VKM Report 2022: 03

Assessment of the risks to honey bees and biodiversity in Norway posed by the predatory wasp species *Vespa velutina* and *V. mandarinia*

Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered Species of the Norwegian Scientific Committee for Food and Environment

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21.02.2022

ISBN: 978-82-8259-386-1
ISSN: 2535-4019
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Cover photo: *Vespa velutina* by Charles J. Sharp, Wikimedia Commons.

Suggested citation: VKM, Katrine Eldegard, Daniel Flø, Lawrence Kirkendall, Martin Malmstrøm, Anders Nielsen, Claus Rasmussen, Hugo de Boer, Kjetil Hindar, Johanna Järnegren, Kyrre Kausrud, Eli Rueness, Eva B. Thorstad and Gaute Velle. (2022). Assessment of the risks to honey bees and biodiversity in Norway posed by the predatory wasp species *Vespa velutina* and *V. mandarinia*. Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered Species of the Norwegian Scientific Committee for Food and Environment. VKM Report 2022:03, ISBN: 978-82-8259-386-1, ISSN: 2535-4019. Norwegian Scientific Committee for Food and Environment (VKM), Oslo, Norway.

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Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of three VKM members, two VKM staff and one external experts. Three referees commented on and reviewed the draft opinion. The VKM Panel on Alien organisms and Trade in Endangered Species (CITES), assessed and approved the final opinion.

Authors of the opinion

The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2019). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group or the VKM Panel on Alien organisms and Trade in Endangered Species (CITES) that assessed and approved the work.

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Acknowledgements

VKM would like to thank Bjørn Dahle (Norwegian Beekeepers Association (Norges Birøkterlag)) for valuable information, especially on on parasites and pathogenic organisms, and Allan H. Smith-Pardo for supplying detailed photos of all three species. VKM would also like to thank Martin Husemann (University of Hamburg) and Theo Zeegers (Naturalis Biodiversity Centre, Leiden) for help with data on presence of *V. velutina* in Germany and Netherlands, respectively.

VKM would especially like to thank the referees Claire Villemant (Natural History Museum, Paris), Yoko Luise Dupont (Aarhus University) and Per Kryger (Aarhus University) for their valuable comments through critical review of the draft opinion. VKM emphasises that the referees are not responsible for the content of the final opinion. In accordance with VKM's routines for approval of a risk assessment (VKM, 2018), VKM received the comments before evaluation and approval by VKM Panel on Alien Species and Trade in Endangered Species (CITES), and before the opinion was finalised for publication. Tanya S. Kristiansen (VKM secretariat) is acknowledged for her contribution on figure layout and details.

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

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Summary

Key words: Asian giant hornet, murder hornet, yellow-legged-hornet, establishment, competition, predation preventive measures, risk reducing measures, ecosystem service.

Background

There is growing international concern about the realized and potential impacts on beekeeping and on native biodiversity caused by recent invasions of two large Asian hornet species, the yellow-legged hornet (*Vespa velutina*, also called the Asian hornet) and the Asian giant hornet (*V. mandarinia*). Consequently, the Norwegian Food Safety Authority and the Norwegian Environment Agency jointly requested the Norwegian Scientific Committee for Food and Environment to assess the risks to Norwegian biodiversity and to beekeeping in Norway from the potential import, establishment and spread of these two species, and the risks of negative consequences arising from such introductions. VKM was also asked to summarize possible risk-reducing measures that could prevent or reduce the introduction, establishment and spread of each species.

Methods

VKM established a project group with expertise in social bees and wasps, insect biodiversity, and invasion biology. The group carried out a literature search of the relevant sources of available information (published or on websites) on the biology and ecology of the two alien *Vespa* species, and modelled areas of current or future climatic suitability in Norway for each species using Maxent for modelling species distributions and using Köppen-Geiger climate classification maps. Potential hazards with respect to negative impacts on biodiversity and beekeeping were identified and evaluated. We then conducted a semi-quantitative risk assessment for each hornet species. We also reviewed briefly the potential impacts on ecosystem services and agriculture should either hornet become established, and reviewed and evaluated methods used to prevent the import of these species or to mitigate their impact should they enter and become established in Norway.

Invasion history and biology of the two alien hornet species?

The yellow-legged hornet, *V. velutina,* has recently been unintentionally imported to Europe and to South Korea. This species has now spread rapidly throughout France, where it was first observed in 2004, to other parts of Europe where it now can be found as far north as Hamburg in Germany and Meppel in The Netherlands. The spread of the yellow-legged hornet outside its native range in Asia has been slower than in Europe, but it has now spread throughout South Korea and has established populations on islands of southwestern Japan.

Results of DNA analyses suggest that the European population of *V. velutina* had just one origin, eastern China.

The Asian giant hornet, *V. mandarinia*, was first discovered in the Pacific Northwest of North America in 2019, in adjacent areas of British Columbia in Canada and Washington State in the USA. The species has been collected in the same limited area in small numbers every year since, suggesting that it has become established but has not spread significantly. Results of DNA analyses suggest that *V. mandarinia* colonies in this region are from two separate origins.

These two large hornets are of economic concern because they rapidly form colonies with thousands of workers during the summer and early fall and they prey in a coordinated fashion on colonies and foraging workers of domesticated and escaped (feral) honey bees. Concerns for native biodiversity arise because the alien hornets also consume large numbers of a wide range of native insects. Depredations of honey bee colonies can be severe, with partial or entire colonies being destroyed over a few hours or days (hence the designations of both species by news outlets and social media as "murder hornets"). The most widely used honey bee species, the so-called western honey bee, *Apis mellifera* (the species cultivated throughout Europe), has no evolved defenses against these hornet species, and major losses from predation by the two hornets have been reported for western honey bee colonies in Europe and East Asia. Negative impacts on native, natural ecosystems due to predation on native insects are poorly known.

Either of the Asian hornet species could potentially compete with the native European hornet, *V. crabro.* The European hornet has only recently re-established populations in southern Norway; the species is generally common where it naturally occurs in Eurasia. Studies of direct competition for food and other lines of evidence suggest that the niches of *V. crabro* and invasive *V. velutina* in Europe overlap considerably. However, there are no data showing that *V. crabro* populations have been depressed by the presence of the alien species in Europe.

For *V. velutina*, there have been several investigations of associated parasites and pathogens. Several studies have suggested potential for transferring parasites or diseases from the hornet to honey bees; as yet, there is little evidence that this is an additional threat from the presence of invasive hornets.

Are there areas of Norway that are suitable for either species?

There appears to be suitable habitats available for both *V. velutina* and *V. mandarinia* in Norway. However, it is not clear whether current or future climatic conditions are suitable for *V. velutina*. Our own prediction model results indicate no climatically suitable areas in Norway, neither given current environmental conditions nor using predicted future climates. However, published model outputs that use slightly different datasets and methodology do indicate that coastal areas of at least southern and western Norway could be climatically suitable for *V. velutina*, both today and in the future. For the more temperate species, *V. mandarinia*, recent ecological niche modelling shows that much of Europe, including of Norway, is already climatically suitable.

Entry, establishment and spread

As *V. velutina* is already established (and is widespread) in Europe, we conclude that it is more likely ("Moderately likely") that *V. velutina* will enter Norway, compared to *V. mandarinia* ("Very unlikely"), in the next 10 years. For both species, we expect that the risk will increase over time, due to both climate change (more suitable environmental conditions) and a higher cumulative likelihood of accidental import. However, due to climatic preferences we conclude that establishment and further spread in Norway is more likely for *V. mandarinia* ("Likely") compared to *V. velutina* ("Moderately likely"), should either species enter Norway.

Hazards and overall risks

Because of its success in recent decades in spreading widely outside of its native range, there is currently considerable research into the biology and ecology of *V. velutina.* Much less is known about *V. mandarinia*. Given that the two species are largely similar in their behaviours and ecology, we often extrapolated from the former to the latter when identifying hazards for this report.

We identified the following specific hazards relevant to the Terms of Reference and assessed the risks of each occurring:

- *Predation on honey bees.* Both hornet species can devastate local populations of honey bees. Loss of workers or entire colonies impact both honey production, production of wax and propolis, and pollination of a variety of crops, especially fruit trees. The overall risk posed to beekeeping in Norway by hornet predation is assessed to be **Moderate** for both *V. velutina* and *V. mandarinia*.
- *Predation on native arthropods.* We find that either hornet would pose a **Moderate** risk to native arthropods in terms of predation.
- *Competition with native arthropods.* In Europe, the main concern is competition with the native European hornet, *V. crabro.* Competition could potentially be for both prey and nest sites. For Norway we conclude that the impact would be minor. Due to differences in likelihood of these species getting to Norway, the overall risk of hornet invasion to *V. crabro* due to competition is **Moderate** for *V. velutina* and **Low** for *V. mandarinia*.
- *Introduction or spread of disease-causing agents.* Either hornet species might be found to be capable of introducing or spreading pathogens. Little is known about the effects of most of the microorganisms associated with *V. velutina* and there are no

data on the viruses and bacteria associated with *V. mandarinia*. Therefore, only *V. velutina* was assessed in this regard. From what is known, we assess the overall risk of introduction and spread of pathogens to be **Low**.

- *Introduction and spread of parasites.* As with pathogens, more information is available for *V. velutina,* and therefore only assessed for this species. We conclude that the overall risk of introduction and spread of parasites is **Low.**

Impact on ecosystem services and agriculture

There could be both negative and positive impacts on ecosystem services, should either species become established in Norway. Pollination services would be most strongly impacted negatively since both hornet species prey on pollinators and also frighten them away. Positive impacts include preying on crop pests, plant pollination, and seed dispersal.

Mitigation measures

Because of their high capacity for self-dispersal and the automatic handling of cargo arriving from countries where the species already occur, preventing entry of alien *Vespa* species will be near impossible. Early detection and eradication are key to keeping alien *Vespa* species from establishing populations in Norway. Detection is most successful when the public is enlisted (citizen science efforts). Finding nests will require developing skills in tracking foraging workers or the use of more advanced technology such as radiotagging or harmonic radar. Should an alien hornet species become established, targeted control measures will need to be developed. A key component would be mapping and predicting species distributions. It is possible to eliminate or reduce hornet numbers around apiaries, but care must be taken to prevent collateral damage to native animals. One promising approach to reducing harmful effects on honey bee colonies is adding protective mesh devices to hive entrances.

Uncertainties

There are several uncertainties affecting the assessment of likelihood of entry and spread, and the risks arising from establishment of colonies of these two invasive hornets. The most important uncertainty regards climate suitability in Norway for *V. velutina*. We discuss uncertainties inherent in species distribution modelling and differences between the results of our own models and those in recent publications. It is also difficult to assess the likelihood of fertilized queens infiltrating ships, trucks, and private vehicles. A primary cause for uncertainty is the lack of recent research on *V. mandarinia.* In addition, we lack knowledge on the potential for both species to introduce or spread pathogens and parasites.

Sammendrag på norsk

Nøkkelord: Asiatisk kjempeveps, morderveps, japansk geithams, etablering, konkurranse, predasjon, preventive tiltak, risikoreduserende tiltak, økosystemtjenester.

Bakgrunn for rapporten

Internasjonalt er det en økende bekymring for at nylige invasjoner av to fremmede arter av asiatiske kjempeveps, asiatisk geithams (*Vespa velutina*) og japansk geithams (*V. mandarinia*), skal forårsake negative effekter på birøkt og på biologisk mangfold. Mattilsynet og Miljødirektoratet har derfor i fellesskap bedt Vitenskapskomiteen for mat og miljø om å vurdere risikoen for birøkt i Norge og norsk naturmangfold ved potensiell import, etablering og spredning av disse to artene, og risikoen for negative konsekvenser av slike introduksjoner. VKM ble også bedt om å oppsummere mulige risikoreduserende tiltak som kan forhindre eller redusere introduksjon, etablering og spredning av hver av artene.

Metoder

VKM opprettet en prosjektgruppe med ekspertise på veps, sosiale (kolonilevende) bier, biologisk mangfold hos insekter og invasjonsbiologi. Gruppen gjennomførte et litteratursøk i relevante informasjonskilder (vitenskapelige publikasjoner og på nettsider) om biologien og økologien til de to fremmede *Vespa*-artene. Vi modellerte nåværende og fremtidig klimatiske forhold i norske områder som vil være egnet for hver art ved bruk av Maxent modellering av potensiell utbredelse og Köppen-Geiger klimaklassifiseringskart. Vi identifiserte og evaluerte potensielle farer (hazards) med tanke på negative effekter på birøkt og biologisk mangfold. Vi gjennomførte deretter en semikvantitativ risikovurdering for hver av de to fremmede geithamsartene. Vi har også kort oppsummert mulige virkninger på økosystemtjenester og landbruk dersom de fremmede geithamsene etablerer seg i Norge. Vi har gjennomgått og evaluert mulige tiltak for å forhindre import av disse artene, og for å redusere negative effekter dersom de etablerer seg i Norge.

Invasjonshistorie og biologi til de to fremmede geithamsartene

Den asiatiske geithamsen, *V. velutina,* har nylig blitt utilsiktet importert til Europa og Sør-Korea. Arten har spredt seg raskt over hele Frankrike, hvor den først ble observert i 2004, og til andre deler av Europa hvor den finnes så langt nord som Hamburg i Tyskland og Meppel i Nederland. Spredningen av asiatisk geithams utenfor artens naturlige utbredelsesområde i Asia har vært langsommere enn i Europa, men den har nå spredt seg over hele Sør-Korea og har etablert bestander på øyene sørvest i Japan. Resultater av DNA-analyser tyder på at den europeiske populasjonen av *V. velutina* har én opprinnelse i det østlige Kina.

Den japanske geithamsen, *V. mandarinia*, ble først oppdaget på Stillehavskysten av Nord-Amerika i 2019, i tilstøtende områder av British Columbia i Canada og Washington State i USA. Siden har arten blitt funnet i et lite antall innenfor det samme begrensede området hvert år, hvilket tyder på at arten har etablert seg, men ikke spredt seg nevneverdig. Resultater av DNA-analyser tyder på at *V. mandarinia*-kolonier i denne regionen har to separate opphav.

De to geithamsartene skaper bekymringer for økonomien, særlig for birøktere. Begge artene kan danne kolonier med tusenvis av arbeidere i løpet av sommeren og tidlig på høsten, og begge artene jakter på en koordinert måte på honningbiearbeidere og -kolonier. Bekymringer for biologisk mangfold skyldes at geithamsartene også konsumerer store mengder av et bredt spekter av stedegne insekter. Predasjonen på honningbier kan være så alvorlig at honningbiekolonier blir delvis eller fullstendig ødelagt i løpet av noen få timer eller dager (derav omtalen av begge artene som "morderveps" i nyhetskanaler og sosiale medier). Den mest brukte honningbiearten, europeisk honningbie, *Apis mellifera*, som kultiveres i hele Europa, har ikke utviklet noe forsvar mot de fremmede geithamsartene, og det er rapportert om store tap forårsaket av predasjon fra begge artene for kolonier av europeisk honningbie i Europa og Øst-Asia. Kunnskapen om mulige negative påvirkninger på naturlige økosystemer som følge av predasjon på stedegne insekter, er begrenset.

Begge de asiatiske geithamsartene kan potensielt konkurrere med den stedegne europeiske geithamsen, *V. crabro*. Den europeiske geithamsen har nylig reetablert bestander i Sør-Norge, og arten er generelt vanlig der den forekommer naturlig i Eurasia. Studier av direkte konkurranse om mat, og kunnskapsgrunnlaget for øvrig, tyder på at det er betydelig overlapp i de økologiske nisjene til *V. crabro* og den invaderende *V. velutina* i Europa. Det er imidlertid ingen data som viser at *V. velutina* har forårsaket reduksjon i *V. crabro*-populasjoner i Europa.

For *V. velutina* har det vært flere undersøkelser av assosierte parasitter og patogener. Flere studier har antydet potensial for overføring av parasitter eller sykdommer fra asiatisk geithams til honningbier, men foreløpig er det lite som tyder på at dette representerer en tilleggstrussel mot honningbier eller biologisk mangfold ved invasjon av *V. velutina*.

Finnes det egnete leveområder i Norge for de fremmede geithamsartene?

Det er finnes sannsynligvis egnete habitater for både *V. velutina* og *V. mandarinia* i Norge. Det er imidlertid usikkert om nåværende eller fremtidige klimatiske forhold er egnet for *V. velutina*. VKMs resultater fra prediksjonsmodelleringen, tyder på at det ikke finnes klimatisk egnede områder for arten i Norge, verken under nåværende klimaforhold eller under anslått fremtidig klima. Resultater av publiserte modeller som er basert på andre datasett og annen metodikk, indikerer imidlertid at kystområder på Sør- og Vestlandet kan være klimatisk egnet for *V. velutina*, både i dag og i fremtiden. For *V. mandarinia* viser nyere publiserte økologiske nisjemodeller at store deler av Europa, inkludert Norge, allerede er klimatisk egnet.

Introduksjon, etablering og spredning

Ettersom *V. velutina* allerede er etablert og er utbredt i Europa, vurderer vi at det er mer sannsynlig («moderat sannsynlig») at *V. velutina* vil komme inn i Norge enn at *V. mandarinia* («svært usannsynlig») vil gjøre det i løpet av de neste 10 årene. For begge artene forventer vi at risikoen vil øke over tid, både på grunn av klimaendringer (gunstigere forhold) og en høyere kumulativ sannsynlighet for utilsiktet import. På grunn av klimatiske preferanser, konkluderer vi imidlertid med at etablering og videre spredning i Norge er mer sannsynlig for *V. mandarinia* ("sannsynlig") sammenlignet med *V. velutina* ("moderat sannsynlig"), dersom artene skulle komme inn i Norge.

Farer (hazards) og generelle risikoer

På grunn av artens suksess med å spre seg vidt utenfor sitt opprinnelige område de siste tiårene, foregår det for tiden betydelig forskning på biologien og økologien til *V. velutina*. Det finnes langt mindre kunnskap om *V. mandarinia*. Fordi det er store likheter mellom de to artenes atferd og økologi, har vi ofte ekstrapolert fra førstnevnte til sistnevnte når vi har identifisert farer i denne rapporten.

Vi identifiserte følgende farersom relevante for oppdraget, og vi har vurdert risikoen for at hver enkelt av dem skal inntreffe:

- Predasjon på honningbier. Begge de fremmede *Vespa*-artene kan ødelegge lokale bestander av honningbier. Tap av arbeidere eller hele kolonier påvirker både honningproduksjon og produksjon av voks og propolis, og pollinering av en rekke avlinger, spesielt frukttrær. Risikoen for negative følger på birøkt i Norge som følge predasjon på honningbier, er vurdert til å være **moderat** for både *V. velutina* og *V. mandarinia*.

- Predasjon på stedegne artropoder (insekter og andre leddyr). For begge de fremmede *Vespa*-artene vurderer vi at predasjon vil utgjøre en **moderat** risiko for stedegne artropoder.

- Konkurranse med stedegne artropoder (insekter og andre leddyr). I Europa er den største bekymringen konkurranse om byttedyr og reirplasser med den stedegne europeiske geithamsen, *V. crabro*. Vi konkluderer v med at konkurransen vil være liten i Norge. På grunn av forskjeller mellom *V. velutina* og *V. mandarinia* med tanke på sannsynlighet for at disse artene vil komme til landet, vurderer vi at risikoen for negativ effekt på biodiversitet på grunn av konkurranse med stedegne arter vil være **moderat** for *V. velutina* og **lav** for *V. mandarinia*.

- Innføring eller spredning av sykdommer. Begge de fremmede *Vespa*-artene kan være i stand til å introdusere eller spre patogener. Det finnes lite kunnskap om effekten av de fleste mikroorganismene som er assosiert med *V. velutina*, og det er ingen data om virus eller bakterier assosiert med *V. mandarinia*. På bakgrunn av det som er kjent, vurderer vi den samlede risikoen for introduksjon og spredning av patogener til å være **av** for begge arter.

• Innføring og spredning av parasitter. Som for patogener, finnes det mer informasjon for *V. velutina*. Vi konkluderer med at den totale risikoen for introduksjon og spredning av parasitter er **lav** for begge *Vespa*-artene.

Påvirkning på økosystemtjenester og landbruk

Det kan få både negative og positive effekter på økosystemtjenester dersom en eller begge de to fremmede *Vespa*-artene etablerer seg i Norge. Pollineringstjenester vil bli sterkest negativt påvirket siden begge artene både spiser og skremmer bort pollinerende insekter. Positive påvirkninger inkluderer predasjon på skadedyr, plantepollinering og frøspredning.

Forebyggende tiltak

Fordi fremmede *Vespa*-arter har høy kapasitet for selvspredning, og fordi håndtering av gods som kommer fra land der artene allerede forekommer i stor grad er automatisert, vil det være nærmest umulig å hindre at fremmede *Vespa*-arter før eller siden kommer til Norge. For å hindre at fremmede *Vespa*-arter etablere bestander i Norge, vil det være svært viktig å oppdage og bekjempe artene så tidlig som mulig. Sannsynligheten får å oppdage artene er størst hvis man informerer og involverer brede lag av befolkningen. For å finne *Vespa*-bol kreves ferdigheter i å spore arbeiderveps på matsøk, eller bruk av mer avansert teknologi som radiomerking eller radar. Hvis en fremmed *Vespa*-art etablerer seg i Norge, vil det bli behov for målrettede bekjempelsestiltak. En nøkkelkomponent vil da være kartlegging og prediksjon av artens utbredelse. Det er mulig å eliminere eller redusere antall geithams rundt bigårder, men det må utvises forsiktighet for å forhindre skadelige effekter på stedegne arter. En metode for å redusere skadelige effekter på honningbiekolonier, er å montere et finmasket gitter foran inngangen på bikubene.

Usikkerhetsfaktorer

Det er flere usikkerhetsmomenter som påvirker vurderingen av sannsynligheten for introduksjon og spredning, og risikoen som følger med etablering av kolonier av fremmede *Vespa*-arter. Den største usikkerheten er hvorvidt klimaet i Norge er egnet for *V. velutina*. Vi diskuterer usikkerheter knyttet til modellering av artenes utbredelse og forskjeller mellom resultatene av våre egne modeller og resultatene i nyere publikasjoner. Det er også vanskelig å vurdere sannsynligheten for at befruktede dronninger kan komme seg om bord på skip, lastebiler og private kjøretøy. En viktig kilde til usikkerhet er også mangelen på nyere forskning på *V. mandarinia*. I tillegg mangler vi kunnskap om potensialet for begge *Vespa*-artene til å introdusere eller spre patogener og parasitter.

Glossary and synonyms

Glossary

Colony Collapse Disorder (CCD)	An unusually sudden, drastic decrease in the numbers of worker bees that is not clearly caused by a single factor such as disease, starvation, or colony failure. Rather, CCD seems to be a result of a combination of factors such as parasites and pathogens, pesticides, and environmental stress, among others.
Eusocial	A technical term for animals with cooperative parental care that live in colonies and have a caste system that includes reproductives and non-reproducing workers or guards (reproductive division of labour). The most common eusocial animals are ants (all species), termites (all species), and bees and wasps (some species). In eusocial bees and wasps, the reproductive individuals in colonies (queens) are female, as are the workers.
Honey bees	In this assessment (as in much of the scientific literature) "honey bees" refers to the western honey bee, *Apis mellifera*. However, two domesticated *Apis* species are widely used in apiculture (beekeeping): *Apis mellifera* (western honey bee, European honey bee), managed throughout the world; and *A. cerana* (eastern honey bee, Asian honey bee) managed in south, southeastern, and east Asia. Honey, wax and propolis are also collected from wild or semi-domesticated species of several genera in the Apinae tribe Meliponini; these species are known as "stingless bees" and not as "honey bees".
Hornets	The common name for wasp species in the genus *Vespa*. These large wasps include our native European hornet *Vespa crabro* and the two invasive species treated here, the yellow-legged hornet (Asian hornet), *V. velutina,* and the Asian giant hornet, *V. mandarinia*. "Hornets" is also sometimes used for larger wasp species in other genera (such as *Dolichovespula,* yellowjackets that are also called "baldfaced hornets" in N. America). "Wasps" and

	"hornets" are used interchangeably for *Vespa* species in the literature and in this report.
Varroa mites	The common name for mites in the genus *Varroa* is "varroa mites". The pest of domesticated honey bees is the species *Varroa destructor*.
Vespine	Refers to members of the Vespinae subfamily of wasps. The Vespinae include what are commonly referred to as yellowjackets (the genera *Vespula* and *Dolichovespula*) and hornets (*Vespa*), plus a small south Asian genus (*Provespa*).

Synonyms

The two invasive hornets that are the subject of our report have sometimes been reported under older names that are no longer valid (synonyms). Synonyms of *Vespa velutina* Lepeletier, 1836, include the following (Smith-Pardo, 2020):

Vespa auraria Smith, 1852
Vespa crabro var*. immaculata* Morawitz, 1889
Vespa fruhstorferi Stadelmann, 1894
Vespa velutina var*. ardens* du Buysson, 1905 (1904)
Vespa auraria var*. nigrithorax* du Buysson, 1905 (1904)
Vespa velutina var*. celebensis* Pérez, 1910
Vespa velutina var*. megei* Pérez, 1910
Vespa mongolica var*. divergens* Pérez, 1910
Vespa flavitarsus Sonan, 1929
Vespa auraria flavitarsis Ma, 1937
Vespa velutina variana van der Vecht, 1957
Vespa velutina karnyi van der Vecht, 1957
Vespa velutina sumbana van der Vecht, 1957
Vespa velutina timorensis van der Vecht, 1957
Vespa velutina floresiana van der Vecht, 1957
Vespa velutina pruthii van der Vecht, 1959

Vespa mandarinia described by Smith, 1852 has been reported under the following other names and that are now synonymized under *V. mandarinia* (Smith-Pardo, 2020):

Vespa magnifica Smith, 1852
Vespa japonica Radoszkowski (in Motschulsky), 1857
Vespa bellona Smith, 1871
Vespa magnifica var*. latilineata* Cameron, 1903

Vespa mandarina Dalla Torre, 1894
Vespa magnifica var*. nobilis* Sonan, 1929
Vespa magnifica sonani Matsumura, 1930

Background as provided by the Norwegian Food Safety Authority and Norwegian Environment Agency

The Norwegian Food Safety Authority and The Norwegian Environment Agency ask the VKM to assess the risk of Norwegian beekeeping and unfortunate consequences for biological diversity caused by the species Asian Hornet and Asian Giant Hornet.

