

areas with a spreading speed of up to 100 km/y (Rome et al. 2012).

Vespa. v. nigrithorax shows the highest values in the animal impacts (predation on honey bees) and human impacts (nuisance) categories, where the risk assessment produced an aggregated impact mean score of 0.55. On the other hand, the relatively low environmental impact score of 0.23 confirms the low risk (C1) assessed with the ISEIA protocol in the previous section.

The overall risk score is 0.39, which, in a ranking exercise, can be considered a medium value.

3.4. Outreach and citizen science feedback

In spring 2016, the Department for the Environment of the Luxembourg Ministry of Sustainable Development and Infrastructures published a leaflet in German about *V. v. nigrithorax*, in cooperation with the Nature and Forestry Administration, the National Museum of Natural History, natur&ëmwelt and the National Beekeepers Association. A French version was produced in spring 2017. Both language versions have been updated and reissued in December 2020.

Between the publication of the first editions of the leaflets and the first observation of *V. v. nigrithorax* in Luxembourg on 2020-09-02, 18 reports were sent to the authorities, mostly mistaken for *Vespa crabro*, the Eurasian hornet, the only *Vespa* species native to Luxembourg (Sauber & Hoffmann 1974: 255). 29 reports were sent between the first observation (2020-09-02) and the press release (2020-09-28), and 12 were correct. After the press release, 104 reports were sent until 2020-11-24, of which 11 were indeed reporting the Asian hornet.

Of the 151 reports of *V. v. nigrithorax*, 23 were correct and 18 records without photo or specimen could not be validated. In the remaining reports, the following species have been mistaken for the Asian hornet: a bumblebee *Bombus* sp. (1x), the Saxon wasp *Dolichovespula saxonica* (Fabricius, 1793) (1x), *Dolichovespula* sp. (1x), the European paper wasp *Polistes dominula* (Christ, 1791) (6x), *Polistes nimpha* (Christ, 1791) (1x), the pale giant horse-fly *Tabanus bovinus* Linnaeus, 1758 (2x), the native Eurasian hornet *Vespa crabro* Linnaeus, 1758 (63x), the German wasp *Vespula germanica* (Fabricius, 1793) (31x), *Vespula* sp. (1x) and the hornet mimic hoverfly *Volucella zonaria* (Poda, 1761) (2x).

On social media, the announcement on 2020-09-07 of the first record of *V. v. nigrithorax* in Luxembourg on the Facebook

page of the Museum reached 61,397 people and produced 12,870 post engagements (picture clicks, comments and shares) until 2020-09-16 (P. Michaely in litt.). This caused a considerable increase in visitor numbers and views of the neobiota.lu portal of the Museum.

To enhance public awareness, on 15th September 2020 the first author published a detailed article on *V. v. nigrithorax* on the Luxembourgian Wikipedia (Wikipedia contributors 2020). As of the 25th of March 2021, the page has been viewed 472 times (44 of which were edits).

4. Discussion

Here we report the detection and distribution of the invasive alien hornet species *V. v. nigrithorax* in Luxembourg, subsequent to a report by a citizen from Junglinster, who brought one hornet worker to the MNHNL (Fig. 3).

The wide distribution of the collecting localities and their reciprocal distance might suggest that the introduction of *V. v. nigrithorax* in Luxembourg is not recent and, perhaps, of different origins. Certainly, both findings in the Minette region have to be related to the hornet population of Meurthe-et-Moselle in France, where this species has already been recorded in 2015 (Renaudeau 2017). In contrast, the findings in central Luxembourg might reveal that this species is present, but still undetected, in neighbouring areas in Belgium and Germany.

According to Choi et al. (2012), the spread rate of *V. v. nigrithorax* was 10-20 km / year in Italy and in South Korea, while it was about 100 km / year in France (Rome et al. 2012). Based on these values, this species might indeed have colonised Luxembourg very recently, taking advantage of the mild temperature of these last years. This seems all the more likely as Luxembourg is located at the northeastern limit of the distribution range in Europe (Fig. 9).

Vespa v. nigrithorax commonly builds two nests in a season: primary nests, built in spring, are often found in or on man-made