Background

Asian Hornet *(Vespa velutina)*

Asian Hornet is a stinging wasp, related to the European hornet (*Vespa crabro*) found in Norway. It originally belongs to Asia and is found in mountainous regions from Afghanistan to China and Indonesia.

The Asian Hornet like to stay calm at night, as opposed to the European hornet. Otherwise, this species way of life and course of life is reminiscent of the other hornets. The society is annual, and the nest is often built in trees. Only the future queens stay alive through the winter. Each forms a new society in the spring and is initially alone in building a nest and caring for eggs and later larvae and pupae. Eventually this work is taken over by newly hatched workers, and the queen can fully concentrate on laying eggs. During one season she can produce 6000 offspring. In early autumn the first sexually mature males (drones) and females hatch, an average of 350 during the autumn. Males and females mate. The old queen dies, and the society disintegrates. The young queens find a place where they can spend the winter, while workers and males die.

The adult hornets feed the larvae with chewed insects and occasionally other meat food, while in return they get a protein-rich juice back from the larvae. They also eat sap, nectar and juice from overripe fruits. The size of the hornet, the speed and powerful jaws allow them to take quite large and defensible prey. The stringer is mostly used for defence.

In 2004, Asian Hornets were detected in Southwestern France (Lot-et-Garonne) and have since spread (Rome et al. 2009). It is also well established in Spain, Portugal, Italy, and in recent years has also spread to Switzerland, Belgium, Germany and Luxembourg. In the summer of 2016, it was found for the first time on the Channel Islands of Jersey and Alderney – later in the year also near Tetbury in Gloucestershire, a good distance from the Channel coast. In Europe, the species is seen as an invasive species and is considered undesirable. The hornet is a predatory insect that attacks honey bees and other insects. For honey bees, the Asian Hornet is a documented threat.

Asian Giant Hornet *(Vespa mandarinia)*

The Asian Giant Hornet is the largest of the stinging wasps. It also belongs to the same genus as European hornet (*Vespa crabro*) that is found in Norway, and it is reminiscent of this in way of living. It originally belongs to temperate and tropical regions of eastern Asia, southern Asia, mainland southeast Asia and eastern Russia. The Asian Giant Hornet has a body length of 45 millimeters and a wingspan of up to 75 millimeters. It has a stinger of 6 millimeters and injects a large amount of powerful poison. In the vernacular, the Asian Giant Hornet is also called «The murder wasp».

Asian Giant Hornets prefer to live in forests and in low mountains and avoid almost all plains and high mountains. The Asian Giant Hornet is the hornet species that is most dependent on green areas. It creates nests by digging, by using existing tunnels dug by rodents or other digging animals, or by occupying spaces near rotten pine roots, and has almost exclusively underground nests. It mainly eats larger insects such as bees, other hornet species and locusts, insects that live in colonies, and honey from honey bees.
Western honey bees do not have a natural defence mechanism against the Asian Giant Hornet.

In late 2019 Asian Giant Hornets were found in Western North America, mainly in the Vancouver area. Nests have also been found in Washington in the United States. Several observations of both insects and nests of Asian Giant Hornet have been made in these areas in 2020 and 2021.

Legal background

The Food Act with underlying regulations does not prevent the introduction of Asian Hornet and Asian Giant Hornet into Norway or the spread of these species in Norway if they should be introduced. The importation of Asian Hornets and Asian Giant Hornets into Norway requires a permit in accordance with regulations on alien organisms under the Biodiversity Act.

Terms of reference as provided by the Norwegian Food Safety Authority and Norwegian Environment Agency

The Norwegian Food Safety Authority and the Norwegian Environment Agency ask VMK to describe:

1) Status of the occurrence of Asian Hornet (*Vespa velutina*) in Europe
   Status of the occurrence of Asian Giant Hornet (*Vespa mandarina*) in Europe

2) Investigate the probability of import, establishment and spread of Asian Hornet and Asian Giant Hornet in Norway

3) Investigate the negative consequences of the import, establishment and spread of Asian Hornet and Asian Giant Hornet in Norway on:

   a. Honey bees
   b. Biodiversity beyond honey bees

4) Characterize the risk associated as a result of the import, establishment and spread of Asian Hornet and Asian Giant Hornet in Norway on:

   a. Honey bees
   b. Biodiversity beyond honey bees

5) Summarize possible risk-reducing measures to:

   a. Prevent/reduce the introduction, establishment and spread of Asian Hornets and Asian Giant Hornet.
   b. Prevent/reduce negative consequences given the introduction, establishment and spread of Asian Hornet and Asian Giant Hornet in Norway.

1 Introduction

1.1 Problems related to invasive arthropods

Numerous examples exist of invasive arthropods causing harm to native biodiversity. Harm can be caused if established populations of a non-native species impact the structure and dynamics of native ecosystems, such as by outcompeting native species for resources, by preying on native species, or by introducing or increasing the spread of parasites and diseases that can infect the local fauna. Invasive arthropods can harm food production and forestry, and some are associated with the transmission of diseases in humans. The Invasive Species Compendium (cabi.org) and the Global Invasive Species Database (iucngisd.org) present long lists of invasive species that pose serious risks to native biodiversity, agriculture, or forestry, and the lists include many arthropods.

Species with advanced social behaviour, such as termites, ants, and eusocial species (see Glossary) of bees and wasps, are overrepresented among invasive arthropods. Once introduced, social species are more likely to become established and spread widely, and more likely than other invasive species to have measurable impacts on native ecosystems (Beggs et al. 2011, Lester and Beggs 2019). Due to their complex social organization, eusocial termites, ants, bees and wasps share traits such as high local abundance, being generalists with respect to resource requirements, having sophisticated communication systems, and having coordinated group aggressive behaviour when threatened (Beggs et al. 2011).

In addition, species in which the queens may mate with several males (polyandrous species) have the advantage of arriving in new areas with a larger genetic diversity, as compared to species where females mate with only one male. Notably, females of the highly successful invasive wasps *Vespa velutina*, *Vespula germanica* (Fabricius) and *Vespula vulgaris* (Linnaeus) have higher mating frequencies than their relatives (Arca et al. 2015). The ongoing invasion of Europe by *V. velutina* (Subsection 1.3.2) was likely initiated by a single queen that had mated with 3 or 4 males (Arca et al. 2015).

Social wasps of the genus *Vespula* have spread to most parts of the world and have become significant pests with major impacts on ecosystems because of their large colony sizes (e.g., *V. vulgaris* can have colonies with up to 230,000 workers), high reproductive capacity and flexible predation (Lester and Beggs 2019, Harrop et al. 2020). Two of the common eusocial wasps native to Norway, *V. germanica* (Norw. *tyskveps*) *and V. vulgaris* (Norw. *jordveps*) are invasive species elsewhere: *V. germanica* in South America (Argentina), Australia, and New Zealand; *V. vulgaris* in S. America (Argentina) and New Zealand (Beggs et al. 2011, Pereira et al. 2016).

1.2 Biology of relevant *Vespa* species

1.2.1 Taxonomy and distribution

Paper wasps in the tribe Vespini, family Vespidae, are divided into four genera, three of which are common in Scandinavia: *Vespa* (1 species in Norway), *Vespula* (4 species in Norway) and *Dolichovespula* (7 species in Norway). The last genus in Vespini, *Provespa*, is only found in the Indo-Malayan region (Carpenter and Kojima 1997).

A total of 22 species are reported for the genus *Vespa*, including several species that are invasive outside their native range (Smith-Pardo et al. 2020). Two species are native in Europe, including the widespread European hornet, *Vespa crabro* Linnaeus, and the oriental hornet *Vespa orientalis* Linnaeus in southern Europe (Matsuura and Yamane 1990, Carpenter and Kojima 1997). A map of the distribution of *V. crabro*, *V. velutina* and *V. mandarinia* is shown in Figure 1.2.1-1.

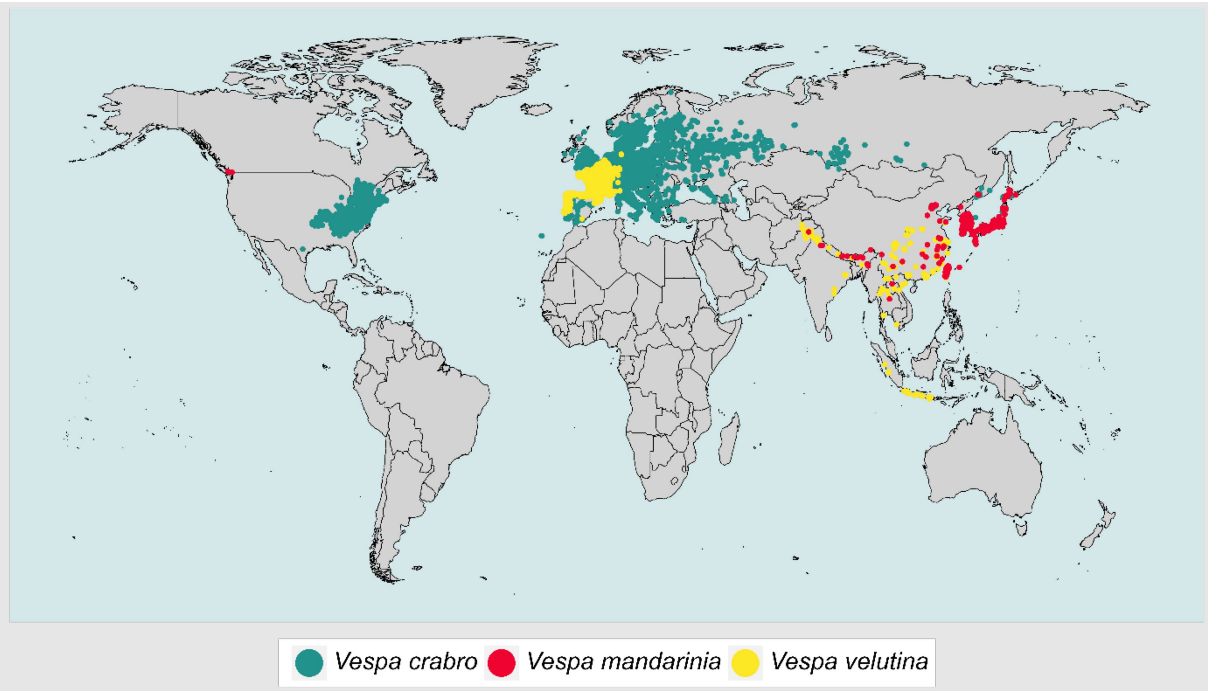

Figure 1.2.1-1: Distributions (native and invaded ranges pooled) of the two species that are risk assessed in the current report; *Vespa velutina* (yellow) and *V. mandarinia* (red); and of the European hornet *V. crabro* (green), based on reliable observations from European and Mediterranean Plant Protection Organization (EPPO) and CABI databases).

1.2.1.1 Vespa crabro [European hornet]

Vespa crabro (Norw. *geithams*) is the single species of the genus native to Scandinavia (Douwes et al. 2012). The common name European hornet is misleading, as its native distribution includes large parts of Eurasia (east to Japan) and Algeria. *V. crabro* was absent from Norway from 1911 to 2007 but is now common over much of the southeastern part of the country, north to Hedmark (http://www.artsdatabanken.no/Pages/148252/Geithams). It is gradually spreading along the coast of southern Norway. The European hornet was introduced to New York in the mid-1980s and is now widespread in eastern North America (Akre et al. 1980).

1.2.1.2 *Vespa velutina* (Yellow-legged hornet, Asian hornet)

Vespa velutina is native to central and southeast Asia, ranging from Afghanistan in the northwest to Indonesia in the southeast (Arca et al. 2015). Its native distribution includes Afghanistan, Pakistan, India, Bhutan, Nepal, southern China, Hong Kong, Taiwan, Myanmar, Thailand, Laos, Vietnam, Malaysia, Malaya, and Indonesia. This species has invaded South Korea, Japan and Europe (see 1.3.2 for details), but has not yet been found in Scandinavia as of January 2022 (Robinet et al. 2019, Jeong et al. 2021 and various online databases).

1.2.1.3 Vespa mandarinia (Asian giant hornet)

Vespa mandarinia is native to southern Eurasia, ranging from India to Korea and Japan (Archer 1995). Its native distribution includes India, Sri Lanka, Bhutan, Nepal, Myanmar, Thailand, Laos, Vietnam, Malaysia, Malaya, China, Hong Kong, Taiwan, eastern Russia, Korea, and Japan (including Ryukyus). The only known successful establishment of this species outside its native range is in British Columbia (Canada) and the northwest corner of Washington State (USA) just over the border from Canada (Wilson et al. 2020, Norderud et al. 2021).

1.2.2 Morphology and identification

The alien hornet species could be confused with native European hornets or wasps by the general public. Queens of *V. mandarinia* are quite distinctive, at nearly 5 cm long, with yellow-orange head and dark legs. Workers and males have similar colors but smaller size (around 3–4 cm). Adults of *V. velutina* more closely resemble native wasps and hornets. *V. velutina* and the native hornet *V. crabro* are larger than the other vespids; both have workers and males whose sizes range from 2 to 3 cm. *V. velutina* queens are similar in size to larger workers but are heavier (Rome et al. 2015), while *V. crabro* queens are larger (around 3.5 cm)[1] (Matsuura and Yamane 1990, Kwon and Choi 2020).

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[1] www.vespavelutina.co.uk/asianhornet.html

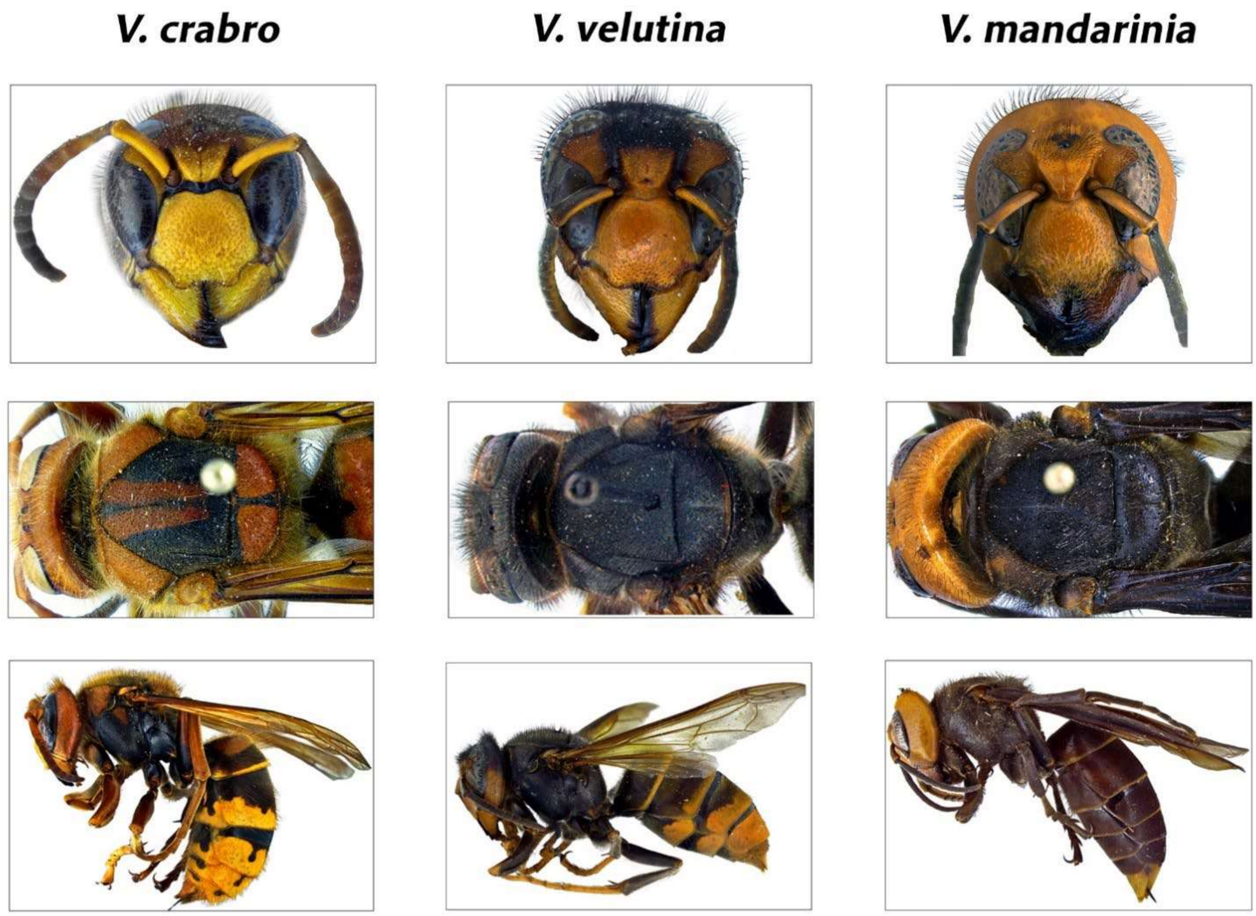

Figure 1.2.2-1: Frontal view of workers, dorsal view of head and mesoscutum, and in bottom row a lateral view of the three *Vespa* species. Not to scale and coloration may vary considerably according to subspecies or other local conditions. Photos: Allan H. Smith-Pardo.

V. crabro has a predominantly yellow abdomen, as do most of the wasp species found in Norway and has a bright yellow scape (first segment of the antenna); the body of *V. velutina* is largely black, with orange stripes at apex, and the scape darker coloured (Figure 1.2.2-1). *V. velutina* is usually referred to as the yellow-legged hornet due to the distinctive yellow lemon colour of the ends of the legs (tarsi), which in *V. crabro* are yellow-orange to brown. Both hornets lack the bright yellow markings seen on the upper side of the thorax (middle body segment) of wasp species native to Norway (*Vespula, Dolichovespula*). However, identification of specimens or photographs of individuals that might be *V. velutina* or *V. mandarinia* should always be verified by taxonomic experts (Sumner et al. 2019).

Adults of the three species, *V. crabro, V. velutina* and *V. mandarinia* can be separated with greater certainty by close examination of certain specific features (Figure 1.2.2-1).

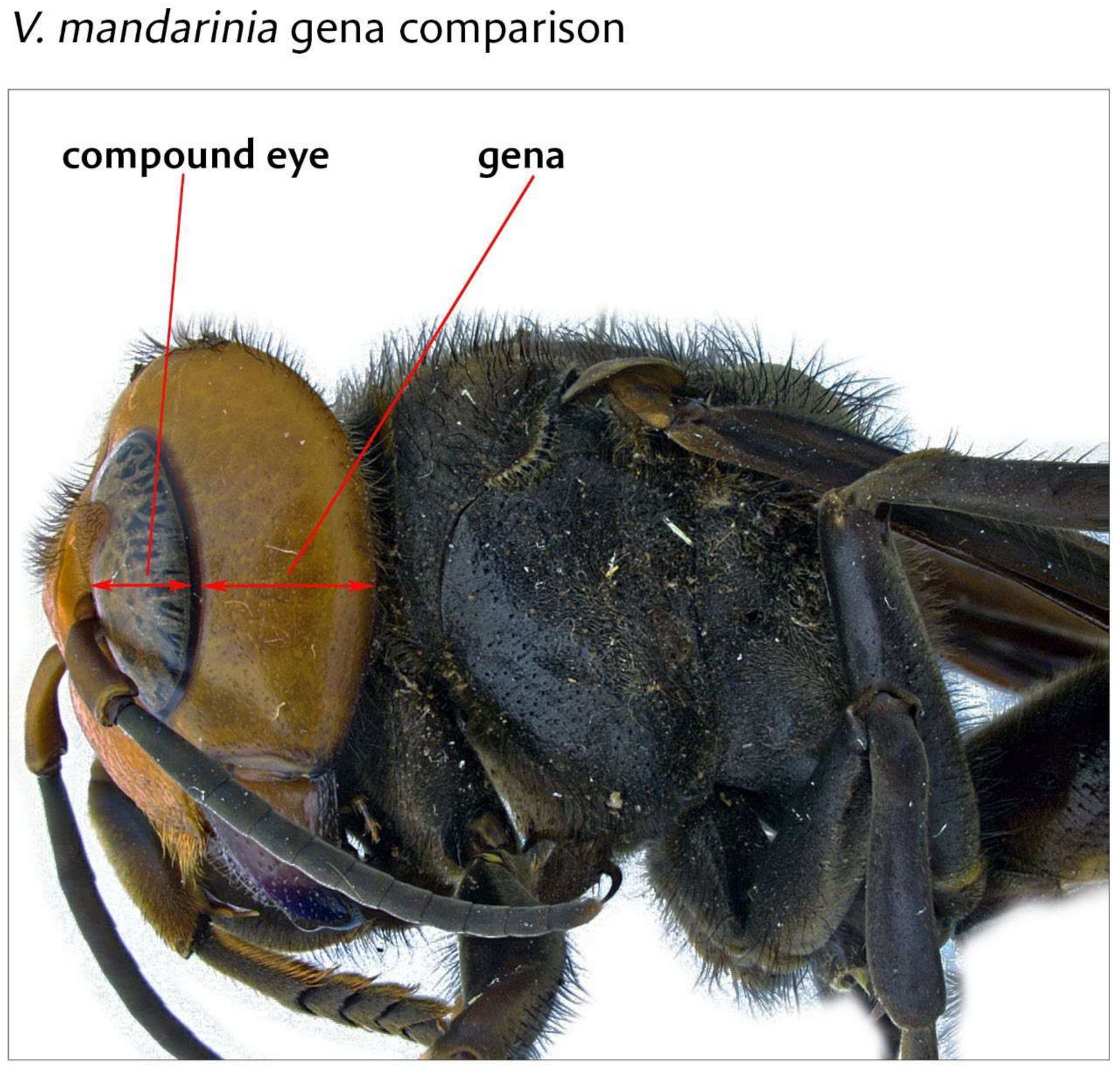

Figure 1.2.2-2: Side view of *V. mandarinia*, illustrating the 1.7X ratio of the wider gena width compared to the compound eye width. Photo: Allan H. Smith-Pardo.

V. mandarinia is the largest of the species and has in side view the gena more than 1.7 times the medial width of the compound eye (Figure 1.2.2-2); the interocellar distance is much less than the distance from posterior ocelli to the posterior margin of the head (Figure 1.2.2-3) (Smith-Pardo et al. 2020).

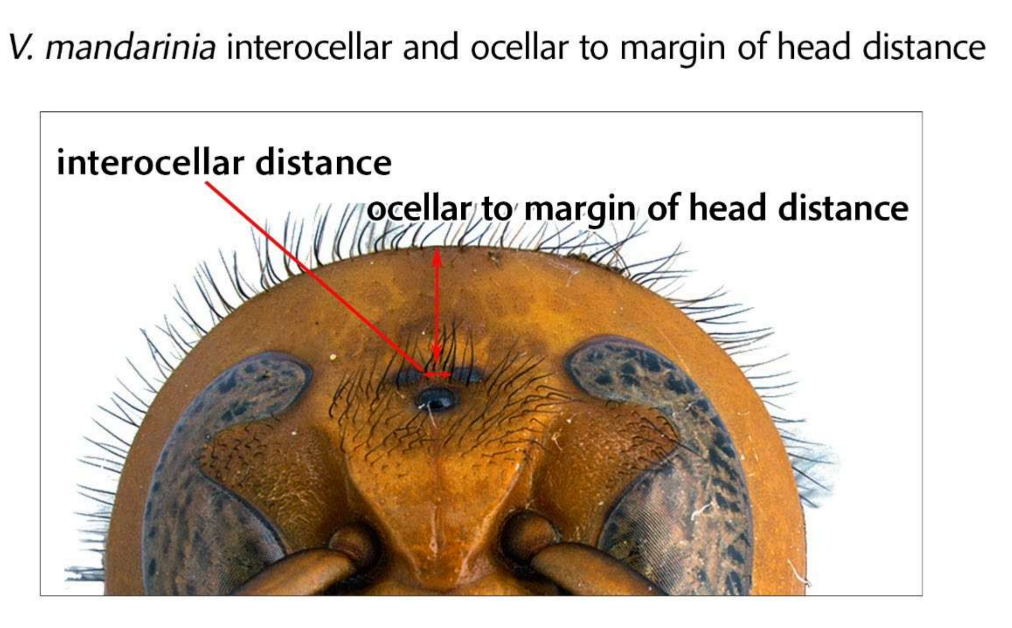

Figure 1.2.2-3: Frontal view of *V. mandarinia*, illustrating the short interocellar distance in comparison to the long distance from the hind ocelli to the edge of head. Photo: Allan H. Smith-Pardo.

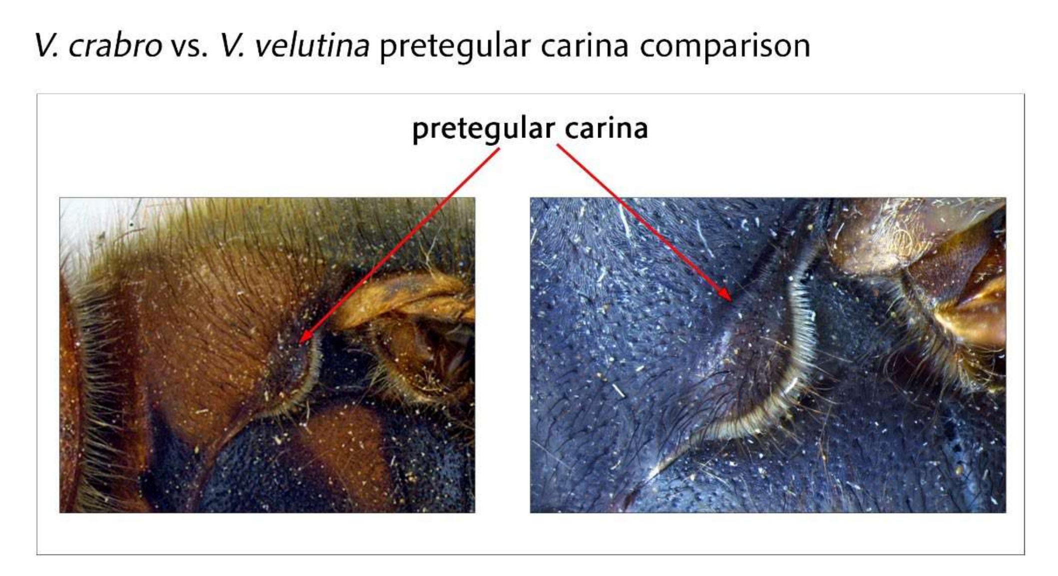

Figure 1.2.2-4: Lateral view of pretegular carina (ridge) from *V. crabro* and *V. velutina*. This is located right in front of the basis of the front wing and before the tubercle. *V. crabro* has the pretegular carina complete (left) while *V. velutina* has an incomplete pretegular carina (right). Photos: Allan H. Smith-Pardo.

V. crabro and *V. velutina*, in contrast, have both a narrow genal area and the interocellar distance is as long or almost as long as the distance from the posterior ocellus to the eye (ocellocular distance). The two species can be separated because *V. crabro* has the pretegular carina complete (Figure 1.2.2-4) and the clypeus is medially with coarse large punctures, these separated by one puncture diameter or less (Figure 1.2.2-5). *V. velutina* has an incomplete pretegular carina and the middle of clypeus with only small punctures, these separated by more than one puncture diameter (Smith-Pardo et al. 2020).

V. crabro vs. *V. velutina* clypeus comparison

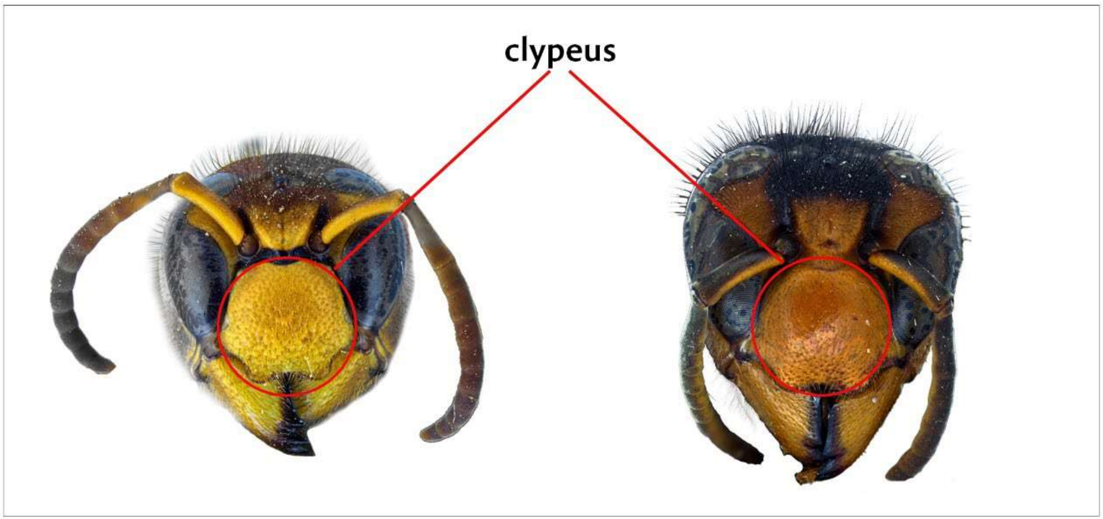

Figure 1.2.2-5: Frontal view of *V. crabro* and *V. velutina*, illustrating the difference in clypeus surface. *V. crabro* at left with coarse or large punctures, separated by one puncture diameter or less and *V. velutina* at right with only small punctures separated by more than one puncture diameter. Photos: Allan H. Smith-Pardo.

Larvae of *Vespa* are quite uniform in morphology and the three species are difficult to separate, especially *V. crabro* and *V. velutina* (Yamane, 1974). In these two species, the temporal region of each cranial half possesses a ventral weakly margined band or fossa called the temporal band, a developed mid-cranial sulcus (also known as median suture, visible above the clypeus), and softly rounded collar processes of the fourth instar spiracle. In contrast, *V. mandarinia* has a ventrally distinct and well margined band or fossa called the temporal band in the temporal region, lacks a mid-cranial sulcus, and the collar processes of the fourth instar spiracle are longer and pointed (Yamane, 1974).

1.2.3 Life cycle

All hornets are eusocial insects that nest in colonies with cooperative brood care. They have a caste system involving a queen and workers, as do honey bees, bumble bees and ants. Colonies of hornets in temperate climates are annual and, similar to bumble bees, colonies are founded in the spring by single mated queens once they emerge following overwintering and hibernation.

In the initial or embryonic phase, the queen (or foundress) will gather larval provisions for the small nest. The nest includes brood layers with cells for prey provision; the queen will deposit a single egg in each cell. The egg develops into a larva that, following five instar stages, pupates and hatches into a female adult worker hornet. Once a number of workers have been reared, they will continue to expand the nest, both by adding additional layers of wood pulp, constructing brood cells and provisioning of the cells. The queen spends most of her time laying eggs. Nests are made by chewing wood into a papery construction pulp. By the end of the summer season, new reproductives (males and future queens) are produced in the colony. These will leave the colony for mating and eventually the mated females will hibernate, whereas the males will die (as do the workers). Hibernation usually occurs under bark, under stones or in other hideaways. *V. mandarinia* females dig down into in soft ground and overwinter there (Archer 1995). Nests are not re-used the following year. In contrast to this, occupied persistent winter nests have been reported for *V. velutina* in Spain (Feas Sanchez and Charles, 2019). Individual workers of hornets are relatively short-lived as adults (about three weeks), whereas the adult queen can persist for up to 12 months (Archer 1995).

***V. crabro*:** The worker brood cells of *V. crabro* are 6–7 mm wide, whereas the diameter of the large queen cells is about 10 mm. In Sweden, a *V. crabro* nest can consist of a few hundred individuals during late summer, while more than a thousand individuals can be found in a nest in southern Europe (Douwes et al. 2012). Mated queens leave their overwintering hide in early- or mid-May in Scandinavia and can be seen until early June. Newly hatched queens appear from the end of August to October-November. The workers appear from June to July and can sometimes be observed until mid-October. The males start to fly slightly before the new queens - in mid-August - and they can fly well into October-November (Douwes et al. 2012).

***V. velutina*:** Limited information on their life cycle is available from Europe, and most information is available from within the native range of these species. Colony size, emergence dates, and development time may vary across native and introduced ranges, as the climate is likely a trigger for much of the variation. *V. velutina* workers will appear 30 to 50 days after the nest is established, and the colony size at the end of the summer can reach up to 13,000 workers including several hundreds of potential founder queens (Choi et al. 2012, Rome et al. 2015, Feas Sanches and Charles 2019). Based on simulations of the spread in southwestern France of around 78 km per year, it is assumed that the mated queens migrate before winter hibernation, in search of adequate hibernating sites or after hibernating searching for nesting sites (Robinet et al. 2017). Genetic studies of *V. velutina* have uncovered that females mate with more than one male (a mating system known as polyandry). Polyandry is rare among wasps and is a trait that can have promoted the success of this Asian hornet in Europe (Arca et al. 2015). Multiple matings by females is important because 1) queens need sperm from several males in order to produce enough workers, 2) genetic advantages that may determine the success of invasion, and 3) higher genetic variation among offspring can confer greater resistance of the entire colony to parasites or pathogens (Arca et al. 2015).

***V. mandarinia*:** The species has never been observed in Europe. In Japan, the time of maturity from egg to adult is approximately 40 days (Matsuura 1984). A typical nest consists of 4 to 10 combs and 3000 to 5000 cells (Matsuura and Sakagami 1973, Matsuura and Yamane 1990). A full colony cycle from initiation to dissolvement lasts approximately 6 months (Archer 1995).

1.2.4 Nesting ecology

Nests of *V. crabro* are built above ground, usually in a hollow oak. Roof openings in buildings are also often used for nest establishment. Occasionally, they occur in wooden birdhouses and in abandoned woodpecker nests. Very rarely, the nest is built in the ground or free-hanging. Nest surface structure is a brittle brown and yellowish material built mainly from rotten wood (Douwes et al., 2012).

Nests of *V. velutina* in Europe are often found high in trees (> 10 m), build around branches, and with a spherical or pear-formed shape (Rome et al. 2015, Feas Sanches and Charles, 2019). Buildings are occasionally used (Nakamura and Sonthichai 2004, Rome et al. 2015).

V. mandarinia usually selects subterranean nest sites, including cavities formed by rotten tree roots or made by small vertebrates or snakes (Matsuura and Sakagami 1973, Azmy et al. 2016). Nests in tree hollows are usually below ground or at ground level but can occur up to 2 m above ground. Nests of *V. mandarinia* have been found in man-made structures in urban environments, albeit rarely (Matsuura and Koike 2002).

1.3 Spread of *V. velutina* and *V. mandarinia*

1.3.1 Worldwide

V. velutina has been accidentally introduced to South Korea and France, and from South Korea it is now island hopping into Japan (Takahashi 2019). Genetic analyses suggest that the Korean and French introductions originated from the general region of Zhejiang and Jiangsu provinces in eastern China and hence belong to the subspecies *V. velutina nigrithorax* (Archer 2012, Arca et al. 2015, Namin and Jung 2020). The first find in South Korea was in 2003 and has spread slowly there but is now present throughout nearly all of South Korea (Jeong et al. 2021). The populations on the islands of Japan are believed to have spread recently from South Korea. The first discovery of this species was in 2013, and the establishment in Japan began in 2015 (summarized in Takahashi et al. 2019). This species has also been introduced to Yemen, but we cannot find any information about the fate of the introduction (Carpenter and Kojima 1997) and there are no records from Yemen in Global Biodiversity Information Facility (GBIF; searched 28 Oct. 2021).

The first nest of *V. mandarinia* in North America was found in 2019 in Nanaimo, British Columbia, Canada. Nanaimo is situated on Vancouver Island, across a strait from Vancouver and not far from the USA border. That same year, an adult *V. mandarinia* was collected in Whatcom County, Washington, USA, 95 km to the southeast of the Nanaimo nest. Both localities where the species was detected during 2019 in North America occur in close proximity to international shipping ports, which routinely receive high volumes of cargo from Asia. Despite the proximity of these localities, DNA analysis based on 13 protein coding mitochondrial genes suggested that the Canadian and USA hornets are from different sources: most likely, Japan for the former and South Korea for the latter (Wilson et al. 2020). There have been a handful of subsequent sightings of the species near Nanaimo in southwest British Columbia and northwest Washington State (Wilson et al. 2020, Norderud et al. 2021), including nests[2]. Most recently, a single dead male was reported from Snohomish County in Washington, over 100 km south of previous sightings[3].

1.3.2 In Europe

V. velutina was first observed in France in 2004 but undoubtedly was established earlier, and it is spreading rapidly in Europe (Villemant et al. 2006, Robinet et al. 2019). The species can now be found in Portugal, the northern half of Spain, and throughout France[4], from where it is gradually colonizing eastwards into northwestern Belgium[5] and across the border to Switzerland[6]; Luxembourg (Ries et al. 2021), western Germany and northwestern Italy[7]. Nests were first discovered in England in 2016, though the species likely arrived earlier (Budge et al. 2017, Keeling et al. 2017). Eight nests were found and destroyed between 2016 and 2019, and as of 2020, *V. velutina* did not seem to have become established on the island, as there have been no instances so far of new nests being offspring of another English nest. DNA analyses (microsatellites) showed that all *V. velutina* nests in England

[2] https://agr.wa.gov/about-wsda/news-and-media-relations/news-releases?article=32789

[3] https://agr.wa.gov/about-wsda/news-and-media-relations/news-releases?article=32455

[4] https://frelonasiatique.mnhn.fr/

[5] https://www.vespawatch.be/about/vespa-velutina/

[6] https://ffa-vfb.ch/2017/04/26/apiservice-arrivee-du-frelon-asiatique-en-suisse/

[7] https://www.vespavelutina.eu/en-us/vespa-velutina

derived from current European populations rather than from the species' native range (Jones et al. 2020). Sporadically, nests continue to be found (and destroyed), one in 2020 and two in 2021[8]. Altogether, there have been 21 sightings of *V. velutina* in England; most of these have been from the southernmost counties, but a nest was found in Staffordshire (ca 53° N) and there were confirmed findings of single wasps from Lancashire and Yorkshire (ca 54° N). A single female of *V. velutina* was found 'alive but dying' on 25th of April 2021 outside Dublin in Ireland[9]. In the north of continental Europe, a recent disjunct record of a single specimen from Hamburg, Germany (ca 54° N), was reported in 2019 by Husemann et al. (2020), and a large nest was reported the following year (iNaturalist[10]). *V. velutina* was first discovered in 2017 in the Netherlands and appears to be spreading throughout the country. It was spotted in 16 locations in 2021, as far north as Meppel (ca 53° N)[11] (see also the continuously updated website waarneming.nl).

1.4 Impacts of *V. velutina* and *V. mandarinia*

1.4.1 Impacts of *V. velutina* on native animals

1.4.1.1 Competition with native Vespa and other hornets

V. velutina coexists with several other *Vespa* species in its native range in tropical and subtropical Asia (Martin 1995, 2021). *V. velutina* is invasive in South Korea, where it arrived in 2003 (Kim et al. 2006). By 2010, it had become the most abundant hornet species in the southern part of South Korea, displacing native *Vespa* species, such as *V. simillima* Smith and causing declines in other native species including *V. mandarinia* and *V. crabro* (Choi et al. 2012). In Japan, Ikegami et al. (2020) found strong negative correlations between the occurrence of alien *V. velutina* and native *Vespa* species, especially native *V. m. japonica,* even after accounting for environmental effects and spatial autocorrelation. This suggests strong competition or predation among *Vespa* species (Ikegami et al. 2020). In one-on-one battles with five hornet species native to Korea at artificial food sources, *V. velutina* usually lost, likely because it is smaller in body size than all but one of the native species (Kwon and Choi 2020). *V. crabro* was dominant to *V. velutina* in these fights, but this does not seem to hamper the spread of *V. velutina* in Europe. Invasive *V. velutina* contend with a variety of

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[8] https://www.gov.uk/government/publications/asian-hornet-uk-sightings/asian-hornet-sightings-2020

[9] https://biodiversityireland.ie/asian-hornet-alert/

[10] https://www.inaturalist.org/observations/71974979

[11] https://dutchreview.com/news/asian-hornet-spotted-in-16-dutch-locations/

Vespa species in Asia, most of which are larger, in contrast to contending with only *V. crabro* in Europe, which at least may partly explain the slower spread of the invasive hornet in Asia (Korea and Japan) than in Europe (Villemant et al. 2011, Arca et al. 2015, Ikegami et al. 2020, Kwon and Choi 2020).

In Europe, the native *V. crabro* and the invasive *V. velutina* have overlapping geographic distributions (Figure 1.2.1-1), suggesting that *V. crabro* is the only congener that potentially may compete with *V. velutina.* However, the extent to which *V. velutina* and *V. crabro* compete in Europe is not yet clear. Villemant et al. (2011) suggested that a low level of competition from similar *Vespa* species (only one species) may have contributed to the rapid establishment and spread of *V. velutina* in France. Yet, empirical evidence – especially from field-based studies – is scarce, and even less is known about the potential competition between *V. velutina* and other wasps in Europe.

A study from northwest Spain comparing the distributions of *V. velutina* and *V. crabro* found relatively higher numbers of *V. velutina* in low-altitude coastal areas, whereas *V. crabro* was captured mainly at higher altitudes, which may indicate that *V. crabro* is better adapted to colder climates (Rodriguez-Flores et al. 2019). On a smaller spatial scale, a study from France found that the apiaries where *V. crabro* workers were observed were in the least urban landscapes, whereas the relative proportion of *V. velutina* was highest in urban areas (Bonnefond et al. 2021). This is in line with findings from South Korea, where Choi et al. (2012) found a significant positive correlation between the abundance of invasive *V. velutina* and the degree of urbanization. However, *V. velutina* can adapt to a wide range of habitats, including forests (Ikegami et al. 2020).

In Europe, *V. velutina* and *V. crabro* overlap little in choice of nesting sites: *V. crabro* is restricted to cavities or sheltered sites, while *V. velutina* can nest in confined spaces but prefers exposed sites (Cini et al. 2018). Nonetheless, in France, Rome et al. (2015) found dead queens of *V. crabro* below *V. velutina* nests and *vice versa*, suggesting that *V. velutina* and *V. crabro* queens may compete for nesting sites. In South Korea, invasive *V. velutina* has been found to displace the smaller *V. simillima* (Kwon and Choi 2020), which has a similar nesting biology (Choi et al. 2012). Numerical dominance of *V. velutina* over *V. crabro* depends on the number of nests in an area. *V. velutina* queens have a higher reproductive potential with their nests having more cells in each nest and producing larger numbers of workers and adults, and hence *V. velutina* colonies are much larger than those of *V. crabro* (Villemant et al. 2011, Monceau et al. 2015a).

Field studies have found some degree of temporal segregation with a later seasonal emergence of *V. crabro* compared to *V. velutina*, giving *V. velutina* a competitive advantage to exploit early food resources and search for nest sites (Monceau et al. 2015a). However, Sánchez and Arias (2021) report that both *V. velutina* and *V. crabro* were present throughout the year, showing similar phenological cycles and maximum abundances in autumn. On a finer temporal scale, *V. velutina* is largely diurnal and is generally not active during night-time, whereas *V. crabro* is also active at lower light intensities (Perrard et al. 2009, Kelber et al. 2011, Poidatz et al. 2018, Feás Sánchez and Charles 2019).

V. velutina and *V. crabro* also exhibit other behavioural differences, with higher levels of boldness, exploration and activity observed for *V. velutina* queens (Monceau et al. 2015b). Cini et al. (2018) observed no differences in the exploratory behaviour under laboratory conditions, but *V. velutina* workers showed a higher ability in exploiting protein sources, with apparently lower energy needs than *V. crabro* workers. Cini et al. (2018) also found that constitutive antibacterial activity was greater in *V. crabro* than *V. velutina* workers, suggesting differences in the immune system between the two species.

There is considerable dietary overlap between *V. velutina* and *V. crabro*. Both species are generalists and prey on honey bees, native pollinators and a range of other native insects (Matsuura and Yamane 1990, Cini et al. 2018, Rome et al. 2021, Verdasca et al. 2021). Bonnefond et al. (2021) suggested that *V. crabro* creates its own micro-niche instead of competing with *V. velutina*. This is in agreement with Monceau et al. (2015b) and Cini et al. (2018), who found only partial overlap between these two hornet species in seasonal phenologies and their foraging activity on carbohydrate and protein resources; *V. crabro* were more attracted to carbohydrate and *V. velutina* were more attracted protein baits. Monceau et al. (2015a, p. 466) concluded that four years after *V. velutina* was observed in their study area in France, "the co-occurrence of the native and the invading hornet species could be considered stabilized". Field-based evidence from a recent study in Italy concluded that the presence of *V. velutina* has not led to an evident replacement of native *V. crabro* or *Vespula* species during the four years since invasion (Carisio et al. preprint).

Monceau et al. (2015a) also suggested that there may be some degree of predator facilitation of native *Vespa* species in areas where invasive *V. velutina* and *V. crabro* co-exists; the predation pressure on honey bees by *V. velutina* can be very strong and *V. crabro* may take advantage of weakened colonies, which are less defended, or scavenge left-over dead bees after attacks by *V. velutina* on honey bee colonies.

1.4.1.2 Predation on native species

Invasive *V. velutina* are generalist, opportunistic predators that feed on locally abundant insects (Perrard et al. 2011, Rome et al. 2021, Verdasca et al. 2021). Based on studies of 16 nests in France, Rome et al. (2021) estimated that the *V. velutina* colonies they studied preyed on 411 species. They estimated that an average *V. velutina* colony consumed about 97,000 'honey-bee sized' prey, which amounts to about 11 kg of insects per season, preying on honey bees (38%), flies (30%) and social wasps (20%), plus over 150 species of other insects and spiders. The predominance of honey bees and social wasps is in line with the findings from a metabarcoding study that was aimed at detecting predation on honey bees (Verdasca et al. 2021). Notably, despite the abundance of social Hymenoptera in the diet, there is no indication that *V. velutina* poses a threat to bumble bees (*Bombus* spp.). For example, only one out of nearly 1300 Hymenoptera prey specimens identified by Rome et al. (2021) belonged to the genus *Bombus*.

Rome et al. (2021) found that the proportion of non-honey bee prey was higher in rural areas. The prey distribution and diet composition relative to environmental context found by Rome et al. (2021) is in line with previous findings from France (Villemant et al. 2011). Carisio et al. (2019) reported that *V. velutina* nest density had a negative effect upon local insect communities in Northwest Italy, including wild bee and diurnal butterfly abundances. Kishi et al. (2017) found many carcass fragments of greenbottle flies (*Lucilia* spp., Calliphoridae) and a wasp (*Vespula* sp.) in nests of invasive *V. velutina* in Japan, but noted that prey composition and abundance remain little studied.

Adult *V. velutina* that visit flowers to feed on nectar also frequently hunt flower-visiting insects as food for their larvae (Ueno 2015, Kishi et al. 2017). Following the introduction of *V. velutina* to Europe, concerns have been raised about reduced pollinator populations, given that bees, wasps and other pollinators constitute a large part of its diet (Genovesi 2015, Fedele et al. 2019, Laurinio et al. 2020, Rome et al. 2021, Verdasca et al. 2021). Yet, although negative impacts on pollinator populations, and consequently reduced pollination services (of wild and crop plants), have been hypothesized and inferred from observational studies, the extent of impact on native biodiversity is not completely understood.

1.4.1.3 Behavioural changes in native species

Rojas-Nossa and Calviño-Cancela (2020) demonstrated reduced pollination services in invaded areas as a consequence of invasive *V. velutina* hunting pollinators in patches of a wild mint, *Mentha suaveolens,* in Spain. *V. velutina* workers were frequent and successful hunters of flower visitors. Consequently, in patches with *V. velutina* predators, there was a significant reduction in patch visitation rates of honey bees, flower visitation rates of small hymenopterans, and time spent visiting flowers by bumble bees (*Bombus* spp.) and hover flies (Syrphidae). These behavioural changes by the pollinators resulted in lower quantities of conspecific pollen on stigmas of the studied native plant in patches where *V. velutina* was present.

1.4.1.4 Food resource for natural enemies

The most important predators of Vespinae wasps are birds and mammals (e.g., Birkhead 1974, Kim and Choi 2021, Detoni et al. 2021). Macià et al. (2019) documented predation by European honey buzzards (*Pernis apivorus*) on the nests of *V. velutina* in Catalonia (Spain), and the use of this resource by a breeding pair of honey buzzards to provision their nestlings. In another study from Spain, Rebello et al. (2019) found that larvae of *V. velutina* made up more than 50% of the prey in each of the four honey buzzard nests they monitored. Rebello et al. (2019) also reported an increase in the number of breeding pairs of the honey buzzards and in their reproductive success in the study area since the arrival of *V.*

velutina. In South Korea, native yellow-throated martens (*Martes flavigula*) prey on reproductive individuals of invasive *V. velutina* and native wasp species (Kim and Choi 2021). The papers by Macià et al. (2019) and Kim and Choi (2021) both suggest that birds may act as biological control agents where *V. velutina* occurs at high densities. The literature on biological control supports the idea that generalist predators can significantly reduce prey populations (Symondson et al. 2002).

1.4.1.5 Impacts of control measures on non-target species

Traps intended to eradicate or limit *V. velutina* also kill many Diptera, Hymenoptera (including *V. crabro*), Lepidoptera and other non-target insects (Rome et al. 2011, Goldarazena et al. 2015, Rojas-Nossa et al. 2018, Rodríguez-Flores et al. 2019, Ikegami et al. 2020, Sánchez and Arias 2021). Rome et al. (2011, p. 7) warned that "the uncontrolled mass trappings and colony destruction […] might be more deleterious to entomofauna than the pest problem itself". Even more targeted measures, such as the use of poison baits that *V. velutina* workers carry back to the nest (e.g., Kishi and Goka 2017) could lead to unintentional poisoning of natural enemies that prey upon the nest, like honey buzzards.

1.4.2 Impacts of *V. velutina* on honey bees

Hornets take on a wide variety of flying insects, but social insect colonies provide concentrated sources of potential prey, and consequently honey bees make up a large proportion of the diet of *V. velutina* (Perrard et al. 2009, Villemant et al. 2015, Rome et al. 2021). Predation on honey bees by *V. velutina* is a major problem for apiculture, particularly in areas beyond its native range, such as South Korea and France (Abrol 2006; Tan et al. 2007; Arca et al. 2014, Laurinio et al. 2020). Though these hornets have been in South Korea for less than two decades, their impact is said to be so severe as to render beekeeping uneconomical (Jeong et al. 2021). In Europe, where *V. velutina* was first seen in 2004 (in France: Villemant et al. 2006), the overall impact on honey bee colony survival has not yet been evaluated. Estimates from French beekeepers of colony loss vary from 5% to 80% (mean estimate 30%) (Kennedy et al. 2018). Predation on honey bees is the main economic consequence of hornet invasions, threatening both crop pollination and production of honey, beeswax and propolis production (Alaniz et al. 2020).

1.4.2.1 Predation on honey bees

Unlike *V. mandarinia*, *V. velutina* rarely mass attack and take over entire hives; rather, they chase and capture foraging worker bees returning to the hive ("hawking" behaviour), usually in the vicinity of the beehive (Tan et al. 2007, Requier et al. 2019). In its native range, *V. velutina* attacks the native eastern honey bee, *Apis cerana*, as well as the introduced western honey bee, *Apis mellifera*. The co-evolving eastern honey bee has behaviours to counter hornet attacks that reduce losses of workers or colonies, whereas the western honey bee has not (Arca et al. 2014, Cappa et al. 2021). In comparing the two, Tan et al. (2007) found that, when hornets were hawking near a hive, *A. cerana* recruits three times more guard bees to ward off attackers than *A. mellifera*, and speed up their entry to the hive where *A. mellifera* slows down their entry flight behaviour. Further, *A. cerana* uses "wing shimmering" as a visual pattern disruption mechanism, a behaviour lacking in *A. mellifera*. The overall hawking success rates were three times higher for wasps hunting *A. mellifera* foragers than for those of *A. cerana* (Tan et al. 2007).