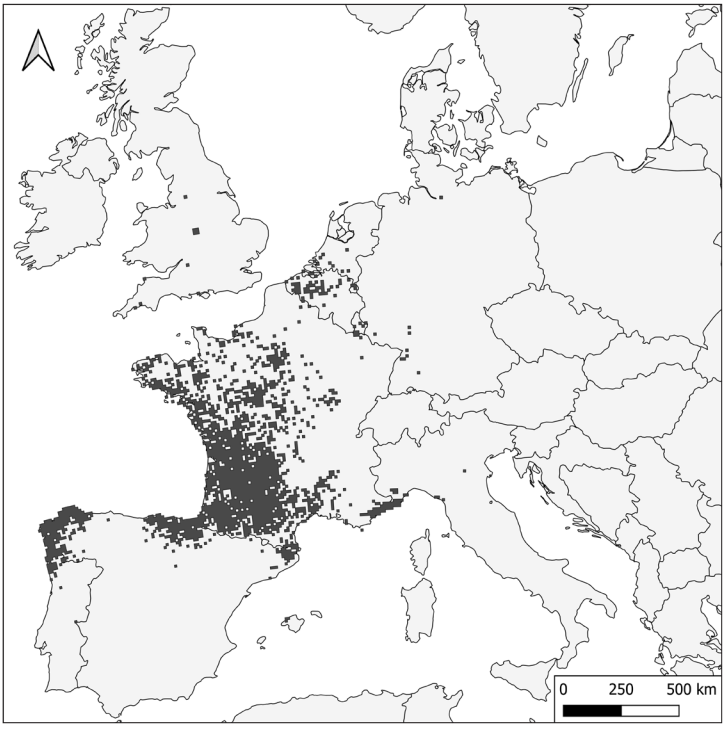

Fig. 9. Distribution of *V. v. nigrithorax* in Europe as of 2021-03-25. Data source: EASIN. Layer: EEA Copernicus 10 km grid.

structures, while secondary nests, built in summer, are more likely to be found on natural structures, such as in tree canopies well above the ground, or occasionally in undisturbed and sheltered areas in buildings (Franklin et al. 2017). These secondary nests are inhabited by the last generation of breeding hornets, 300 to 500 young queens, most of which will leave the nest starting from mid-September to seek out an overwintering site. During the last weeks of its existence, when the nest is slowly being abandoned, workers and young queens make themselves known in the surroundings by seeking out ripe or rotten fruit to feast on. Young queens mostly mate multiple times and leave the nests. This coincides with the time when the general public becomes aware of the hornet and when the nests should be located in order to destroy them. Yet, at this time of the year, the nests are difficult to find because the trees have not shed their leaves. Therefore, the species will probably continue to spread in the country in 2021 and the following years. To counteract this, radio telemetry or infrared detection could be used to try to locate the nests early (Kennedy et al. 2018).

In this context, we would like to mention potential side effects on non-target species as a consequence of uncontrolled mass trapping and colony destruction by beekeepers and the general public. Traps and poisoned baits kill numerous other insects, notably the common yellow-jackets (*Vespul*a sp., *Dolichovespula* sp.) and the Eurasian hornet *Vespa crabro*, while nests treated with insecticides and left in situ threaten birds that feed intensively on broods of poisoned colonies (Villemant et al. 2010).

Upon the establishment of *V. v. nigrithorax* in Luxembourg, the Forestry and Nature Administration (ANF) commissioned the preparation of an action plan in autumn 2020, which was completed in early 2021 (Proess 2021). To date, the impacts of *V. v. nigrithorax* on the native wasp community is poorly understood. Carisio et al. (2020) assessed the impacts of its presence on *V. crabro*, *Vespula vulgaris* and *Vespula germanica*, by comparing the invaded area with an uninvaded one. Overall, the results suggest that native Vespidae have probably avoided or minimised competition pressure and therefore the presence of *V. v. nigrithorax* has not led to an evident replacement of *V. crabro* and *Vespula* spp. This provides reassurance regarding the conservation status of native European Vespidae following the *V. v. nigrithorax* invasion.

Finally, due to the combination of press release and publication on the internet, the outreach turned out to be quite efficient in terms of feedback from citizen scientists and page visits on the neobiota.lu portal, social media and lb-Wikipedia. As for the reports by citizen scientists, the majority of observations were mistaken for *Vespa crabro* and *Vespula germanica*.

5. Conclusions

Having been recorded 24 times from 6 areas in 3 cantons of the Gutland, *V. v. nigrithorax* may be considered 'established' in the southern part of Luxembourg. We can assume that each area had its own nest, which equates to 6 nests. Being aware that the species was only reported from inhabited areas frequented by people, we may also assume that more nests exist in more remote areas, namely in zones used for agriculture and forestry. Considering that each nest can produce between 3-500 young queens that will spread out and hibernate, and assuming that 1% of these young queens survive and will be able to found a new colony, an ongoing expansion can be assumed in the future under similar environmental conditions.

We recommend beekeepers to place "muzzles" on the entrances to their hives, a sort of latticework airlock in front of the entrance that reduces stress on the bees by preventing any hornet species from getting too close to the entrances (CARI 2017: 6).

Acknowledgements

We thank the following people and institutions for their respective contributions: Thierry Helminger for reporting the first observation and depositing the first sample in the Museum collections on 2020-09-02; the citizen scientists who reported hornets and nests; Tiago de Sousa

for information on the notifications of the species to the EU Commission; beside the first and last author, Svenja Christian, Jennifer Cross and Tiago De Sousa performed the risk assessment after the Harmonia+ protocol; Paul Braun, digital curator at MNHNL, for producing the distribution maps in figures 8 & 9. Finally, we thank Claude Meisch for peer reviewing and providing useful suggestions on the manuscript and Caroline Grounds for proofreading the manuscript.

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