1.4.2.2 Behavioural changes in honey bees

Predation on foraging bees seriously disrupts foraging behaviour and can lead to colony collapse due to reduced returns of nectar and pollen (Laurino et al. 2019, Requier et al. 2019). The mere presence of hornets hovering around beehives triggers an increase in oxidative stress in workers, making them less efficient foragers and most likely more susceptible to pathogens (Leza et al. 2019).

1.4.3 Spread of pathogens to native species and to honey bees

A major concern regarding entry and establishment of alien species is the potential for introduction of pathogens to the ecosystem, especially pathogens of species related to the invasive organism. An introduction of a new organism to an ecosystem is really the introduction of an entire community comprising the host species and its external and internal symbiotic organisms (Skillings 2016, Foster et al. 2021); these include various mixes of mutualists, commensalists and parasites. The internal symbionts include viruses and other microorganisms which might be pathogenic to other organisms in the environment, especially to those related to the alien species.

The parasites and diseases that accompany introduced plants and animals can often spread to native species. It has been posited that introduced *Vespa* species can be vectors of parasites or diseases that can affect honey bees (Choi et al. 2012, Gabín-Garcia et al. 2021). Consequently, there have been a number of studies aiming to determine which foreign organisms might be associated with *V. velutina* and hence potentially transmitted to other bees or wasps via *V. velutina*'s nectar feeding or through predation. Nothing is known on the biology of the vast majority of the symbiotic microorganisms uncovered in these studies.

Gabín-García et al. (2021) determined the prevalence and diversity of a wide variety of internal microbial parasites for Iberian populations of *V. velutina* and compared the communities of selected families of microsporidia, protozoa, and gregarines found in *V. velutina* with those found in coexisting native vespines (species of *Vespa*, *Vespula*, and *Polistes*) and bumble bees (*Bombus* spp.). They found that *V. velutina* was most similar to the native *V. crabro* and carried most of the same microorganisms as the other wasps that they studied. They considered it very unlikely that *V. velutina* has introduced new parasites to Europe. Rather, they considered the primary risk to native fauna being that the invasive species could affect native pathogen-host dynamics, either by increasing dispersal of the parasites or by selecting for changes in their transmission or virulence.

Two 'macro' parasitic native enemies of *V. velutina* have been reported in Europe. One is a thick-headed fly (family Conopidae; *Conops vesicularis*), whose larvae develop as internal parasitoids of adult wasps and bumble bees. *C. vesicularis* has been found in dead *V. velutina* queens (Darrouzet et al. 2014). The other parasite is a mermithid nematode of the genus *Pheromermis*, probably *P. vesparum,* which is a parasite of social wasps in Europe (Villemant et al. 2015). However, Villemant et al. (2015) found that this nematode has limited impact on hornet colony survival and argue that neither the mermithid nor the conopid parasites are likely to be able to hamper the *V. velutina* invasion. There are very few nematode parasites in honey bees, and no records of nematodes that live freely in honey bee colonies and attack honey bees in hives (Zoltowska et al. 2015).

Sanchez and Arias (2021) found ectoparasitic varroa mites (presumably the species *Varroa destructor*) on *V. velutina*. Varroa mites reproduce in beehives of both *A. cerana* and *A. mellifera.* These mites feed on the fat body tissue of bees and cause pathologies ranging from reduced resistance to pesticides to shorted lifespans. In addition to the direct harm they cause to bees, they vector (or are reservoirs for) at least five virulent bee diseases, including deformed wing virus and Israeli acute paralysis virus (di Prisco et al 2011, Ramsey et al. 2019). Varroa mites are considered one of the main stress factors driving honey bee declines in North America and Europe (Goulson et al. 2015, Ramsey et al. 2019). Sanchez and Arias (2021) raise the possibility that *V. velutina* could become a new dispersal vector of varroa mites and the diseases they carry. It should be noted, though, that only 5 of 286 wasps they examined had mites (one mite on each wasp).

The iflavirus deformed wing virus (DWV) infects a wide range of hosts and is globally epidemic in honey bees; it has been widely investigated because of its close association with honey bee colony collapse (de Miranda and Genersch 2010, Goulson et al. 2015). Because of its economic impact, deformed wing virus is the most intensively studied insect pathogen in the world, and it is considered the most significant hazard for apiculture in Norway (Bjørn Dahle, Norwegian Beekeepers Association, pers. comm. 18 Dec. 2021). DWV is the most prevalent virus in honey bees, with at least 55% of colonies on average being infected globally (Martin and Brettell 2019). The virus has minor direct negative effects on adult host bees, but when transmitted by *Varroa* mites to developing bee pupae it can lead to pupal death or to adults with deformed wings and abdomens. In a 2014 survey of viruses present in *V. velutina* hornets captured in southeastern France, Dalmon et al. (2019) found DWV in all samples, suggesting that the hornets could serve as a viral reservoir. Similarly, Evison et al. (2012) found DWV to be common in *Vespula vulgaris* (as well as in *Bombus terrestris*), raising the possibility that that hornet, too, could transmit DWV to honey bees. Dalmon et al. (2019) detected 19 viruses in asymptomatic or symptomatic *V. velutina*. More studies are needed to determine whether these viruses represent a threat to native insects.

In an extensive metagenomic survey for microflora that could be associated with Colony Collapse Disorder (CCD), Cox-Foster et al. (2007) found that Israeli acute paralysis virus (IAPV) was consistently present in colonies affected by CCD, in which most adult worker bees suddenly disappear from a hive, for no apparent reason. Although IAPV is not consistently associated with CCD, there is a strong negative correlation between colony size and the level of IAPV infections, and it is well established that IAPV is an important cause of mortality for honey bees (Chen et al 2014).

Yañez et al. (2012) established that IAPV was present in *V. velutina* in China, demonstrating that predatory wasps such as *V. velutina* could be alternative hosts (reservoirs) for this and other honey bee viruses. The likelihood of transmission from wasps to honey bees or native Hymenoptera remains to be determined (Smith-Pardo et al. 2021). This virus was found in a few honey bee colonies in Norway in a survey of viruses conducted from 2010 to 2011 (B. Dahle, pers. comm. 18 Dec. 2021).

Moku virus, a recently described iflavirus from honey bees, wasps and *Varroa* (Mordecai et al. 2016), was also detected in V*. velutina* by Dalmon et al. (2019) and was subsequently found in Belgian populations of the invasive hornet (Garigliany et al. 2017) and in honey bee colonies regularly attacked by *V. velutina* (Garigliany et al. 2019). The latter researchers suggested that the virus spread from *V. velutina* to the bee colonies. Highfield et al. (2020) found Moku virus in *V. velutina* in the UK (but not in those from France or China), but in only 7% of the UK hornets and these were from only one locality. The virus was most common in native *V. vulgaris,* being found in 71% of screened individuals. They also recorded Moku virus in native *V. crabro* from one site in the UK, but not from *V. crabro* from France. The pathogenicity of Moku virus to bees and wasps is not yet known (Highfield et al. 2020). However, it is closely related to slow bee paralysis virus, which is highly virulent to honey bees but rarely detected (Mordecai et al. 2016). Moku virus had not been described at the time when bee viruses were surveyed in Norway a decade ago. Given its widespread presence in vespines and honey bees in the UK (Highfield et al. 2020), it is likely that Moku virus is already present in Norway (B. Dahle, pers. comm. 18 Dec. 2021).

1.4.4 Impacts of *V. mandarinia* on native species and on honey bees

Because the introduction of *V. mandarinia* to southwestern Canada and northwestern USA is recent (first discovered in 2019; Zhu et al. 2020), little is known about the species' behaviour and ecological impacts in its introduced range. Given its capacity of spread and extensive areas of suitable climate and habitat conditions and high human activity, there is a risk for rapid spread across North America (Alaniz et al. 2020, Zhu et al. 2020, Nuñez-Penichet et al. 2021).

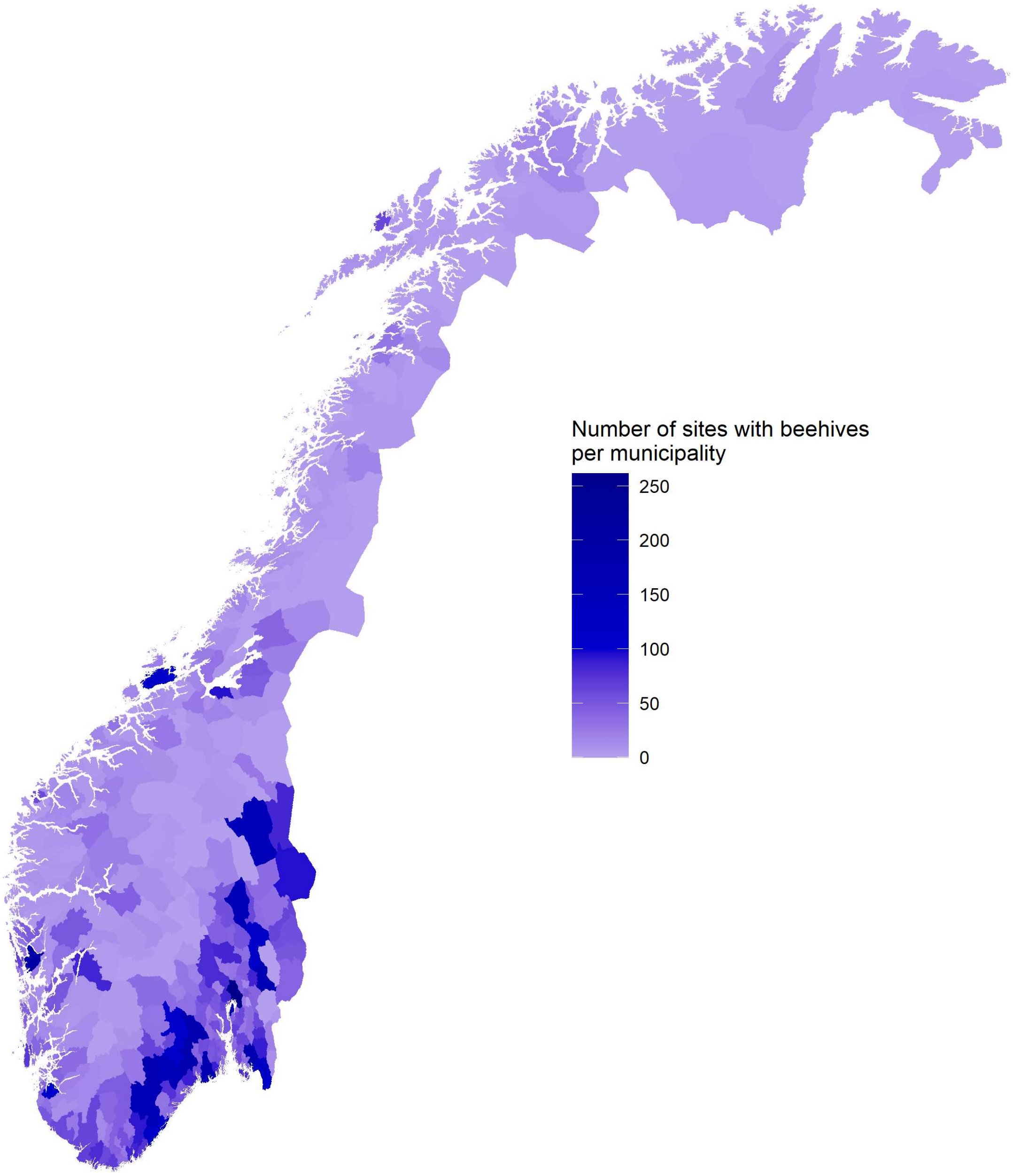
Assessment of impacts of introduced *V. mandarinia* on honey bees and native biodiversity have so far relied on modelling approaches and expert opinions (Alaniz et al. 2020, Nuñez-Penichet et al. 2021, Norderud et al. 2021). Model assumptions and expert opinions are, in turn, based on knowledge about the ecology of *V. mandarinia* and its impact on honey bees and native biodiversity in its native range in Asia, as well as observed and predicted impacts of the congeneric invasive *V. velutina* in Europe and Asia. Papers published after the introduction of *V. mandarinia* into North America mostly build on earlier literature that dates back to the 1970s through the 1990s (Nuñez-Penichet et al. 2021, Norderud et al. 2021).

Negative impacts of invasive *V. mandarinia* on native biodiversity and honey bees would likely be similar to impacts of invasive *V. velutina.* Because *V. mandarinia* is larger than *V. velutina*, it a may be a more efficient predator outside its native range of species that have not co-evolved and developed defence mechanisms against attacks (Nuñez-Penichet et al. 2021). The difference in body size could also make *V. mandarinia* a stronger competitor to native *V. crabro* in Europe, although they do co-exist in Asia (Kwan and Choi 2020). Areas with suitable climate and habitat in the USA overlap extensively with apiculture, fruit production, and with areas of high richness of native bees of similar size and ecological function as in the native range of *V. mandarinia* (Alaniz et a. 2020, Norderud et al. 2021, Nuñez-Penichet et al. 2021).

1.5 Honey bees in Norway

Honey bees are not native to Norway, and due to the lack of sizable hollow trees (i.e. *Tilia* and *Quercus*), honey bees can predominantly survive winters in managed hives. Beekeeping is mainly small-scale and most honey bees are kept for honey production. The honey is either sold locally or sent to the Norwegian Beekeepers Association and distributed through *Honningsentralen* as "Norwegian honey". Fruit and berry producers often collaborate with local beekeepers and borrow hives from these. Only a few beekeepers rent out hives to fruit tree orchards or raspberry farms for pollination services.

According to the Norwegian Food Safety Authority, there are about 12,500 locations where beehives are kept in Norway. The exact number of hives at each location is unknown, and numbers vary among years. The majority of the beehives are found along the coast in the southern parts of Norway, though some of these hives are moved to higher elevations in autumn to forage from heather *Calluna vulgaris*. Figure 1.5-1 illustrates the number of beehive locations per municipality in Norway in 2021.


Number of sites with beehives
per municipality
250
200
150
100
50
0

2 Methodology and data

2.1 Methodology for risk assessment

2.1.1 GB-NNRA general risk assessment

In order to conduct a full risk assessment of the *Vespa* species, we first used a modified version of the Non-native Species Secretariat for Great Britain form (GB Non-native Risk Assessment scheme, or GB-NNRA, http://www.nonnativespecies.org/home/index.cfm), with permission to adapt the template granted by the GB-NNRA.

The form was developed by a consortium of risk analysis experts in 2005, and has since been improved and refined, and then tested and peer-reviewed by risk analysis experts operating with similar forms in Australia, New Zealand (Roy et al. 2013). The GB-NNRA form complies with the Convention on Biological Diversity and reflects standards used by other forms, such as the Intergovernmental Panel on Climate Change, the European Plant Protection Organization, and the European Food Safety Authority.

GB-NNRA is a qualitative risk assessment method, which comprises a range of questions covering all aspects requested in our Terms of Reference. GB-NNRA is divided into two major sections (A and B). Only section B was used for the risk assessment in the current report. The questions cover an organism's probability of entry and the pathways of entry, establishment, and spread, the potential impact the organisms may have on biodiversity, and effects of climate change. For each question, the assessor ranks the uncertainty of their response, and can also add further comments. A wide range of organisms have previously been assessed by VKM using this method, for example, risk analyses for arachnids and certain insects (VKM 2016), land snails (VKM 2017) and crustaceans (VKM 2021).

2.1.2 Modified GB-NNRA protocol used for *Vespa* species

The unaltered version of the EU NON-NATIVE SPECIES RISK ANALYSIS – RISK ASSESSMENT TEMPLATE V1.0 (27-04-15) can be found here: http://www.nonnativespecies.org/index.cfm?pageid=143. The adapted version used for all risk assessments in the current report is provided below (Tables 2.1.2-1 – 2.1.2-6), and the specific changes made to the original template are listed in Appendix I.

Table 2.1.2-1: Scheme used for assessment of likelihood of entry through various pathways

LIKELIHOOD OF ENTRY			
Important instructions: • Entry is the introduction of an organism into Norway. Not to be confused with spread, the movement of an organism within Norway.			
Question	**Response**	**Confidence**	**Comments**
1.1. How many active pathways are relevant to the potential entry of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	None Very few (1-3) Few (4-6) Moderate (7-10) Many (11-20) Very many (20+)	Low Medium High	
1.2. List relevant pathways through which the organism could enter. Where possible give details about the specific origins and end points of the pathways. For each pathway, answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary).		Low Medium High	

PATHWAY NAME			
Question	**Response**	**Confidence**	**Comments**
1.3. Is entry along this pathway intentional (e.g., the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?		Low Medium High	
1.4. How likely is it that the organism will travel along this pathway from the point(s) of origin, multiple times (>10) over the course of one year? <u>Subnote: </u>Under comment, discuss how likely the organism is to get onto the pathway in the first place.	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: Under comment, consider whether the organism could multiply along the pathway.	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
1.6. How likely is the organism to survive existing management practices during passage along the pathway?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	

1.7. How likely is the organism to enter Norway undetected?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
1.10. Summarised likelihood of the organism entering a suitable habitat in Norway through this pathway	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	

Table 2.1.2-2: Scheme used for assessment of likelihood of establishment

LIKELIHOOD OF ESTABLISHMENT			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
2.1. How likely is it that the organism will be able to establish in Norway, based on the similarity between climatic conditions in Norway and the organism's current distribution?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.2. How likely is it that the organism will be able to establish in Norway, based on the similarity between other abiotic conditions in Norway and the organism's current distribution?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.3. How likely is it that the organism will become established in protected conditions (in which the environment is artificially maintained, such as wildlife parks, glasshouses, aquaculture facilities, aquaria, zoological gardens) in Norway? Sub-note: gardens are not considered protected conditions	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.4. How widespread are habitats or species necessary for the survival, development, and multiplication of the organism in Norway?	Very isolated Isolated Medium widespread Widespread Ubiquitous	Low Medium High	

2.5. How likely is it that establishment will occur despite management practices (including eradication campaigns), competition from existing species or predators, parasites or pathogens in Norway?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.6. How likely are the biological characteristics (including adaptability and capacity of spread) of the organism to facilitate its establishment in Norway?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.7. How likely is it that the organism could establish in Norway despite low genetic diversity in the founder population?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.8. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in Norway? (If possible, specify the instances in the comments box.)	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
2.9. Estimate the overall likelihood of establishment in Norway (mention any key issues in the comments box).	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	

Table 2.1.2-3: Scheme used for assessment of likelihood of spread

LIKELIHOOD OF SPREAD			
Important notes: • Spread is defined as the expansion of the geographical distribution of an alien species within an area.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
3.1. How likely is it that this organism will spread widely in Norway by *natural means*? (Please list and comment on the mechanisms for natural spread.)	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
3.2. How likely is it that this organism will spread widely in Norway by *human assistance*? (Please list and comment on the mechanisms for human-assisted spread.)	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
3.3. How likely is it that spread of the organism within Norway can be completely contained?	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	

3.4. Based on the answers to questions on the potential for establishment and spread in Norway, define the area endangered by the organism.	[insert text]	Low Medium High	
3.5. Estimate the overall potential for future spread for this organism in Norway (using the comments box to indicate any key issues).	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	

Table 2.1.2-4: Scheme used for assessment of magnitude of environmental impact

MAGNITUDE OF ENVIRONMENTAL IMPACT			
Important instructions: • Each section starts with the impact elsewhere in the world, then considers impacts in Norway separating known impacts to date (*i.e.*, past and current impacts) from potential future impacts.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
4.1. How much environmental harm is caused by the organism within its existing geographic range, excluding Norway?	Minimal Minor Moderate Major Massive	Low Medium High	
4.2. How much impact would there be if genetic traits of the organism were to be transmitted to other species, modifying their genetic makeup and making their environmental effects more serious?	Minimal Minor Moderate Major Massive	Low Medium High	
4.3. How much impact do other factors (which are not covered by previous questions) have? (Specify these other factors in the comments box)	Minimal Minor Moderate Major Massive	Low Medium High	
4.4. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in Norway?	Minimal Minor Moderate Major Massive	Low Medium High	
4.5. Indicate any parts of Norway where environmental impacts are particularly likely to occur (provide as much detail as possible).	[insert text + attach map if possible]	Low Medium High	
4.6. Estimate the expected ecological impacts of the organism if it is able to establish and spread in Norway (despite any natural control by other organisms, such as predators, parasites, or pathogens that may already be present).	Minimal Minor Moderate Major Massive	Low Medium High	

Table 2.1.2-5: Scheme used for assessment of impact of climate change

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
5.1. What aspects of climate change (up to the year 2070), if any, are most likely to affect this risk assessment?	[insert text]	Low Medium High	
5.2. What aspects of the risk assessment are most likely to change as a result of climate change? • Establishment • Spread • Impact on biodiversity • Impact on ecosystem functions	[insert text]	Low Medium High	

Table 2.1.2-6: Scheme used for summarizing risk assessment

RISK SUMMARIES for [species name]			
	RESPONSE	**CONFIDENCE**	**COMMENTS**
Summarise Entry	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
Summarise Establishment	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
Summarise Spread	Very unlikely Unlikely Moderately likely Likely Very likely	Low Medium High	
Summarise Ecological Impact	Minimal Minor Moderate Major Massive	Low Medium High	
Conclusion of the risk assessment	Low risk Moderate risk High risk	Low Medium High	

2.1.3 Rating and descriptions

In order to provide clear justification of the ratings given in the risk assessment template, the Panel used ratings and adapted versions of the descriptors from Appendix E in the Scientific Opinion of the European Food Safety Authority (EFSA, 2015). A description of the ratings used can be found in Tables 2.1.3-1 – 2.1.3-6 below. The definitions used to describe the confidence in each assessment are presented in Table 2.1.3-7.

Table 2.1.3-1: Rating of likelihood of entry of the organism into Norwegian nature.

Rating	Descriptors
Very unlikely	The likelihood of entry is very unlikely because: • is undocumented in the export countries/region, • There is no direct import of goods from countries where the species is present.
Unlikely	The likelihood of entry is unlikely because: • The species is not found in any European country, OR • Direct import of goods from countries where the species is present is limited
Moderately likely	The likelihood of entry is moderately likely because: • The species is not found in any other Nordic country, OR • Direct import of goods from countries where the species is present is moderate
Likely	The likelihood of entry is likely because: • The species is present in the south of Sweden, OR • Direct import of goods from countries where the species is present is high
Very likely	The likelihood of entry is very likely because: • The species is present in large parts of Sweden, OR • Direct import of goods from countries where the species is present is very high

Table 2.1.3-2: Rating of the likelihood of establishment.

Rating	Descriptors
Very unlikely	The likelihood of establishment is very low because: • environmental conditions are unsuitable throughout Norway, • of the absence or very limited availability of required foods, • the occurrence of other considerable obstacles prevents establishment.
Unlikely	The likelihood of establishment is low because: • environmental conditions are unsuitable in most parts of Norway, • of the limited availability of required foods, • the occurrence of other obstacles prevents establishment.
Moderately likely	The likelihood of establishment is moderate because: • environmental conditions are suitable in a few areas of Norway, • required foods are abundant in a few areas of Norway, • no obstacles to establishment occur.
Likely	The likelihood of establishment is high because: • environmental conditions are suitable in some parts of Norway, • required foods are widely distributed in some parts of Norway, • no obstacles to establishment occur. • Alternatively, the species has already established in some areas of Norway.
Very likely	The likelihood of establishment is very high because: • environmental conditions are suitable in most parts of Norway, • required foods are widely distributed in Norway, • no obstacles to establishment occur. • Alternatively, the species has already established in Norway.

Table 2.1.3-3: Rating of the likelihood of spread.

Rating	Descriptors
Very unlikely	The likelihood of spread is very low because: • the species has limited spreading capabilities, • highly effective barriers to spread exist (*e.g.*, patchy distribution of habitats), • required foods and nesting resources are not, or are very rarely, present in the area of possible spread.
Unlikely	The likelihood of spread is low because: • the species has limited spreading capabilities, • effective barriers to spread exist (*e.g.*, patchy distribution of habitats), • required foods and nesting resources are occasionally present.
Moderately likely	The likelihood of spread is moderate because: • the species has limited spreading capabilities, • partly effective barriers to spread exist, • required foods and nesting resources are abundant in some parts of the area of possible spread.
Likely	The likelihood of spread is high because: • the species has effective ways to spread, • no effective barriers to spread exist, • required foods and nesting resources are abundant in some parts the area of possible spread.
Very likely	The likelihood of spread is very high because: • the species has effective ways to spread, • no effective barriers to spread exist, • required foods and nesting resources are widely present in the whole risk assessment area.

Table 2.1.3-4: Rating of the magnitude of impact on biodiversity.

Rating	Descriptors
Minimal	No impact on local biodiversity
Minor	Potential impacts on local biodiversity are within normal fluctuation.
Moderate	Impacts may cause moderate reductions in native biodiversity.
Major	Impacts may cause severe reductions in local biodiversity with consequences for ecosystem functions and services.
Massive	Impacts may cause severe reductions in local biodiversity (local extinctions), with severe consequences for ecosystem functions and services.

Table 2.1.3-5: Rating of the magnitude of impact on honey bees.

Rating	Descriptors
Minimal	No impact on local honey bee colonies
Minor	Potential impact on local honey bee colonies, but only occasional deaths of workers
Moderate	Impact may cause moderate reduction in viability of local honey bee colonies.
Major	Impact may cause severe reductions in local populations (weakened colonies and occasional colony losses) with measurable consequences for ecosystem functions and services provided by honey bees
Massive	Impact may cause severe reductions in local honey bee populations (high proportion of colony extinctions), with severe consequences for the ecosystem functions and services provided by honey bees.

Table 2.1.3-6: Rating of the likelihood of the specific impacts in the assessment.

Rating	Descriptors
Very unlikely	Negative consequences is expected to occur with a likelihood of 0-5%
Unlikely	Negative consequences is expected to occur with a likelihood of 5-10%
Moderately likely	Negative consequences is expected to occur with a likelihood of 10–50%
Likely	Negative consequences is expected to occur with a likelihood of 50-75%
Very likely	Negative consequences is expected to occur with a likelihood of 75-100%

Table 2.1.3-7: Ratings used for describing the level of confidence.

Rating	Descriptors
Low	Most information is missing on the species distribution, ecological requirements, and climate tolerance. Subjective judgement may be introduced without supporting evidence. Unpublished data are frequently used.
Medium	Some information is missing on the species distribution, ecological requirements, and climate tolerance. Subjective judgement is introduced with supporting evidence. Unpublished data are sometimes used.
High	Information is available on the species distribution, ecological requirements, and climate tolerance. Little or no subjective judgement is introduced. Little or no unpublished data are used.

2.2 Assessment of specific hazards

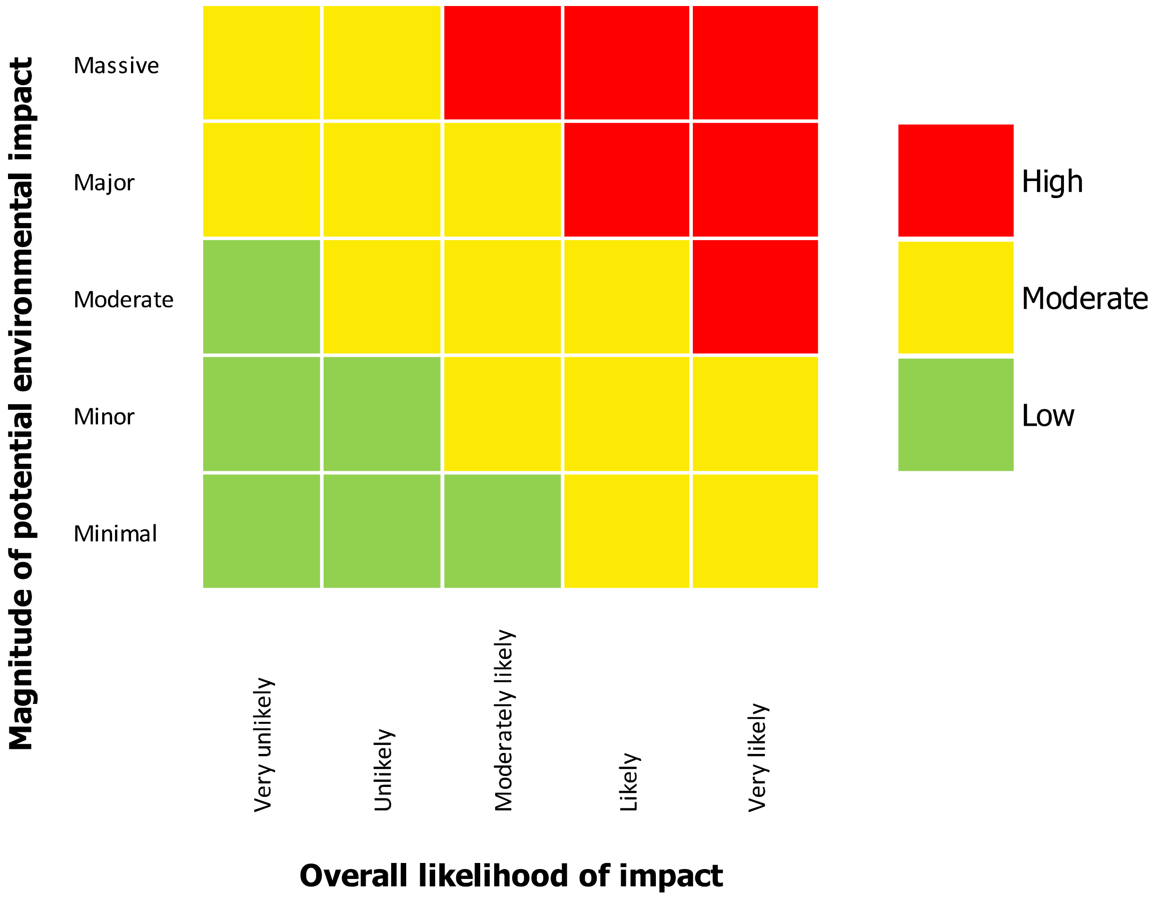
For the questions outlined in the ToR, hazards were identified and assessed independently. VKM assesses each potential hazard in four standardized steps: hazard identification, hazard characterization, likelihood, and risk characterization. These are judged by the project group experts. *Table 2.1.3-7* describes the ratings for the level of confidence the project group has given the assessments.

Under "**Hazard identification**", we describe the specific hazard and why this hazard is considered in the current assessment. Examples include specific species relevant for import, competition with native species or a hitchhiking disease-causing organism. The known effects of the hazard are presented and referenced examples of the known impacts from other countries are included.

Under "**Hazard characterization**", the specific potential effects of the hazard in question are described for Norwegian conditions. Examples include which areas or habitats that a species can thrive in, which species the invading species would compete with (or predate on) and what species that can be infected by hitchhiking organisms. The potential magnitude of the specific hazard is then characterized from "Minimal" to "Massive" as described in ***Tables 2.1.3-4* and *2.1.3-5*** (for biodiversity and honey bees respectively).

Under "**Likelihood**", we assess how likely it is that the characterized hazard occurs. Likelihood intervals range from "Very unlikely" to "Very likely", as described in ***Table 2.1.3-6.*** Depending on the nature of the hazard, this assessment could include aspects like the likelihood of entry, establishment and spread, which could include additional, independent, assessments, and which are rated according to the applicable tables (***Tables 2.1.3-1 – 2.1.3-3***).

Finally, under "**Risk characterization**", the risk to honey bees or other biodiversity in Norway, posed by the specific hazard, is characterized as either "Low", "Medium" or "High", based on the magnitude of potential impact of that hazard and the overall likelihood of this occurring. This characterization follows the matrix presented in ***Figure 2.2-1.***



2.3 Literature search

As a foundation for this risk assessment, VKM commissioned a methodical literature search from the National Public Health Organization library. The search is based on a PICO scheme with known species names and synonyms (common names), various keywords (such as Ecology, Risk, Threat, Impact, Invasive etc), a list of comparative keywords (e.g., Honey bees. Hymenoptera and *Vespa crabro*) and finally various potential outcomes (e.g., Establishment, Spread, Risk reducing measures). The search was refined using five pre-defined relevant articles. This search returned 185 unique references. The complete overview of the searched databases and results is listed in Appendix II. References found in relevant articles were then used to search for further information, where relevant. Additionally, new searches were conducted for specific themes when necessary.

2.4 Other literature

In addition to the peer reviewed literature, some previous risk assessments and technical reports were used. These are referenced in the text. Also, governmental and institutional websites, and even social media (e.g., YouTube, blogs etc.) were used for different data on occurrence and eradication efforts etc. These are referenced as footnotes in this assessment.

2.5 Data and models

2.5.1 Species distribution modelling

Caution should be taken when modelling species distributions because of a high degree of uncertainty caused by various sources of error, such as erroneous occurrence data caused by misidentification of species, sampling bias, coordinate inaccuracies and georeferencing errors. However, we believe that species distribution models like Maxent can aid us in exploring the current and future potential distribution of *V. velutina* to assess the risk of establishment and spread in Norway. All modelling and data handling was done using The R Project for Statistical Computing (R Core Team version 4.1.2) and additional R libraries.

2.5.2 Species occurrence data

Occurrence data for *V. velutina* was gathered from multiple databases using the spocc (Chamberlain 2021) and rgbif (Chamberlain et al. 2021) libraries. Occurrence records with missing coordinates but with a locality description were georeferenced. Data was cleaned using the CoordinateCleaner (Zizka et al. 2019) library. We attempted to remove sampling bias by subsampling occurrence data by manipulating raster grid cell size. Coordinates from countries where *V. velutina* is known not to occur were removed (e.g., Sweden) before geographic outliers were removed according to the median absolute deviation. In addition, occurrence points above 1500 m.a.s.l. were removed. Because the frequency of occurrence points had a bimodal distribution along all important environmental gradients, only occurrence data from Europe were used in the final model. Background points were drawn from a radius of 1000 km around the occurrence points.

2.5.3 Environmental explanatory data

The standard 19 bioclimatic variables average for the years 1970–2000 in 1 km spatial resolution was downloaded from Worldclim (https://worldclim.org and Hijmans 2017). For future climate data, the equivalent 19 bioclimatic variables for the year 2070 (average for 2061-2080), greenhouse gas scenarios 8.5 and GSM MPI-ESM-LR were downloaded. Multiple other environmental explanatory variables were explored but not used in the final models. Highly correlated variables were removed before modelling. The Köppen-Geiger climate classification maps (Beck et. al. 2018) at 1-km resolution were plotted by overlying the occurrence data and extracting the raster information using the raster library (Hijmans 2021a).

2.5.4 Modelling and tuning

The "trainMaxNet" function from the enmSdm library (Smith 2021) was used to find the Maxent model with the highest AICc across all possible combinations of master regularization parameters and feature classes (best model, betamultiplier = 1 with linear and hinge features). A combination of varSel from SDMtune (Vignali et al. 2020) and forward manual selection was run in Maxent (version 3.4.4) using the dismo library (Hijmans et al. 2021) to find the explanatory variables with the highest contribution. The five most important variables in descending order were Bio 4 - Temperature Seasonality (temperature change over the course of the year), Bio 17 - Precipitation of Driest Quarter (precipitation during the driest three months of the year), Bio 11 - Mean Temperature of Coldest Quarter (mean temperatures during the coldest three months of the year), Bio 1 - Annual Mean Temperature, and Bio 5 - Max Temperature of Warmest Month. The final 5-fold cross validation model had an AUC of 0.858, which is good.

3 Assessments

3.1 Suitable habitats in Norway

The predicted modelled potential distribution of *V. velutina* under the current climatic conditions using Maxent (Figure 3.1-1) and the Köppen-Geiger climate classifications (Figure 3.1-2) suggest that the climatic conditions are not suitable for the species in Norway (see section 2.5 for data and methods). However, according to the same models, the climatic conditions are not suitable for *V. velutina* in South Korea either. *V. velutina* was first encountered in South Korea in 2003 and is now present throughout most of the country (Jeong et al. 2021). The model also fails to predict presence of *V. velutina* in Afghanistan, Pakistan, and several provinces in China (Figures 1.2.1-1 and 3.1-1). In contrast, according to spatial predictions of *V. velutina* produced by Villemant et al. (2011), which are based on Asian native records only, there is a noticeable probability for *V. velutina* to establish in southeast Korea (Figure 4 in Villemant et al. 2011). The same prediction map suggests that substantial areas along the Norwegian coast as far north as Nordland may be climatically suitable for *V. velutina*). However, a prediction map based on records of *V. velutina* from native and invaded ranges suggests that only limited areas along the coast of southern and western Norway may be climatically suitable (Figure 5 in Villemant et al. 2011). Finally, a recent climate suitability map produced by Barbet-Massin and colleagues (Figure 2 in Barbet-Massin et al. 2020), which is based on presence data from both native and invaded ranges, predicts that northern Germany and Denmark are not climatically suitable (likelihood = 0) for *V. velutina*. Our prediction model indicates that the estimated likelihood for these regions span from 0.1 to 0.3 on a scale from 0 to 1 (Figure 3.1-1). Barbet-Massin et al. (2020) correctly predicts that southeast Korea is climatically suitable for *V. velutina*. It should also be noted that when modelling the spatial distribution of a species as a function of climate variables, a mismatch between predicted and observed distributions may be due to lack of information about the species' distribution, or may indicate that climate is not necessarily the limiting factor for the species' range expansion. In conclusion, we cannot rule out the possibility that *V. velutina* may establish in Norway.

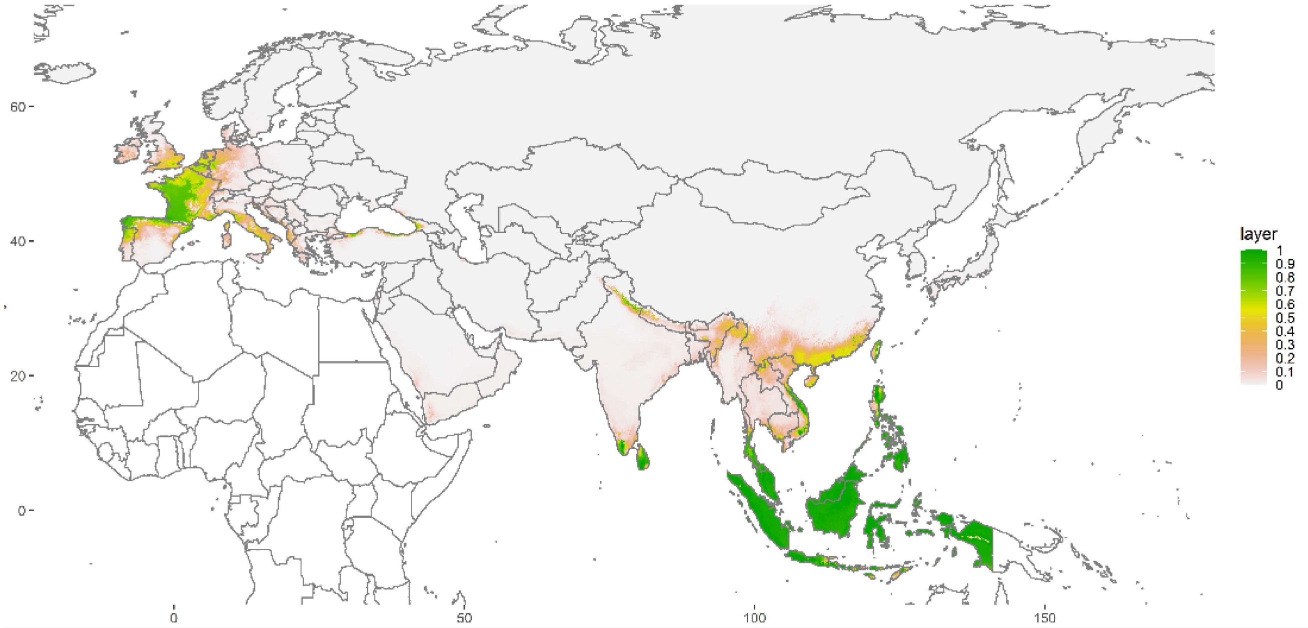


Figure 3.1-1: Potential distribution of *Vespa velutina* in Eurasia as predicted by Maxent and based on the current climatic conditions (5-fold cross validation). Estimates between 0 (white) and 1 (green) indicate probability of presence.

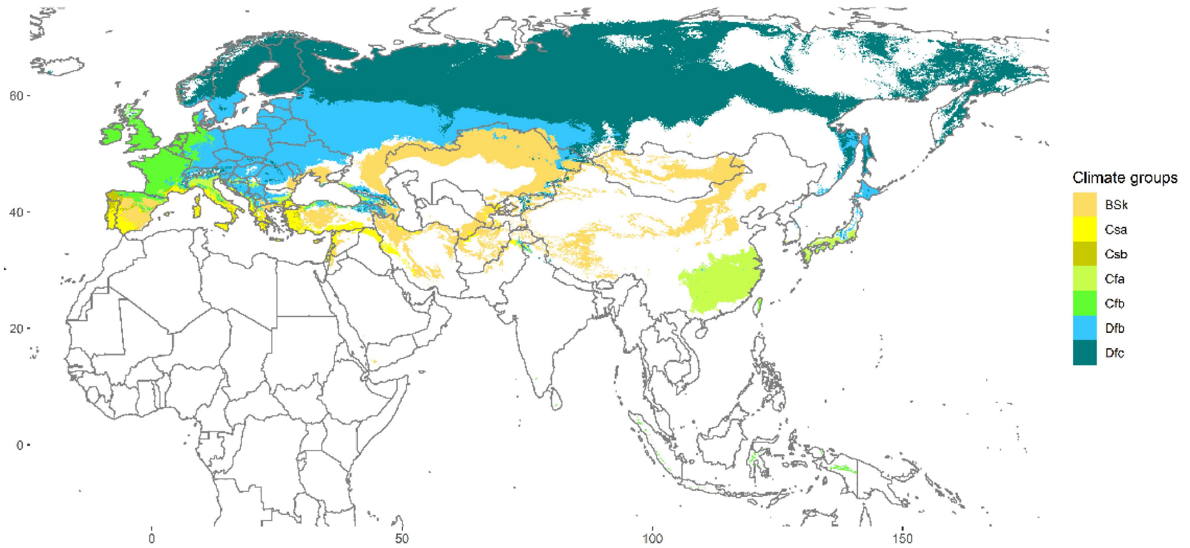


Figure 3.1-2: Köppen-Geiger climate classification map, with 1km resolution, shows only the classifications for areas where *V. velutina* is found according to the gbif occurrence data. The climate groups correspond to Cold semi-arid climates (BSk), Hot-summer mediterranean climate (Csa), Warm-summer mediterranean climate (Csb), humid subtropical climate (Cfa), Oceanic climate (Cfb), Hemiboreal climate (Dfb) and Subarctic climate (Dfc).

For *V. mandarinia*, a recent global forecast of habitat suitability based on ecological niche modelling shows that almost all of mid-, western- and northern Europe, including mainland Norway, is climatically suitable for *V. mandarinia* (Zhu et al. 2020, figure 1D). *V. mandarinia* thrives under cooler temperatures and higher annual precipitation levels than *V. velutina* (Zhu et al. 2020). There is substantial overlap between the areas that are predicted to be climatically suitable for *V. mandarinia* in Norway and areas with high densities of beehives today, i.e., the south-eastern parts of the country (Figures 1.5-1 and Figure 1 D in Zhu et al. 2020).

3.2 Influence of climate change

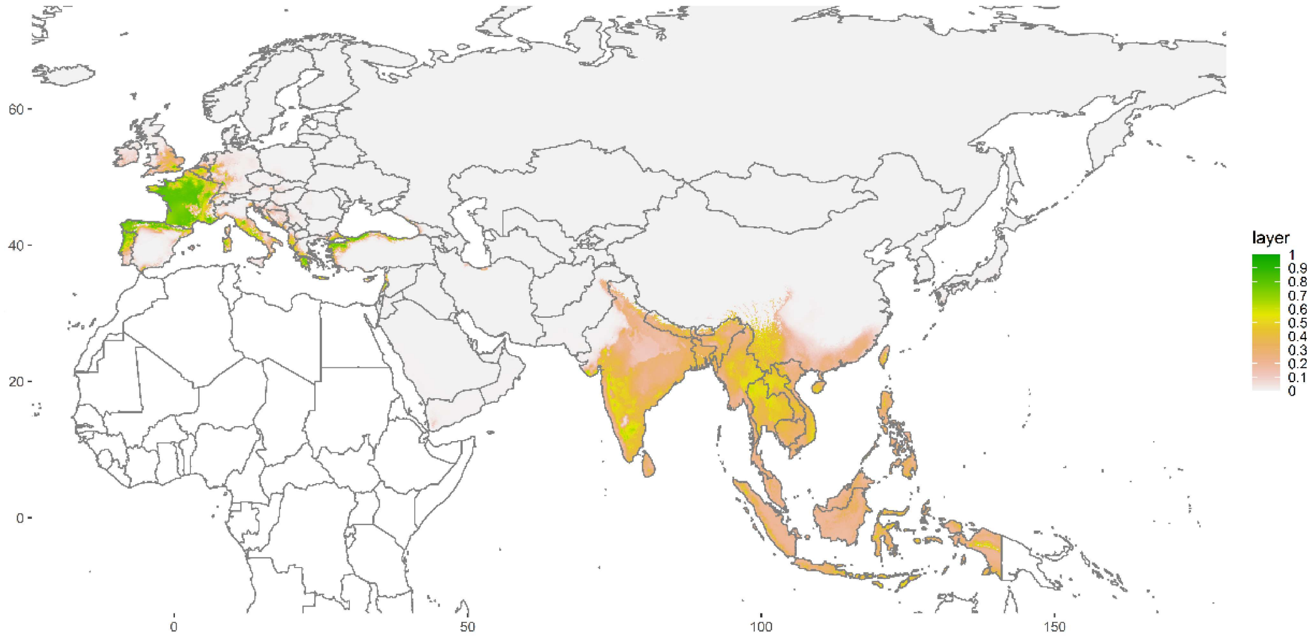


Figure 3.2-1: Potential distribution of *Vespa velutina* in Eurasia as predicted by Maxent. Prediction based on the future climatic conditions (5-fold cross validation). Estimates between 0 (white) and 1 (green) indicate probability of presence.

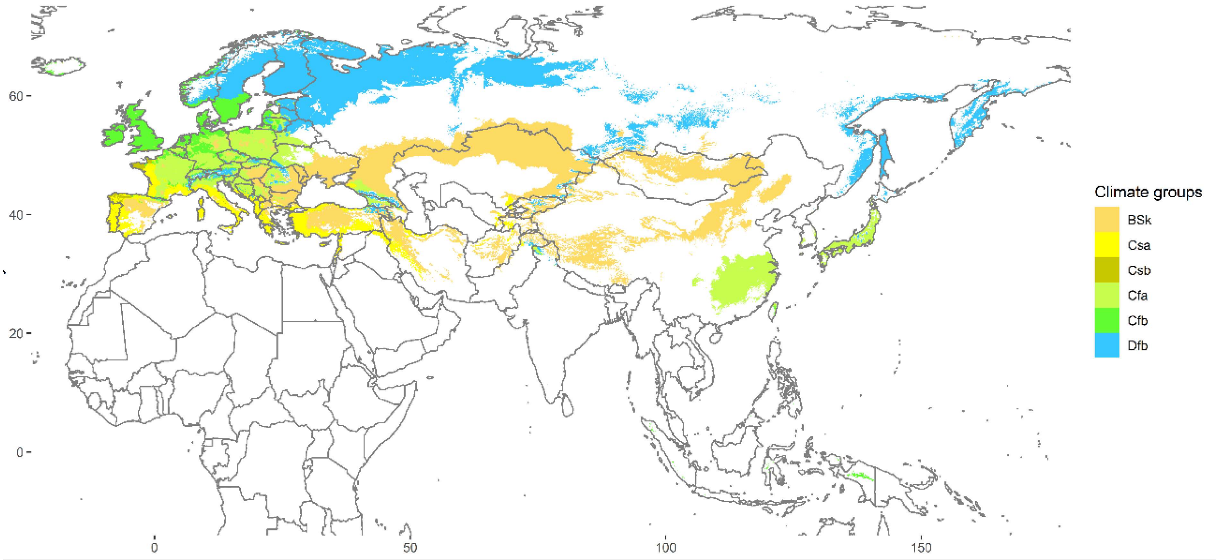


Figure 3.2-2: Köppen-Geiger climate classification map, with 1km resolution, shows only the classifications for areas where *V. velutina* is found according to the gbif occurrence data. The climate groups correspond to Cold semi-arid climates (BSk), Hot-summer mediterranean climate (Csa), Warm-summer mediterranean climate (Csb), humid subtropical climate (Cfa), Oceanic climate (Cfb), Hemiboreal climate (Dfb)

The predicted potential distribution of *V. velutina* under future climatic conditions (bioclimatic variables in 2070 according to Worldclim https://worldclim.org and Hijmans (2017); greenhouse gas scenarios 8.5 and GSM MPI-ESM-LR; Figure 3.2-1) and the future Köppen-Geiger climate classifications (Figure 3.2-2) suggests that future climatic conditions will not be suitable for the species in Norway. However, the model of Barbet-Massin et al. (2013) predicts that climate suitability for *V. velutina* will increase in the future (to year 2100) across Eurasia, including Norway, in response to climate change. Thus, as stated in Section 3.1, we cannot rule out the possibility that *V. velutina* could become established in at least coastal southern Norway, and that a warmer climate will make establishment more likely. In coastal southern Norway, there is substantial overlap between the areas that will be climatically most suitable for *V. velutina* and areas with the highest densities of beehives today (compare Figures 1.5-1 and 3.2-1).

No forecast of its distribution under climate warming has been produced for *V. mandarinia*, but according to the recent global forecast by Zhu et al. (2020), almost all of Europe, except the warmest and driest areas in the Mediterranean region, is climatically suitable for *V. mandarinia* under current climate conditions.

3.3 Predation

3.3.1 Predation on honey bees

3.3.1.1 HAZARD IDENTIFICATION

The main hazard for beekeepers is losses to hornets of significant numbers of workers or even of entire colonies. Predation on honey bees is the primary economic impact of hornet invasions. Both hornet species are ruinous predators of domesticated honey bees in their native ranges. *V. velutina* has proven capable of severely impacting local honey bee populations during the relatively short time it has been in Europe and in South Korea (Kennedy et al. 2018, Jeong et al. 2021).

V. mandarinia has only recently gained a foothold in North America, but should eradication efforts fail, it is feared to be similarly destructive to apiculture, and potentially over large parts of the continent (Zhu et al. 2020, Norderud et al. 2021).

Harassment of workers of honey bees by hornets reduces the efficiency of the collection of pollen and nectar. The presence of hornets near beehives disrupts foraging and decreases worker longevity (Requier et. al. 2019), and stresses bees physiologically (Leza et al. 2019).

3.3.1.2 HAZARD CHARACTERIZATION

Both crop pollination and the production of honey, beeswax and propolis would be negatively impacted should either hornet become established and spread widely in the coastal regions of southern Norway, where beekeeping is most dense (Fig. 1.5-1). Due to expected densities of *V. velutina* and *V. mandarinia*, should they establish, the project group expect the impact to be limited to local areas and not necessarily whole municipalities.

Due to the effects observed in other countries, the project group assesses the **potential magnitude of impact** on honey bees in Norway, from predation from either ***V. velutina*** or ***V. mandarinia*** to be **"Moderate"** with "Medium" confidence.

3.3.1.3 LIKELIHOOD

Both Asian *Vespa* species are annuals in the sense that workers die in the end of the season and only the next year's queens overwinter. So, the likelihood of entry for these hornets mirrors the likelihood that queens enter the country alive.

For ***V. velutina***, pathways of entry of queens to Norway could either be natural dispersal (only likely if southern Sweden is colonized) or human-mediated dispersal such as with cargo, private vehicles, ferries, or other vessels (see Appendix III). The species is spreading fast in Europe and has been introduced and established several times outside its native range. The likelihood of entry naturally increases with time and will be a function of direct trade with Asia (especially China and South Korea), as well as trade with European countries where *V. velutina* is particularly abundant (currently, Spain, Portugal, and France). A slight increase in the likelihood of entry could result from an increased number of people traveling from regions where *V. velutina* is common and there is a chance that queens can enter vehicles or vessels. Human-mediated dispersal seems to be an important contributor to the rapid expansion this hornet's range in Europe (Bertolino et al. 2016, Robinet et al. 2017, Carvalho et al. 2020, Jones et al. 2020). VKM assesses the **likelihood of entry** to be **"Moderately likely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

V. mandarinia is not established in Europe, so entry to Norway would have to be human mediated via overseas cargo, as likely occurred on two separate occasions in North America (see section 1.3.1 about spread of *V. mandarinia* worldwide and see Appendix IV). VKM assesses the **likelihood of entry** to be **"Very unlikely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Europe.

Based on the climatic tolerances of ***V. velutina,*** the current and future climatic conditions in Norway, and the climate conditions in already invaded areas (see chapters 3.1 and 3.2), VKM concludes that it is "**Moderately Likely**" with "Low" confidence that *V. velutina* would **establish and spread** in Norway should it be introduced (see Appendix III).

The climatic and habitat conditions in Norway are seemingly more suitable for ***V. mandarinia***, as this species is associated with cooler climates, higher amounts of precipitation and environments such as forested areas, parks, agricultural landscapes, and other herbaceous settings (Kim et al. 2020, Alaniz et al. 2020, Norderud 2021). Therefore, VKM concludes that it is "**Likely**" with "Low" confidence that *V. mandarinia* would **establish and spread** should it be introduced (see Appendix IV).

The likelihood of ***V. velutina* or *V. mandarinia*** to have a **negative impact** on honey bees through predation is assessed to be "**Very likely**", with "High" confidence.

In sum, for ***V. velutina***, considering the combined likelihoods of entry, establishment, spread and impact into consideration, VKM assesses the **overall likelihood of negative effects** caused by predation on honey bees to be "**Moderately likely**" with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

In sum, for ***V. mandarinia***, considering the combined likelihoods of entry, establishment, spread and impact into consideration), VKM assesses the **overall likelihood of negative effects** caused by predation on honey bees to be "**Unlikely**" with "Low" confidence within the next 10 years. However, the likelihood will increase with time and especially if the species should establish and spread in Europe.

3.3.1.4 RISK CHARACTERIZATION

Both *Vespa* species are assessed as having a potentially "Moderate" effect on honey bees in Norway, and should they establish and spread, VKM concludes that it is "Very likely" that this impact will occur. However, the overall likelihood of this negative effect depends first and foremost on the species entering Norway, which is assessed as "Moderately likely" and "Very unlikely" for *V. velutina* and *V. mandarinia*, respectively. Therefore, VKM concludes that the **risk posed to honey bees in Norway** from predation by ***V. velutina*** and ***V. mandarinia*** is **"Moderate"**. This assessment is made with "Medium" confidence.

3.3.2 Predation on native arthropods

3.3.2.1 HAZARD IDENTIFICATION

Invasive *V. velutina* in Europe prey on wild native insects and appear to be generalist, opportunistic predators that feed on locally abundant prey (Rome et al. 2021; Verdasca et al. 2021). *V. velutina* has been documented to prey on >150 different species and estimated to prey on >400 different native insect species in France but appears to prey most intensely on honey bees and social *Vespula* wasps (Rome et al. 2021), most likely due to their high abundances. Rome et al. (2021) found that the proportion of non-honey bee prey was higher in rural than in urban areas. The magnitude of the negative effects of predation by *V. velutina* on native arthropods in Europe is largely unknown, but an unpublished study from Italy indicates that the presence of *V. velutina* has a negative effect on local insect communities (Carisio et al. 2019).

In addition to direct effects of predation, perceived risk of predation by *V. velutina* can induce behavioural changes in native arthropods. Rojas-Nossa and Calviño-Cancela (2020) demonstrated reduced pollination services due to the hunting of native flower-visiting insect pollinators by *V. velutina.*

Empirical data on predation by invasive *V. mandarinia* on native insects is not available, but the effects are assumed to be similar to the effects of predation by invasive *V. velutina*. *V. mandarinia* is the largest hornet species in the world and is an efficient predator, especially on social species of Hymenoptera. Also, non-coevolved bee species will most likely be vulnerable to predation (Smith-Pardo et al. 2020).

3.3.2.2 HAZARD CHARACTERIZATION

The potential negative effects of predation by *V. velutina* on native arthropods under Norwegian conditions are expected to be similar to the effects seen in the invaded range in Europe. Where climatic conditions are not too harsh, both suitable habitats and food for *V. velutina* will be abundant in Norway. For ***V. velutina*** the **potential magnitude of the hazard** predation on native arthropods is characterized as **"Moderate**" with "Medium" confidence.

The potential negative effects of predation by *V. mandarinia* on native arthropods under Norwegian conditions are expected to be similar to the potential effects of *V. velutina*. Both suitable habitats and food for *V. mandarinia* will probably be readily available in Norway. Because *V. mandarinia* is larger in size, more severe impacts of predation on native arthropods might be expected for *V. mandarinia* than for *V. velutina*. For ***V. mandarinia*** the **potential magnitude of the hazard** predation on native arthropods is characterized as "**Moderate**" with "Low" confidence.

3.3.2.3 LIKELIHOOD

Both Asian *Vespa* species are annuals in the sense that workers die in the end of the season and only the next year's queens overwinter. So, the likelihood of entry for these hornets mirrors the likelihood that queens enter the country alive.

For ***V. velutina***, pathways of entry of queens to Norway could either be natural dispersal (only likely if southern Sweden is colonized) or human-mediated dispersal such as with cargo, private vehicles, ferries, or other vessels (see Appendix III). The species is spreading fast in Europe and has been introduced and established several times outside its native range. The likelihood of entry naturally increases with time and will be a function of direct trade with Asia (especially China and South Korea), as well as trade with European countries where *V. velutina* is particularly abundant (currently, Spain, Portugal, and France). A slight increase in the likelihood of entry could result from an increased number of people traveling from regions where *V. velutina* is common and there is a chance that queens can enter vehicles or vessels. Human-mediated dispersal seems to be an important contributor to the rapid expansion this hornet's range in Europe (Bertolino et al. 2016, Robinet et al. 2017, Carvalho et al. 2020, Jones et al. 2020). VKM assesses the **likelihood of entry** to be **"Moderately likely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

V. mandarinia is not established in Europe, so entry to Norway would have to be human mediated via overseas cargo, as likely occurred on two separate occasions in North America (see section 1.3.1 about spread of *V. mandarinia* worldwide and see Appendix IV). VKM assesses the **likelihood of entry** to Norway to be **"Very unlikely"** with "Medium" confidence within the next 10 years. However, the likelihood will increase with time and especially if the species should establish and spread in Europe.

Based on the climatic tolerances of ***V. velutina***, the current and future climatic conditions in Norway, and the climate conditions in already invaded areas (see chapters 3.1 and 3.2), VKM concludes that it is "**Moderately Likely**" with "Low" confidence that *V. velutina* would **establish and spread** in Norway should it be introduced (see Appendix III).

The climatic and habitat conditions in Norway are probably more suitable for ***V. mandarinia*** than for *V. velutina* because *V. mandarinia* is associated with cooler climates, higher amounts of precipitation and environments such as forested areas, parks, agricultural zones, and other herbaceous settings (Kim et al. 2020, Alaniz et al. 2020, Norderud 2021). Therefore, VKM concludes that it is "**Likely**" with "Low" confidence that *V. mandarinia* will **establish and spread** should it be introduced (see Appendix IV).

For ***V. velutina***, VKM assesses the **likelihood of negative effects** caused by predation on native arthropods, if the species establishes and spreads in Norway, to be "**Moderately Likely**" with "Medium" confidence.

For ***V. mandarinia***, VKM assesses the **likelihood of negative effects** caused by predation on native arthropods, if the species establishes and spreads in Norway, to be "**Moderately Likely**" with "Low" confidence.

In sum, for ***V. velutina***, taking into account the combined likelihoods of entry, establishment, spread and impact, VKM assesses the **overall likelihood of negative effects** caused by predation on native arthropods to be "**Moderately likely**" with "Medium" confidence within the next 10 years, primarily due to the likelihood of entry. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

In sum, for ***V. mandarinia,*** taking into account the combined likelihoods of entry, establishment, spread and impact, VKM assesses the **overall likelihood of negative effects** caused by predation on native arthropods to be "**Unlikely**" with "Low" confidence within the next 10 years. However, the likelihood will increase with time and especially if the species should establish and spread in Europe.

3.3.2.4 RISK CHARACTERIZATION

Both *Vespa* species are assessed as having a potentially "Moderate" effect on native arthropods, and should they establish and spread, VKM concludes that it is "Moderately likely" that this impact will occur. However, the overall likelihood of this negative effect depends first and foremost on the species entering Norway, which is assessed to be "Moderately likely" and "Very unlikely" for *V. velutina* and *V. mandarinia*, respectively.

Therefore, VKM concludes that the **risk posed to native arthropods** from predation is **"Moderate"** for both *V. velutina* and *V. mandarinia*. This assessment is made with "Medium" confidence.

3.4 Competition

3.4.1 Competition with native arthropods

3.4.1.1 HAZARD IDENTIFICATION

In their native ranges, *V. velutina* and *V. mandarinia* co-exist with a wide variety of other vespines (Matsuura and Yamane 1990, Carpenter and Kojima 1997). In only a few years, *V. velutina* has become the most abundant hornet species in South Korea, where evidence suggests that this invasive species is displacing the smaller native species *V. simillima* (Choi et al. 2012). The concern in Europe (and Norway) is mainly potential competition with the similar-sized *V. crabro*.

Where it has invaded Europe and South Korea, *V. velutina* co-occurs with *V. crabro* but this has apparently not led to the replacement of the native species. There is considerable overlap in their generalist and opportunistic diets and at least partial overlap in climate tolerance, habitat association, phenology, and general exploitation of resources. This suggests that *V. velutina* competes with native *V. crabro* in Europe. However, the nature and intensity of this competition is poorly understood (Cini et al. 2018). There is some overlap in nesting habits between *V. velutina* and *V. crabro*, but at least in South Korea *V. velutina* is much more likely to nest in urban environments than is *V. crabro* (Choi et al. 2012). *V. velutina* colonies typically include a much higher number of individuals than do colonies of *V. crabro,* and thus *V. velutina* can reach higher local population densities than can *V. crabro* (Cini et al. 2018).

To what extent *V. velutina* competes with other European hornets or wasps (other Vespinae) is largely unknown. Competition from a variety of *Vespa* species in Asia, most of which are larger in body size, in contrast to only *V. crabro* in Europe, may at least partly explain the slower spread of the invasive hornet in Asia (South Korea and most recently Japan) than in Europe (Villemant et al. 2011, Arca et al. 2015, Ikegami et al. 2020, Kwon and Choi 2020). See subsection 1.4.1.1 for a more detailed account of the evidence for competitive interactions between invasive *V. velutina* and native hornets.

For *V. mandarinia*, competition with native hornets in invaded ranges is unknown, but likely similar to *V. velutina* should it arrive in Norway.

3.4.1.2 HAZARD CHARACTERIZATION

The potential negative effects of competition caused by *V. velutina* on native hornets under Norwegian conditions are expected to be similar to the effects seen in the invaded range in Europe. The climatic conditions are likely be less suitable for *V. velutina* than for *V. crabro* in Norway. Also, the relative abundance in non-urban areas is higher in Norway than in most parts of continental Europe, favouring *V. crabro* as it seems to prefer such habitats more than *V. velutina* (Bonnefond et al. 2021). For ***V. velutina*** the **potential magnitude of the hazard** competition is characterized as **"Minor**" with "Medium" confidence.

The potential negative effects of competition by *V. mandarinia* with native hornets under Norwegian conditions are expected to be similar to the potential effects of *V. velutina*. Also, since *V. mandarinia* queens prefer environments, such as forested areas, parks, agricultural zones, and other herbaceous settings (Kim et al. 2020, Alaniz et al. 2020, Norderud 2021), competition for habitat might be stronger between *V. crabro* and *V. mandarinia* than between *V. crabro* and *V. velutina*. The climatic conditions in Norway are probably more suitable for *V. mandarinia* than for *V. velutina*. Also, *V. mandarinia* is the largest of all *Vespa* species, and larger body size could make *V. mandarinia* a stronger competitor to native *V. crabro* in Europe than *V. velutina* (Kwan and Choi 2020).

In total, slightly more severe impacts of competition with native hornets might be expected for *V. mandarinia* should it establish in Norway than for *V. velutina*. However, the **potential magnitude of the hazard** competition by ***V. mandarinia*** is characterized as "**Minor**" with "Low" confidence.

3.4.1.3 LIKELIHOOD

Both Asian *Vespa* species are annuals in the sense that workers die in the end of the season and only the next year's queens overwinter. So, the likelihood of entry for these hornets mirrors the likelihood that queens enter the country alive.

For ***V. velutina***, pathways of entry of queens to Norway could either be natural dispersal (only likely if southern Sweden is colonized) or human-mediated dispersal such as with cargo, private vehicles, ferries, or other vessels (see Appendix III). The species is spreading fast in Europe and has been introduced and established several times outside its native range. The likelihood of entry naturally increases with time and will be a function of direct trade with Asia (especially China and South Korea), as well as trade with European countries where *V. velutina* is particularly abundant (currently, Spain, Portugal, and France). A slight increase in the likelihood of entry could result from an increased number of people traveling from regions where *V. velutina* is common and there is a chance that queens can enter vehicles or vessels. Human-mediated dispersal seems to be an important contributor to the rapid expansion this hornet's range in Europe (Bertolino et al. 2016, Robinet et al. 2017, Carvalho et al. 2020, Jones et al. 2020). VKM assesses the **likelihood of entry** to be

"Moderately likely" with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

V. mandarinia is not established in Europe, so entry to Norway would have to be human mediated via overseas cargo, as likely occurred on two separate occasions in North America (see section 1.3.1 about spread of *V. mandarinia* worldwide and see Appendix IV). VKM assesses the **likelihood of entry** to be **"Very unlikely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Europe.

Based on the climatic tolerances of ***V. velutina,*** the current and future climatic conditions in Norway, and the climate conditions in already invaded areas (see chapters 3.1 and 3.2), VKM concludes that it is "**Moderately Likely**" with "Low" confidence that *V. velutina* would **establish and spread** in Norway should it be introduced (see Appendix III).

The climatic and habitat conditions in Norway are probably more suitable for ***V. mandarinia***, as this species is associated with cooler climates, higher amounts of precipitation and environments such as forested areas, parks, agricultural zones, and other herbaceous settings (Kim et al. 2020, Alaniz et al. 2020, Norderud 2021). Therefore, VKM concludes that it is "**Likely**" with "Low" confidence that *V. mandarinia* would **establish and spread** should it be introduced (see Appendix IV).

For ***V. velutina***, VKM assesses the **likelihood of negative effects** caused by competition with native hornets, if the species establishes and spreads in Norway, to be "**Moderately Likely**" with "Medium" confidence.

For ***V. mandarinia***, VKM assesses **the likelihood of negative effects** caused by competition with native hornets, if the species establishes and spreads in Norway, to be "**Moderately Likely**" with "Low" confidence.

In sum, for ***V. velutina***, taking into account the combined likelihoods of entry, establishment, spread and impact, VKM assesses the **overall likelihood of negative effects** caused by competition with native hornets to be "**Moderately likely**" with "Medium" confidence within the next 10 years, primarily due to the likelihood of entry. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

In sum, for ***V. mandarinia***, taking into account the combined likelihoods of entry, establishment, spread and impact, VKM assesses the **overall likelihood of negative effects** caused by competition with native hornets to be "**Unlikely**" with "Low" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Europe.

3.4.1.4 RISK CHARACTERIZATION

V. velutina is assessed as having a potentially "Minor" effect on native hornets through competition, while this is "Moderate" for *V. mandarinia*. Should they establish and spread, VKM concludes that it is "Moderately likely" that this impact will occur. However, the overall likelihood of this negative effect depends first and foremost on the species entering Norway, which is assessed to be "Moderately likely" and "Very unlikely" for *V. velutina* and *V. mandarinia*, respectively. Therefore, VKM concludes that the **risk posed to native hornets** from competition with ***V. velutina*** is **"Moderate"**. For ***V. mandarinia*** the risk is **"Low"**. This assessment is made with "Medium" confidence.

3.5 Introduction of disease-causing agents

In this section, we focus on potential viral pathogens and parasites. We did not find any studies suggesting that invasive wasps pose a special hazard to honey bees with respect to introducing important bacterial pathogens. We present a hazard analysis only for *V. velutina*, as there are insufficient data for *V. mandarinia*.

3.5.1 Viral pathogens

3.5.1.1 HAZARD IDENTIFICATION

Three viral pathogens vectored by varroa mites are treated here because there are indications that they may be frequently associated with *V. velutina* (see subsection 1.4.3). Dalmon et al. (2019) detected 19 viruses in asymptomatic or symptomatic *V. velutina*, but more studies are needed of most of these viruses to determine whether they represent a threat to native insects or domesticated honey bees. Nothing is known of virus associations with invasive *V. mandarinia*. It seems likely that *V. mandarinia* could spread viral pathogens after attacking infected honey bee colonies if the species becomes widespread.

The three viruses that we have discussed (see subsection 1.4.3) are Deformed wing virus (DWV), associated with destruction of honey bee colonies by varroa mite infestation; Israeli acute paralysis virus (IAPV), associated with Colony Collapse Disorder; and the recently described Moku virus. The latter is a focus of research because it is a near relative of slow bee paralysis virus, which is a highly virulent but rarely recorded pathogen (Mordecai et al. 2016). The pathogenicity of Moku virus remains to be ascertained (Highfield et al. 2020), so we cannot analyze the potential for Moku virus becoming a hazard.

3.5.1.2 HAZARD CHARACTERIZATION

Both DWV and IAPV are established in Norway and cause serious problems for apiculture. *V. velutina* is potentially a reservoir of both viruses and could become a new vector. The potential effects of both viral diseases depend on the presence of varroa mites and on colony health. Serious disease results from an interaction between the virus and host stress (Chen et al. 2014). Thus, even if the virus is present in a colony, it is unlikely to cause significant mortality unless the bees are stressed by other factors.

Should *V. velutina* be introduced to Norway and become a new vector, VKM concludes that the magnitude of potential impact would be **"Minor"** for both **Deformed wing virus** and **Israeli acute paralysis virus.** This assessment is made with "Low" confidence.

3.5.1.3 LIKELIHOOD

Both Asian *Vespa* species are annuals in the sense that workers die in the end of the season and only the next year's queens overwinter. So, the likelihood of entry for these hornets mirrors the likelihood that queens enter the country alive.

For ***V. velutina***, pathways of entry of queens to Norway could either be natural dispersal (only likely if southern Sweden is colonized) or human-mediated dispersal such as with cargo, private vehicles, ferries, or other vessels (see Appendix III). The species is spreading fast in Europe and has been introduced and established several times outside its native range. The likelihood of entry naturally increases with time and will be a function of direct trade with Asia (especially China and South Korea), as well as trade with European countries where *V. velutina* is particularly abundant (currently, Spain, Portugal, and France). A slight increase in the likelihood of entry could result from an increased number of people traveling from regions where *V. velutina* is common and there is a chance that queens can enter vehicles or vessels. Human-mediated dispersal seems to be an important contributor to the rapid expansion this hornet's range in Europe (Bertolino et al. 2016, Robinet et al. 2017, Carvalho et al. 2020, Jones et al. 2020). VKM assesses the **likelihood of entry** to be **"Moderately likely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

Based on the climatic tolerances of ***V. velutina,*** the current and future climatic conditions in Norway, and the climate conditions in already invaded areas (see chapters 3.1 and 3.2), VKM concludes that it is "**Moderately Likely**" with "Low" confidence that *V. velutina* will **establish and spread** in Norway should it be introduced (see Appendix III).

The likelihood of ***V. velutina*** to have **negative impact** on honey bees through spread of viral pathogens (i.e., DWV and IAPV) is assessed to be "**Unlikely**" for *V. velutina.* This assessment is made with "Low" confidence.

In sum, for ***V. velutina***, taking the combined likelihoods of entry, establishment, spread and impact into consideration VKM assesses the **overall likelihood of negative effects** caused by spread of viral pathogens (i.e., DWV and IAPV) to be "**Unlikely**" with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

3.5.1.4 RISK CHARACTERIZATION

V. velutina is assessed as having a potentially "Minor" effect on native hornets through spread of viral pathogens (i.e., DWV and IAPV), and should it establish and spread, VKM concludes that it is "Unlikely" that this impact will occur. However, the overall likelihood of this negative effect depends first and foremost on the species entering Norway, which is assessed as "Moderately likely" for *V. velutina*. Therefore, VKM concludes that the **risk posed to honeybees from spreading of viral diseases** with ***V. velutina*** is **"Low"**. This assessment is made with "Medium" confidence.

3.5.2 Parasites

3.5.2.1 HAZARD IDENTIFICATION

Varroa mites are considered here because they are one of the major hazards to both commercial and hobby beekeeping (Sammataro et al. 2000, Ramsey et al. 2019) and because a few have been found attached to specimens of *V. velutina*. The mites debilitate worker bees through their feeding activity and vector highly destructive viral diseases. We did not do a risk assessment of other parasites found on *V. velutina*, because the potential impacts of these parasites on honey bees or native insects are not yet known.

3.5.2.2 HAZARD CHARACTERIZATION

Varroa mites are widespread in the southern half of Norway (B. Dahle, pers. comm. 21 Dec. 2021). The concern associated with the introduction of new wasp species is that they could become new dispersal agents of the mites and mite-borne diseases they vector, since varroa mites were found on 2% of trapped specimens of *V. velutina* in Spain (Sanchez and Arias 2021).

Should ***V. velutina*** be introduced to Norway and become a new vector, VKM concludes that the magnitude of potential additional impact would be **"Minor"** for varroa mites (assessed with "Medium" confidence).

3.5.2.3 LIKELIHOOD

Both Asian *Vespa* species are annuals in the sense that workers die in the end of the season and only the next year's queens overwinter. So, the likelihood of entry for these hornets mirrors the likelihood that queens enter the country alive.

For ***V. velutina***, pathways of entry of queens to Norway could either be natural dispersal (only likely if southern Sweden is colonized) or human-mediated dispersal such as with cargo, private vehicles, ferries, or other vessels (see Appendix III). The species is spreading fast in Europe and has been introduced and established several times outside its native range. The likelihood of entry naturally increases with time and will be a function of direct trade with Asia (especially China and South Korea), as well as trade with European countries where *V. velutina* is particularly abundant (currently, Spain, Portugal, and France). A slight increase in the likelihood of entry could result from an increased number of people traveling from regions where *V. velutina* is common and there is a chance that queens can enter vehicles or vessels. Human-mediated dispersal seems to be an important contributor to the rapid expansion this hornet's range in Europe (Bertolino et al. 2016, Robinet et al. 2017, Carvalho et al. 2020, Jones et al. 2020). VKM assesses the **likelihood of entry** to be **"Moderately likely"** with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

Based on the climatic tolerances of ***V. velutina,*** the current and future climatic conditions in Norway, and the climate conditions in already invaded areas (see chapters 3.1 and 3.2), VKM concludes that it is "**Moderately Likely**" with "Low" confidence that *V. velutina* **establish and spread** in Norway should it be introduced (see Appendix III).

There are few reports of varroa mites attached to *V. velutina* (but see Sanchez and Arias 2021). Varroa mites usually spread when attached to (phoretic on) honey bee workers that steal honey from other beehives or accidentally enter other hives; they can also spread from worker to worker via flowers (Peck et al. 2016). Given that phoresy on predatory wasps is uncommon and that the mites spread easily among bee colonies by honey bee phoresy, we rate the likelihood of ***V. velutina*** having **negative impact on honey bees by increasing the spread of varroa mites** in Norway as "**Unlikely"** with "High" confidence.

In sum, for ***V. velutina***, taking the combined likelihoods of entry, establishment, spread and impact into consideration VKM assesses the **overall likelihood of negative effects** caused by spread of varroa mites to be "**Unlikely**" with "Medium" confidence within the next 10 years. However, the likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

3.5.2.4 RISK CHARACTERIZATION

V. velutina is assessed as having a potentially "Minor" effect on native hornets through spread of varroa mites, and should it establish and spread, VKM concludes that it is "Unlikely" that this impact will occur. However, the overall likelihood of this negative effect depends first and foremost on the species entering Norway, which is assessed to be "Moderately likely" for *V. velutina*. Therefore, VKM concludes that the **risk posed to**

honeybees from further spreading of varroa mites with *V. velutina* is **"Low".** This assessment is made with "Medium" confidence.

4 Impact on ecosystem services and agriculture

4.1 Impact on ecosystem services

Wasps are rarely appreciated as useful insects for the environment and are often considered pests that spoil outdoor activities when people see wasps and fear being stung. However, wasps, including *V. velutina* and *V. mandarinia*, do provide key ecosystem services by acting as predators of crop pests, pollinators of plants, and as seed dispersers, among other useful functions (Brock et al. 2021). When adult *V. velutina* visit flowers to feed on nectar (an important carbohydrate source; Monceau et al. 2015), they also frequently hunt flower-visiting insects as food for their larvae (Ueno 2015, Kishi et al. 2017). Following the introduction of *V. velutina* to Europe, concerns have been raised about reduced pollinator populations, since bees (including domesticated honey bees), wasps and other pollinators constitute a large part of its diet (Genovesi 2015, Fedele et al. 2019, Laurinio et al. 2020, Verdasca et al. 2021). Yet, although negative impacts on pollinator populations and consequently reduced pollination services of wild and crop plants have been hypothesized and inferred from observational studies, the extent of these ecological impacts is still poorly understood. Locally, the wasps' predation on pollinators of agricultural crops in the flowering season is a potential problem for crop pollination.

At the same time, the control of invasive wasps can also disrupt ecosystem services. For example, the use of poison to control adult wasps and their nests may show cascading effects on non-target insects, birds and mammals when wasps interact with other pollinators or when they serve as prey for insectivorous birds and bats (Stanley and Preetha 2016).

Outdoor recreation is an ecosystem service that can be negatively impacted by large hornets, such as the two species under consideration here. Similarly, fruit picking can be disturbed by the presence of large hornets feeding on fruits, such as apples, grapes, or citrus, when workers shift their feeding from protein to sugars in late summer (Rolea and Vieja 2020). In this regard, the two species differ in that *V. mandarinia* represents a more serious risk to human health and safety. In Japan, *V. mandarinia* kills dozens of people per year due to allergic reactions and inflict sting-related injuries to thousands or more (Dooley 2020, Norderud et al. 2021). Empirical evidence from France shows that severe sting-related injuries caused by *V. velutina* occur only under special circumstances and do not differ from those caused by stings from native wasps (de Haro et al. 2010).

4.2 Impact on agriculture

V. velutina feed on ripe fruits in the fall, and have thus become a nuisance for fruit producers, though primarily as a problem for the fruit pickers that fear stings.

Adult *V. mandarinia* feed on sap from a number of plant species and this may lead to crop damage (Norderud et al. 2021). *V. mandarinia* is a competitively dominant species among a number of diurnal sap-feeding species (Yoshimoto and Nishidia 2009).

Both species could also reduce crop pollination services from wild pollinators and domesticated honey bees (se section 4.1). Fedele et al. (2019) assessed the potential effect of *V. velutina* on crop pollination in a selection of regions in Spain, Italy, Portugal and France. They concluded that the production loss rate was low in most fruit producing regions though in certain regions the loss was as high as 26%, due to insufficient pollination service.

5 Mitigation measures

V. velutina is listed as an "invasive alien species of Union concern" by the European Union (EU 2016). Even so, there is no clear coordination among European countries with respect to control or eradication of *V. velutina* (Fedele et al. 2019, Leza et al. 2021). Control measures are carried out at the local level within invaded countries, and there is no agreement on best practice for eradication measures (e.g., Leza et al. 2021). A national eradication plan for *V. mandarinia* has been developed in the USA (Tripodi and Hardin 2020). In Canada, *V. mandarinia* is included in the Province of British Columbia Invasive Species Early Detection Rapid Response Plan and the management objective is eradication[12].

5.1 Inhibiting entry

It is crucial to be prepared through surveillance, early detection and rapid response systems to prevent negative effects of invasive alien species. The likelihood of early detection can be enhanced by increasing awareness, for example through invasive species alert campaigns, such as those in Ireland[13], UK[14], France[15], and USA[16]. In addition to reducing the likelihood of unintentional human-mediated dispersal, increasing public awareness could also prevent introduction of *V. mandarinia* in relation to human consumption since the species is considered a delicacy in its endemic range in Asia and pupae and adults are often semidomesticated for human consumption (Mozhui et al. 2020; Norderud et al. 2021).

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[12] https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/invasive-species/priority-species/insects?keyword=mandarinia

[13] https://biodiversityireland.ie/asian-hornet-alert/

[14] https://www.bumblebeeconservation.org/wp-content/uploads/2018/05/ID_Vespa_velutina_Asian_Hornet_2.0.pdf

[15] https://frelonasiatique.mnhn.fr/signaler-informations/

[16] https://s3.wp.wsu.edu/uploads/sites/2091/2020/01/PestAlert-AsianGiantHornet.pdf

5.2 Mitigation following entry and establishment

5.2.1 Early detection and eradication

Rapid and correct species identification of *V. velutina* and *V. mandarinia* individuals and nests is crucial to prevent establishment outside their native ranges (Smith-Pardo et al. 2020). The native hornet *V. crabro* and the invasive *V. velutina* have similar morphology and it is important to avoid misidentification. Likewise, it is important to correctly identify *V. mandarinia,* should it arrive in new areas. Identification based on morphological traits may not always be possible. Rapid molecular methods for in-field and laboratory identification of *V. velutina* have been developed, which can successfully identify even incomplete/damaged specimens and immature life stages (Stainton et al. 2018).

To prevent establishment of *V. velutina* after entry, the UK has established a successful system for early detection and eradication. The Non-Native Species Secretariat and National Bee Unit in the UK respond to all reports of foraging *V. velutina* and use trajectory tracking techniques to locate and destroy nests[17] (Science for Environment Policy 2021). Microsatellite marker analysis show that the detected nests (nine) and lone individuals (from seven additional sites) are likely the result of separate entries from the European continent (Jones et al. 2020). Follow-up monitoring in affected areas revealed no new nests during subsequent years (Jones et al. 2020).

About three years after the introduction to North America, *V. mandarinia* remains restricted to a small area in the northwestern corner of Washington State and across the border in British Columbia[18] despite the fact that DNA studies suggest that there have been two separate introductions. So far, it appears that the implementation of the early detection and eradication plans developed by the United States Department of Agriculture (Tripodi and Hardin 2020) and the Government of British Columbia (gov.bc.ca) have managed to contain *V. mandarinia* within a limited geographic area and have prevented spread. Eradication has focused on locating and destroying nests, relying heavily on citizen science for finding the species.

It is not feasible to eradicate *V. velutina* in countries where it is established and spreading (Franklin et al. 2017). Targeted control measures could in theory reduce the spread and impact of invasive hornets on native biodiversity and honey bees (e.g., Robinet et al. 2017, Turchi and Derijard 2018). But even with substantial effort, such measures will probably only

[17] http://www.nonnativespecies.org/alerts/index.cfm?id=4

[18] https://agr.wa.gov/departments/insects-pests-and-weeds/insects/hornets/data

slow down the spread and perhaps prevent the species from becoming widespread (see section 5.2.3 Active control measures). However, a possible successful eradication program has been carried out on the Mediterranean island Majorca, using a combination of control methods, including trapping, citizen science, active search for nests, and removal and destruction of nests by trained technicians (Leza et al. 2021). The number of secondary *V. velutina* nests during the six years of campaigns against the species were 1 in 2015, 9 in 2016, 20 in 2017, and 0 during 2018, 2019 and 2020. The last hornet was trapped in June 2018 (Leza et al. 2021).

5.2.2 Surveillance, mapping and predicting species distributions

Preparedness through surveillance will increase the chances for early detection and possible eradication of invasive alien hornets. There is currently no systematic monitoring across Europe, but the honey bee research organization COLOSS aims to set up a network of monitoring stations throughout the area of probable *V. velutina* invasion to monitor its spread in Europe and Asia[19]. Passive traps can be used to detect *V. velutina* and *V. mandarinia* in new locations (Tripodi and Hardin 2020, Leza et al. 2021). Citizen science campaigns can also be effective but requires that a system to process reports from the public is in place (Sumner et al. 2019, Tripodi and Hardin 2020), such as for *V. velutina* in the UK[20]. Citizen science has been critical to finding *V. mandarinia* in the Pacific Northwest (USA and Canada). Soon after the confirmation of the first two reports of the *V. mandarinia* in Washington State in December 2019, the Washington State Department of Agriculture created an Asian Giant Hornet Public Dashboard to share detection and trapping data[21]. From the dashboard one can quickly view on a map the confirmed detections (or nests) in the current year (or previous years), but also all of the negative sightings (based on traps) that have been reported by either the Washington State Department of Agriculture (from 914 traps in 2021) or by the public (771 traps in 2021).

Once invasive hornet species have established, passive traps can be used to delimit the occupied area and monitor spread (Tripodi and Hardin 2020, Leza et al. 2021). In addition, citizen science data can be an important source of information to determine species occurrence and distribution (Sumner et al. 2019, Leza at al. 2021). Sumner et al. (2019) used a combination of (long-term) expert surveying and citizen science data to fit species distribution models of wasp species in the UK, including *V. crabro*, and found that the citizen

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[19] https://coloss.org/projects/velutina/

[20] http://www.nonnativespecies.org/alerts/index.cfm?id=4

[21] https://agr.wa.gov/departments/insects-pests-and-weeds/insects/hornets/data

science data were less spatially biased, and more urban-biased, compared to the long-term monitoring data. For *V. crabro*, just two weeks of citizen science data collection generated coverage comparable to more than four decades of expert monitoring (Sumner et al. 2019).

Predicting future spread based on habitat suitability and human footprint could inform targeted early detection and eradication programs (Bertolino et al. 2016). Differentiating between natural and human-mediated dispersal is difficult but would improve predictions; the spread of *V. velutina* in Europe has been a mix of natural dispersal (Villemant et al. 2011, Robinet et al. 2017) and sudden leaps caused by human-mediated dispersal of queens (Marris et al. 2011, Bertolino et al. 2016).

5.2.3 Active control measures

Eradicating nests is the most effective strategy for limiting the spread of invasive hornets (Kishi and Goka 2017, Kennedy et al. 2018, Kim et al. 2019, Tripodi and Hardin 2020). Finding nests is daunting, however, as workers can fly over the canopy and for long distances (Matsuura and Sakagami, 1973). Finding nests can be accomplished by both low-tech means (baiting for workers and then following them to a nest) and high-tech means (radio tagging). Baiting must avoid collateral damage to bee colonies, but it is possible now to bait specifically for predatory wasps (Tripodi and Hardin 2020). Similarly, there are both low-tech and high-tech means of destroying nests once these have been found.

5.2.3.1 Nest detection

There is a centuries-old tradition in many parts of southern and southeastern Asia of hunting for vespine nests for human food (Matsuura and Yamane, 1990, Nonaka and Yanagihara 2020, Tripodi and Hardin 2020, Tzudir and Markandan 2021). Nest hunting usually takes place in late fall, when colonies contain maximum numbers of protein- and fat-rich larvae and pupae. Hunting earlier in the season is for young nests that can be transplanted and nurtured until late fall, when they are harvested for food. Both *V. velutina* and *V. mandarinia* are targets for nest hunters, in regions where the hornets are native.

Consequently, low-tech means of locating nests exist in those rural cultures that still carry out nest hunting. To find nests, hornet workers are made more visible by attaching light-coloured silk streamers to small bits of attractive food[22] (Matsuura and Yamane 1990, Nonaka and Yanagihara 2020). In their 1990 book *Biology of the Vespine Wasps*, Matsuura and Yamane describe two traditional alternatives for locating wasp nests. One common way of finding colonies is to use bait (such as meat from frogs, fish, or cicadas) to attract

[22] https://blog.gaijinpot.com/secret-life-wasp-hunters-japan/

foraging workers that are caught and flagged. Individuals or teams follow flagged wasps that are returning with food, marking the places where they lost sight of the wasps, until they can trace them to a nest. A second method, carried out by skilled persons alone or in small groups, is to wait near typical nest habitats or where wasps are frequently seen, and simply attempt to follow workers carrying prey back to their nests. It helps that the wasps will congregate around anyone coming within about 10 m of a nest, making it possible for observers to locate the nest site. This form for low-tech nest location demands skills attained through long experience as well as a landscape conducive to rapid human movement.

Today's high-tech techniques include harmonic radar[23] (Maggiora et al. 2019), radiotelemetry (Kennedy et al. 2018; Kim et al. 2019) and drones (Reynaud and Guérin-Lassous 2016). Nests may be located by simple triangulation, where at least three specimens are captured, released at three different locations and their direction of flight is recorded: the nest should be close to where the different lines of flight intersect (Turchi and Derijard 2018). These more technologically advanced methods are still under development. But there is an urgent need for readily available and affordable methods, as traditional triangulation is time-consuming, and many nests are not found (Turchi and Derijard 2018).

The invasion of *V. velutina* in Europe is mostly controlled by locating and destroying of the nests (Barbet-Massin et al. 2020). However, the physical attributes and locations of the nest and the geographic spread makes it very hard to find a nest, and a large proportion of the nests are probably overlooked (Robinet et al 2017, Turchi and Derijard 2018). Nest detection is especially important for control and potentially eradication of *V. mandarinia* in North America, where relatively few colonies are presumed to exist (Kennedy et al. 2018). However, the subterranean nesting habits of this species make locating nests similarly challenging (Tripodi and Hardin 2020).

Tracking of radio tagged individuals was also used successfully by the Washington State Department of Agriculture to locate and exterminate a nest of *V. mandarinia* in the fall of 2020[24]. At a press conference held shortly thereafter, Washington State Department of Agriculture Managing Entomologist Sven-Erik Spichiger was quoted as saying that, given the radio tag's strength, "I'm pretty confident as long as we can get live hornets, we can follow them back, and that really gives us a great tool in an overall eradication program."

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[23] https://www.vespavelutina.eu/en-us/the-project/The-radar

[24] https://www.usda.gov/media/blog/2020/10/29/usdas-cutting-edge-methods-help-deliver-victory-against-asian-giant-hornet

5.2.3.2 Nest destruction

The most established technique to destroy hornet nests is biocide injection, such as injecting permethrin (Turchi and Derijard 2018). A promising and more biodiversity friendly method for quickly destroying nests may be the injection of hot steam (Ruiz-Cristi et al. 2020). On the internet it is easy to find examples of more spectacular methods like shotgun destruction of the nests[25], and drone-borne flame-throwers[26], but the safety and efficiency of such control measures have not been scientifically tested. In practice, nest destruction must be adapted to the situation. For the above-mentioned *V. mandarinia* nest, managers plugged the nest with foam, wrapped the tree in plastic, vacuumed out the hornets and finally injected carbon dioxide into the tree to kill any remaining hornets[27].

Even though nest destruction is more efficient than other control methods, it is not very efficient in reducing population density and spread once *V. velutina* has established. Robinet et al. (2017) developed a mathematical model to simulate the spread of *V. velutina* in France. When running a model that included parameters describing the population growth rate, carrying capacity, self-mediated dispersal and the efficacy of control measures (i.e., the destruction of detected nests) for the period 2013-2020, Robinet et al. (2017) found that increasing the percentage of destroyed *V. velutina* nests from 30% to 60% could reduce the spread of *V. velutina* by 17% and nest density by 29%, whereas if 95% of nests are destroyed, the spread could decline by 43% and nest density by 53%. Thus, even with intensive risk-reducing efforts, the reduction in local densities of *V. velutina* is only moderate, and just slowing down, but not stopping further spread.

Nevertheless, V. *mandarinia* so far remains restricted to a very small area in the northwestern corner of Washington State and across the border in British Columbia since it was first discovered in September 2019. The main strategy for combating *V. mandarinia* in this region has been to locate and destroy nests in the late fall (Tripodi and Hardin 2020).

5.2.3.3 Trapping and killing hornets outside the nest

The most commonly used traps are simple syrup traps intended for trapping workers during the hunting season (Turchi and Derijard 2018). These traps are unspecific and *V. velutina* typically make up only a very small proportion of the total catch (e.g., <1% in Goldarazena

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[25] http://anti-frelon-asiatique.com/piegeage/destruction-des-nids-tres-hauts-tirs-aux-fusils/

[26] https://www.youtube.com/watch?v=uCq8tEwO90Q

[27] https://www.usda.gov/media/blog/2020/10/29/usdas-cutting-edge-methods-help-deliver-victory-against-asian-giant-hornet

et al. 2015). Syrup traps are also widely used for intensive spring trapping of queens, but likely has no effect on number of *V. velutina* nests in the following season and may even be counterproductive if trapping kills highly competitive queens, which may regulate local population densities (Turchi and Derijard 2018). However, Leza et al. (2021) used several types of sticky traps and syrup traps to kill *V. velutina* queens in the spring and to detect the presence of adults, as part of multi-measures six-years eradication program. The program may have eliminated *V. velutina* on the island of Majorca. It is highly uncertain how much trapping would affect *V. velutina*, but irrespective of its (lack of) effect on local *V. velutina* populations, mass trapping could have negative impacts on native biodiversity (Rome et al. 2011, Rojas-Nossa et al. 2018, Rodríguez-Flores et al. 2019, EEA 2012). See subsection 5.3.1 for a more detailed account for the advantages and disadvantages of different types of traps.

5.2.3.4 Biological control

The use of parasites or microbial organisms to control invasive *Vespa* species has not yet been put into practice. An experimental study from controlled laboratory conditions suggests that pathogenic *Beauveria* and *Metarhizium* fungi may be used in the future to control invasive *Vespa* species (Poidatz et al. 2018). Also, parasitic or parasitoid organisms that have already been described to infect *V. velutina,* such as the fly *Conops vesicularis* (Darrouzet et al. 2014) and a *Pheromermis* nematode (probably *P. vesparum*; Villemant et al. 2015), or which are still undiscovered, could potentially be used in the future to control invasive hornets (Turchi and Derijard 2018). However, Villemant et al. (2015) argue that the conopid fly and the mermithid nematode that have been discovered so far, most likely will not be efficient control agents against *V. velutina*. Dalmon et al. (2019) detected 19 viruses in asymptomatic or symptomatic *V. velutina* and emphasized the need for more studies to determine whether some of the viruses represent potential for biological control of *V. velutina*. In a recent paper, Gabín-García et al. (2021) report that *V. velutina* harbours most common hymenopteran enteroparasites (i.e., Microsporidia: Nosematidae; Euglenozoa: Trypanosomatidae and Apicomplexa: Lipotrophidae) as well as several new parasitic taxa, but the potential for using any of these parasites to control *V. velutina* is not known. Also, biological control mechanisms could potentially pose a threat to non-target native insects (Howarth 2000), such as *V. crabro*.

5.2.3.5 Biotechnology

Although not used so far, application of DNA technology to control invasive wasps may be an alternative in the future. In a recent paper, Lester et al. (2020) used a combination of in vitro experiments and mathematical modelling to examine a potential gene drive targeting spermatogenesis to control the invasive common wasp (*Vespula vulgaris*) in New Zealand. They showed that CRISPR gene drives may offer suppression for invasive social wasps (Lester et al. 2020). Likewise, it could be possible to use a CRISPR gene drive to sterilize or partially sterilize a population of *V. velutina*. However, it is also quite possible that such a genetically manipulated hornet would be 're-introduced' to the native geographic range of *V. velutina* in Asia where it could also wipe out native *V. velutina* populations (Turchi and Derijard 2018). Other DNA based techniques, like RNA interference, might be a hypothetical option in the future (Tuchi and Derijard 2018), but we are not aware of studies that have used this technique in any Hymenoptera species.

5.3 Limiting impact on honey bees

Mitigation measures described in chapter 5.2. can also reduce negative impacts of invasive *V. velutina* and *V. mandarinia* on honey bees. Chapter 5.3. gives an overview of possible local mitigation actions in or near apiaries targeting invasive hornets. The advantages and disadvantages of readily available and potential future control measures are presented in Figure 5.3-1. Note that most of these measures will most likely also affect native *V. crabro*.

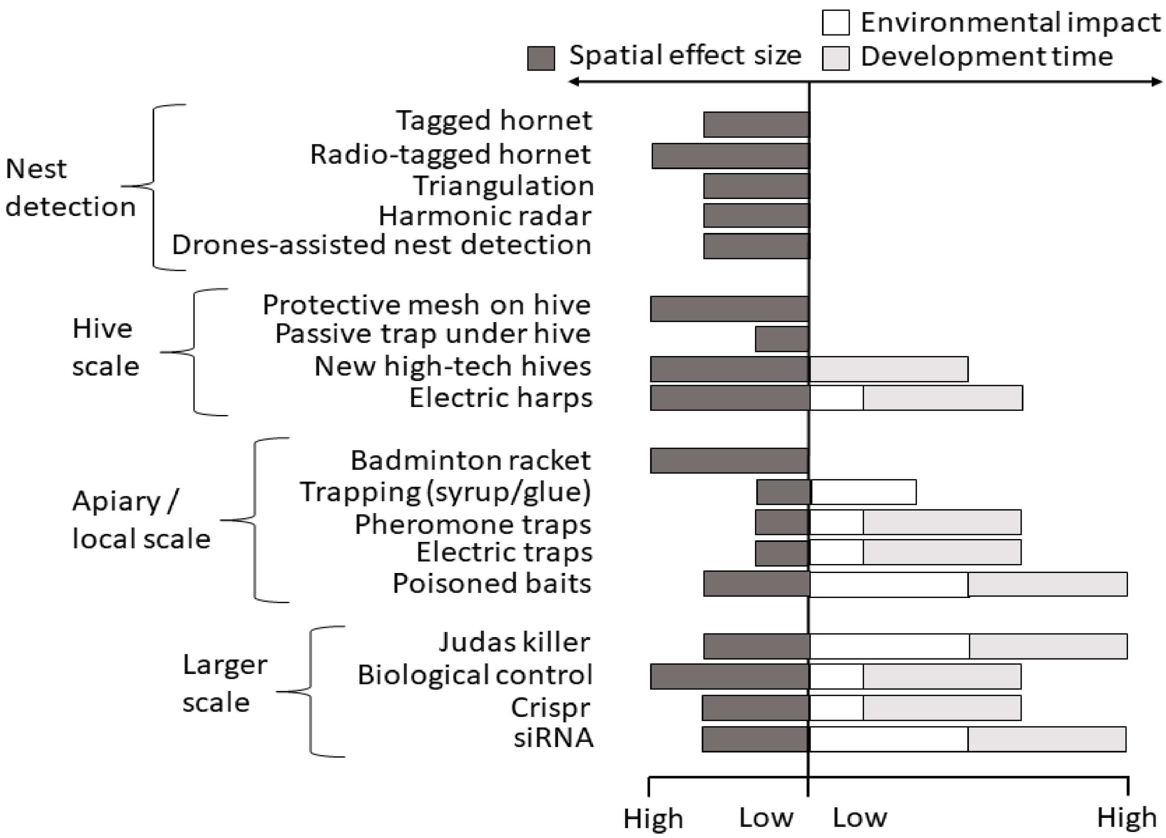

Figure 5.3-1: Measures to control *V. velutina* and reduce its negative impact on honey bees and native biodiversity. The estimates of the spatial effects sizes, environmental impacts and development times are based on figure ESM1 in Requier et al. (2020), who converted the categories "none", "low", "medium" and "high" in Turchi and Derijard (2018) into an ordinal scale with the values 0, 1, 2 and 3. In addition to the methods presented in figure ESM1 in Requier et al. (2020), we added radio-tagging and new high-tech beehive designs.

A number of different techniques for eliminating or reducing the number of hornets in- or near apiaries are currently being used. Research into development of sound control methods is ongoing[28]. For example, improved beehive design may represent a new type of risk-reducing measure. Hives that contain built-in high-tech sensors, cameras and robotics, as well as solutions for protecting the bee colonies from possible threats, such as hornets, may improve colony health and reduce hornet-related mortality of honey bees in the future (e.g., https://beefutures.io/).

5.3.1 Traps and biocides

The most widely applied methods to control *V. velutina* in apiaries are passive trapping of hornets with simple traps with syrup or baits poisoned with insecticide (Kishi and Goka 2017, Turchi and Derijard 2018). However, although intensive trapping may lead to a temporary reduction in the number of hornets near hives (e.g., Shah and Shah 1991), passive trapping does not lead to a substantial or lasting reduction of the local populations of *V. velutina* (Beggs et al. 2011; Monceau et al. 2014; Turchi and Derijard 2018) nor does it efficiently reduce hornet-related impacts on honey bee behaviour, e.g., homing failure and foraging paralysis (Requier et al. 2019). Importantly, such traps have negative environmental impacts because they are not species-specific and therefore pose a threat to a large number of native insects (Rome et al. 2011; Rojas-Nossa et al. 2018, Rodríguez-Flores et al. 2019).

Development of more species-specific pheromone traps is ongoing, but more testing is needed, and such traps are not yet commercially available (see Turchi and Derijard 2018; Requier et al. 2020 with references). Electrical traps are commercially available, but their effectiveness and possible by-catch of native species have not been scientifically tested (Turchi and Derijard 2018).

Glue traps could be efficient because once one hornet individual gets stuck, other individuals soon show up to check out what happened to their co-worker and get trapped too. However, unless the glue trap protected with a 'cage' with mesh sizes small enough to prevent larger animals from passing through, this will be a painful death trap to, e.g., bats and birds[29]. Even if a protective cage is used to prevent unintended killing of larger animals, leaving out passive glue traps can lead to unintentional killing of honey bees and native arthropods.

Rather than killing hornets with poison immediately on site, some beekeepers capture and poison individual *V. velutina* workers whereafter individual workers bring poison back to the

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[28] https://coloss.org/projects/velutina/

[29] https://www.sussex.ac.uk/broadcast/read/48085

nest and contaminate the rest of the colony (also known as 'Judas killer'; Turchi and Derijard 2018). With this method, it is possible to poison the nest without finding it. However, poisoned hornet workers could potentially contaminate the general environment with biocides (Turchi and Derijard 2018), and also poison natural enemies that feed on wasp nests, pupae and larvae.

For small-scale beekeepers, an efficient and environment-friendly method is to use a badminton racket to eliminate hornets that are hovering in front of the hives (Turchi and Derijard 2018). If there is a *V. velutina* nest close to the apiary, this technique can kill up to 30–40 hornets in less than 15 min early in the morning, followed by a marked reduction in predation pressure—and presumably bee stress levels—for the rest of the day (Turchi and Derijard 2018).

5.3.2 Physical modification of beehives

A biodiversity-friendly method of reducing negative effects of *V. velutina* on honey bees is to place a protective mesh device around the entrance of the beehive, with mesh sizes large enough for honey bees to enter and exit, but too small for *V. velutina* (see Requier et al. 2020; photos of the device in the supplementary material ESM3). In the rare cases when hornets manage to enter through the mesh, they are trapped and vulnerable to attacks from guard bees (Turchi and Derijard 2018). Equipping beehives with a protective mesh can drastically reduce foraging paralysis (i.e., stop in flight activity induced by hovering hornets) and increase survival probability in honey bees with about 50% in hornet-stressed bee colonies (Requier et al. 2020). Foraging paralysis is the main mortality factor associated with *V. velutina* for honey bee colonies (Requier et al. 2019).

Another physical modification of beehives to prevent hornets from entering consists of a 4-cm-wide 'chimney' vertical to the bee entrance (see Figure 3 in Turchi and Derijard 2018). This set-up forces the honey bees and hornets to approach the hive entrance vertically. When the hornet enters, it cannot escape attacks from guard bees.

Nuñez-Penichet et al. (2021) also noted that beekeepers in the United States and Mexico may have to adopt mitigation practices developed by Japanese beekeepers, including the use of protective screens or traps at the hive entrance that prevent *V. mandarinia* from entering the hive.

5.3.3 Measures focused on honey bees

Healthy honey bee colonies are less likely to be attacked and better able to defend themselves. It is therefore important to ensure good hygiene in the beehives and to avoid stressing the bees. New hive designs may make it easier to maintain a high hygienic standard and reduce the need for manual inspection of the hives, thereby reducing general stress level (e.g., https://beefutures.io/).

The eastern honey bee has evolved behaviours to counter hornet attacks, thereby reducing losses of workers or colonies. But while eastern honey bees are better able to defend themselves against hornets, colony size is smaller, and they produce less honey than western honey bees. Importantly, in contrast to western honey bees, eastern honey bees are not native to Europe. If domesticated eastern honey bees were introduced to Europe, the risk of establishment in the wild and spread would likely be high. Thus, importing eastern honey bees to Europe would most likely do more harm than good.

5.4 Preventing or reducing negative impacts of invasive hornets in Norway

5.4.1 Early detection and preventing entry

The likelihood of human-mediated entry of *V. velutina* and *V. mandarinia* might be reduced by increasing general awareness about the possibility of unintentional introduction of the species to Norway with cargo or commodities, private vehicles, or for example private camping equipment.

In addition to passive dispersal by human transportation, *V. velutina* has a high capacity for self-dispersal. Inhibiting entry to Norway through natural dispersal will most likely be impossible if the climatic conditions are suitable for the species. However, as long as *V. velutina* has not been found in Sweden or Denmark, it will likely still take years before the species arrives in Norway through natural dispersal.

The chances of preventing entry and establishment of alien hornets will probably increase if a national management strategy is developed and implemented (for example, Tripodi and Hardin 2020). In Europe, the early detection and eradication program implemented by the UK appears to have been successful so far (Jones et al. 2020; Science for Environment Policy 2021). Involving stakeholders and relevant bodies, like the Norwegian Beekeepers Association (Norges Birøkterlag), the Norwegian Biodiversity Information Centre (Artsdatabanken), the cargo transport industry, environmental NGOs and the Norwegian customs, would likely increase the chances of early detection of invasive hornets.

To increase preparedness, a surveillance and monitoring program could be established. The program could be designed to capture entry of *V. velutina* or *V. mandarinia* to Norway, and also to improve our understanding of the distribution of native *V. crabro*. A scientific surveillance or monitoring program could be combined with citizen science data to increase spatial coverage. Because *V. velutina* or *V. mandarinia* appear to prefer honey bees as prey, a substantial proportion of the monitoring sites should be located in apiaries.

To further increase the chances of early detection, one could also mobilize the general public through an invasive species alert campaign and develop an easy-to-use identification guide (fact sheet or app). Identification guides should include diagnostic photos of key morphological traits that differ between *V. velutina*, *V. mandarinia, V. crabro* and other wasp species as featured in guidelines developed for France[30], USA[31] and UK[32]. Tripodi and Hardin (2020, p. 32) recommend that "observers should be encouraged to submit photographs that show a side view of the head [reference to example photo] and include a ruler or other means of determining the size of a specimen to aid in identification". An identification guide aimed at the general public and target groups, like for example beekeepers, could work as a "rapid test": one could establish a system where specimens that are identified as *V. velutina* or *V. mandarinia* in the rapid test, are sent on to species identification by use of molecular methods.

The Norwegian Biodiversity Information Centre (Artsdatabanken) has implemented a web-based solution for subscribing to notifications of species records. This is a free service available to anyone who creates a user account[33]. Users can restrict the species alert subscriptions to a species, species group or geographical area. When choosing a geographical area, it is possible to enter cadastral unit number and property unit number (Norwegian: gårds- og bruksnummer). Users will be notified if a new species is registered at the property in question. It is also possible to select a municipality, county or specify an area on the map. This alert service could be very useful for early with mitigation measures, both for individual beekeepers and local management authorities.

5.4.2 Active control measures

If *V. velutina* or *V. mandarinia* enter or become established in Norway, available measures to eradicate or contain the invasive species, and to prevent spread and negative impacts, as well as the effectiveness and environmental impacts of these risk-reducing measures, would be similar to the measures described in sections 5.1., 5.2 and 5.3. Use of chemical- or physical risk-reducing measures to eliminate invasive species must comply with Norwegian law.

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[30] https://frelonasiatique.mnhn.fr/fiches2/

[31] https://www.bumblebeeconservation.org/wp-content/uploads/2018/05/ID_Vespa_velutina_Asian_Hornet_2.0.pdf

[32] https://s3.wp.wsu.edu/uploads/sites/2091/2020/01/PestAlert-AsianGiantHornet.pdf

[33] https://artsdatabanken.no/Pages/300627/Faa_varsel_naar_artar_blir

New beehive designs that reduce stress through disturbance and improves colony health, and protects from external threats, such as hornets, may reduce future negative impacts on honey bees (https://beefutures.io/).

5.4.3 Passive control measures

Around 25 bird species native to Norway prey on social wasps, including the wasp and hornet specialist European honey buzzard (Ziesemer and Meyburg, 2015, Byholm et al. 2018) and the great grey shrike *Lanius excubitor* and red-backed shrike *Lanius collurio*, which also feed regularly on social wasps. Jays *Garrulus glandarius* and great tits *Parus major* may also prey frequently on wasps (Birkhead 1974). Mammals can also prey on wasps; for example, medium-sized species like badgers (*Meles meles*; Kranz et al. 2016) and pine martens (*Martes martes*; Helldin 2000, Twining et al. 2019), and large sized species like brown bears (*Ursus arctos;* Bojarska and Selva, 2012).

6 Uncertainties

Most instances of “low confidence” in the assessment are due to uncertainty about the modelling of species distributions with respect to the effects of climate, and to lack of knowledge about *V. mandarinia* biology. The biggest (and most important) uncertainty associated with our assessments is whether or not the current and future climatic conditions in Norway can be suitable for *V. velutina*. This is due to insufficient knowledge about what actually limits the distribution of that species, compounded with uncertainties inherent to climate suitability modelling. There is also considerable uncertainty regarding whether *V. velutina*, and to a greater extent, *V. mandarinia*, will actually enter the country. If these alien hornets do enter Norway through self- or human-mediated dispersal, and the climatic conditions are indeed suitable, there is still considerable uncertainty regarding the risk of spreading pathogens and parasites and regarding the impacts on native biodiversity, in particular for *V. mandariania*.

7 Conclusions (with answers to the Terms of Reference)

Our assessment of *Vespa velutina* (the Asian hornet) and *V. mandarinia* (the Asian giant hornet) as potential invasive species in Norway (using the modified GB-NNRA protocol for risk assessment) concludes that they represent a moderate and low risk to biodiversity, respectively (see Appendix III and IV). According to this assessment the main impacts of either species would be on apiculture and native Hymenoptera through predation. The risk assessments come with medium confidence for *V. velutina*; this species has been an invasive alien species for long enough that considerable research has accumulated on its biology and ecology in newly colonized ecosystems in Europe and Asia (mainly, South Korea). The risk assessments come with low confidence for *V. mandarinia* since it has only recently colonized a new continent (North America), and little is known about how it behaves as an invasive species.

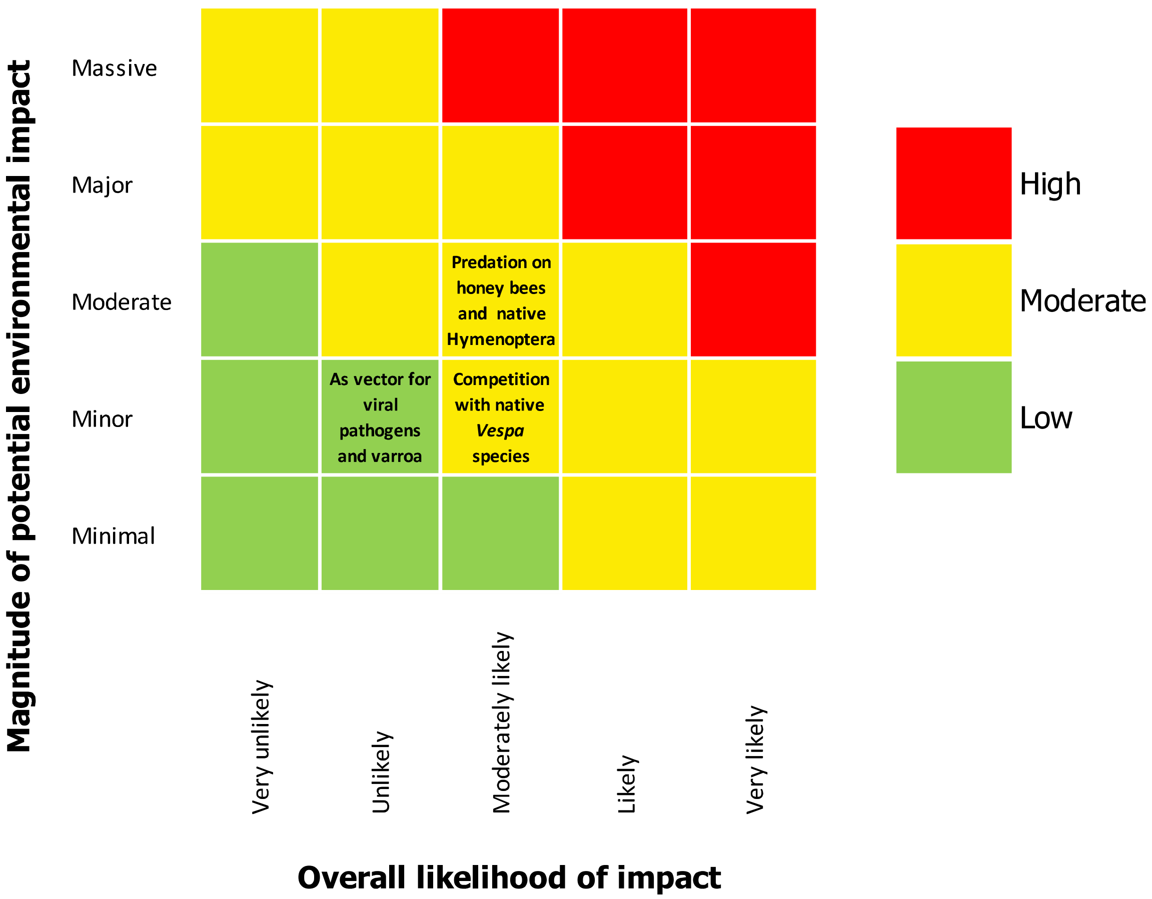

Figure 7-1: Summarized risks for *V. velutina* in a 10-year perspective. The likelihood is expected to increase over time and especially if the species should establish and spread in Sweden.

Compared to the negative impacts on honey bees, impacts of invasive *V. velutina* and *V. mandarinia* on native biodiversity is expected to be less severe, yet the risk is characterized as moderate in both instances. Predation on native insects appears to be the main negative impact, but more empirical studies are needed to understand the impacts of potential exploitative and interference competition between the invasive and native *Vespa* species, other Vespinae wasps and native arthropods in general. See figures 7-1 and 7-2 for risk summary matrices for the two species.

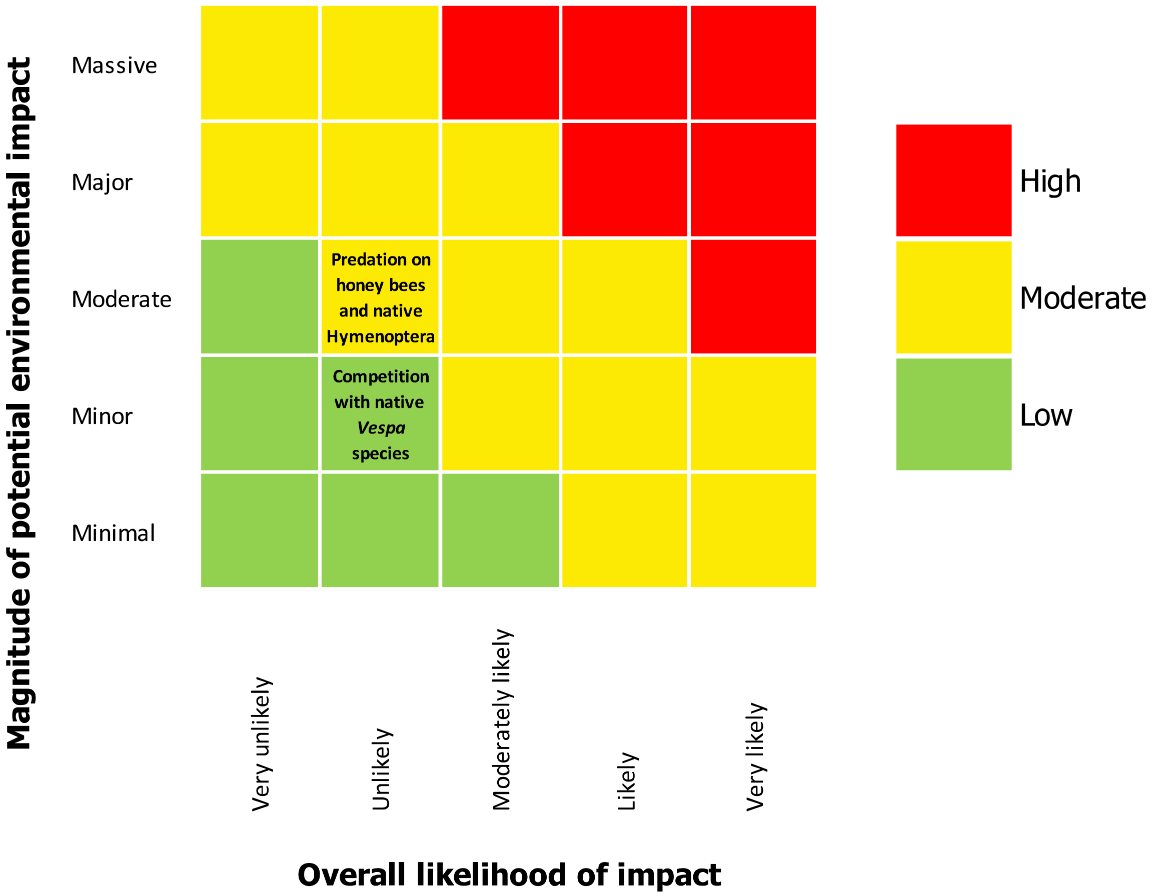

Figure 7-2: Summarized risks for *V. mandarinia* in a 10-year perspective. The likelihood is expected to increase over time and especially if the species should establish and spread in Europe. Assessments of potential impacts of viral pathogens and varroa mites were not carried out for *V. mandarinia* due to lack of data.

Here, we address the Terms of Reference point-by-point.

1) *Vespa velutina* (the Asian hornet) has established and spread in Europe and is now established in Germany, France, Belgium, the Netherlands, Spain, Italy, and Portugal. A limited number of individuals have also been found in the UK, and a single 'alive but dying'

female was discovered in Ireland in April 2021. The species was first sighted in France in 2004 and is still spreading in Europe.

Vespa mandarina (the Asian giant hornet) has never been recorded in Europe. Outside its native range, it has only been collected in a small region of northwestern North America, where it was first collected in 2019.

2) Mated queens of both *V. velutina* and *V. mandarinia* can survive long distance travels during winter hibernation, for example, should they fly into containers or cargo ships. The entry of *V. velutina* to Europe and *V. mandarinia* to northwestern USA and southwestern Canada is believed to have occurred with the help of cargo. Since *V. velutina* is already established in Europe the **likelihood of import** is considerably higher for this species than for *V. mandarinia*, as it could enter the country by cargo, motor vehicles, trains, or passenger ferries, or even spread to Norway by flights or carried by winds. VKM assesses it to be "Moderately likely" with "Medium" confidence, that *V. velutina,* and "Very unlikely" with "Medium" confidence that *V. mandarinia* will enter Norway, considering that neither of them is currently established in an adjacent country. The likelihood will increase over time, especially if the species spread to countries closer to Norway. Should one of these species enter Norway, we find it "Moderately likely" that *V. velutina* and "Likely" that *V. mandarinia* would **establish** viable populations, based on habitat use, climate tolerances and current distributions of each species. The likelihood for *V. velutina* comes with "Medium" confidence, since available distribution models, including our own, show contrasting results with respect to the potential climate suitability of Norway. The likelihood for *V. mandarinia* comes with "Low" confidence since it has never been recorded in Europe and very limited information on its establishment beyond its native range is available. If the two species are able to enter Norway, we find it "Likely", with "Medium" confidence, that they will be able to **establish** and **spread** further. Based on climate suitability and ecological requirements, VKM concludes that *V. velutina* would be able to spread within southeastern and western coastal Norway, and the more cold-tolerant *V. mandarinia* would be able to spread in forested coastal areas from Sweden to north of Trondheim, as well as in some inland forested areas.

3a) If the two species are able to establish and spread in Norway, they could have **negative effects on honey bees** directly through predation and spread of diseases (including the varroa mite). They could also have indirect effects on honey bees through causing behavioural changes, reducing foraging, colony health, honey production and pollination services.

3b) With respect to **negative impacts on biological diversity** in Norwegian nature, the two species consume large numbers of insects. Both species are generalists, foraging on a wide array of prey but mainly on what is readily available. Pollinators change their behaviour when *V. velutina* is present, consequently providing poorer pollination services to crops and wild plant communities. Both species have a large dietary overlap with native *V. crabro* and some other wasp species, however the degree and effect of such competition is poorly understood.

4a) If *V. velutina* or *V. mandarinia* are able to establish and spread in Norway, VKM assesses the risk for negative effects on honey bees, through predation, behavioural changes and spread of diseases and parasites, to be "Moderate" and "Very likely". However, since we assess it to be "Moderately likely" and "Very unlikely" that *V. velutina* and *V. mandarinia*, respectively, will enter Norway within the next 10 years, we expect the risk posed to honey bees in Norway from predation by either *V. velutina* or *V. mandarinia* to be "Moderate", although less likely for *V. mandarinia*. This assessment is made with "Medium" confidence. We assess the risk from spreading of viral pathogens and parasites (varroa mites) as "Low".

4b) The two species of Asian hornets can have a negative impact on biodiversity in Norway either through predation or competition. In terms of predation, VKM concludes that both species can have a "Moderate" impact on biodiversity, and although this is more likely for *V. velutina* than *V. mandarinia*, both species pose a "Moderate" risk. Regarding competition, VKM concludes that the potential impact on native hornets from competition with either *V. velutina* or *V. mandarinia* is "Minor". As this impact is more likely for *V. velutina* than *V. mandarinia* the risk posed to native arthropods from predation is considered to be "Moderate" for *V. velutina* and "Low" for *V. mandarinia*. Both these assessments are made with "Medium" confidence.

It has also been hypothesised that the two species might affect pollinator behaviour, consequently reducing pollination services to crops and wild plant communities. However, although invasive hornets could potentially kill large numbers of native pollinators and infer changes in pollinator behaviour, which could reduce pollination services, the ecological impacts on pollination remain poorly understood.

5a) To prevent introduction, establishment and spread of *V. velutina* and *V. mandarinia*, we highlight the importance of surveillance, early detection, and rapid response systems. It is important to follow the spread of the species in Europe, especially if either species enters Sweden. Increasing public awareness to avoid unintentional import and spread and developing and disseminating tools for correct identification of the species are also important. Eradicating nests is likely the only strategy that can limit the spread of invasive hornets once they have established colonies. Finding and destroying nests can be accomplished with a range of methods (see section 5.2.3). Trapping workers is much less effective than locating nests and would pose threats to native arthropods due to the large bycatch. Poisonous baits can have an effect on colony size but could also affect native arthropods and predators of hornets (e.g., birds). Biotechnology methods have been proposed for limiting the spread of hornets beyond their native range, but no methods are currently available.

5b) If either of the two species is able to establish and spread in Norway, detection and eradication of nests will be central to limiting further spread and to minimizing negative impacts on honey bees and native biodiversity. To minimize the impact on honey bees, it is important to have strong and healthy colonies that are able to defend themselves; there might also be a need for new beehive designs that incorporate ways to prevent hornets from entering.

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Appendix I

Modifications made to the GB-NNRA protocol for risk assessment of Asian *Vespa* species.

The unaltered version of the EU NON-NATIVE SPECIES RISK ANALYSIS – RISK ASSESSMENT TEMPLATE V1.0 (27-04-15) can be found here:
http://www.nonnativespecies.org/index.cfm?pageid=143

Specific changes made to the original version of the GB-NNRA questionnaire:

EU chappeau: Removed entirely as our focal area is solely Norway.

Section A: Removed entirely; we used the Aquatic Species Invasiveness Screening Kit (AS-ISK) for this purpose

Section B: Several aspects are deleted, others are subject to minor alterations, and some are merged to better fit the purpose. In all instances "Europe" is changed to "Norway". We have removed all questions related to economic impact as these are not relevant in the context of negative impact on biodiversity. For the sections "Probability of spread" and "Probability of impact" the questions have been rephrased in an attempt to improve the language and to increase precision, and to make them better suited for this particular type of risk assessment. The scale of responses here is also changed and now follows the scale used in most of the questions under "Likelihood of entry" and "Likelihood of establishment". The scale of "Uncertainty" is changed to "Confidence" and reduced to three levels: "low", "medium" and "high" as the information available on the species we assessed is too course to allow for a finer scale of uncertainty. See list of detailed alterations below.

Likelihood of establishment

1.12. As is (now numbered 2.1).

1.13. As is (now numbered 2.2).

1.14. As is (now numbered 2.3).

1.15. As is (now numbered 2.4).

1.16. Removed, none of the species assessed require particular host organisms.

1.17, 1.18, 1.19, 1.21. Merged (now numbered 2.5).

1.20. Removed.

1.22. 1.23 Merged (now numbered 2.6).

1.24. Removed.

1.25. As is (now numbered 2.7)

1.26. As is (now numbered 2.8).

1.27. Removed.

1.28. As is (now numbered 2.9).

Likelihood of spread

2.1. As is (now numbered 3.1).

2.2. As is (now numbered 3.2).

2.3. Re-phrased (now numbered 3.3).

2.4. As is (now numbered 3.4).

2.5. Removed. None of the species assessed have established in Norway.

2.6. Removed. None of the species assessed have established in Norway.

2.7. Removed. None of the species assessed have established in Norway.

2.8. Removed. None of the species assessed have established in Norway.

2.9. As is (now numbered 3.5).

Magnitude of impact

2.10. Deleted. Not possible to assess economic impact based on the limited information available.

2.11. Removed. Not possible to assess economic impact based on the limited information available.

2.12. Removed. Not possible to assess economic impact based on the limited information available.

2.13. Removed. Not possible to assess economic impact based on the limited information available.

2.14. Removed. Not possible to assess economic impact based on the limited information available.

2.15. Rephrased (now numbered 4.1).

2.16. Removed. None of the species has established in Norway.

2.17. Removed. None of the species have established in Norway.

2.18. Removed. None of the species have established in Norway.

2.19. Removed. None of the species have established in Norway.

2.20. Removed. None of the species have established in Norway.

2.21. Removed. None of the species have established in Norway.

2.22. Rephrased (here numbered 4.2).

2.23. Removed. Potential impact on human health is covered in the risk analyses under question number 4.3.

2.24. Removed.

2.25. Rephrased (now numbered 4.3).
2.26. As is (here numbered 4.4).
2.27. Rephrased (now numbered 4.5)

Additional number 4.6 with summary of impact: Estimate the expected ecological impacts of the organism if it can establish and spread in Norway (despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present).

Additional questions – climate change

3.1 As is (now numbered 5.1).
3.2 Removed.

3.3 As is but added a list of aspects to be assessed is added, namely: establishment, spread, impact on biodiversity, and impact on ecosystem functions (now numbered 5.2).

Additional questions – Research

Removed.

Appendix II

Litterature seach schemes

TITTEL PÅ SØKET **Vespa velutina og V. mandarinia**

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Kommentar:	Fra 2015-
Dublettsjekk i EndNote:	Før dublettkontroll: 214 Etter dublettkontroll: 185

Database: **Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions(R) <1946 to November 19, 2020>**

Dato: 23.08.2021

Antall treff: 102

1	Wasps/	6034
2	("Vespa velutina" or "Vespa mandarina" or "Murder hornet?" or "Japanese giant hornet?" or "Asian giant hornet?" or "Yellow legged hornet?" or "Asian predatory wasp?" or "Asian black hornet?" or "Vespa").tw,kf.	554

3	1 or 2	6341
4	Bees/	14038
5	Beekeeping/	344
6	(Honeybee? or "Honey bee?" or "Solitary bee?" or Apis mellifera or Hymenoptera? or Vespi#ae or "European hornet?" or "Vespa crabro" or beekeeping or apiculture).tw,kf.	21368
7	5 or 6	21408
8	Biodiversity/ or Ecology/ or Ecosystem/	140014
9	Introduced Species/	6135
10	Temperature/	250408
11	Thermotolerance/	1036
12	Behaviour, Animal/	110415
13	(ecolog* or impact population or climat* or invasi* or distribut* or rang? or thermotolerant* or thermo tolerant* or physiolog* or biodiversity or "foraging activit*" or interception?).tw,kf.	4031623
14	((anti-predatory or antipredatory) adj1 behavio?r).tw,kf.	80
15	((thermal or heat) adj1 (adapti* or tolera*)).tw,kf.	4329

16	or/8-15	4369549
17	Risk Assessment/	286623
18	((risk or threat) adj3 (measur* or assessment? or effect? or analys* or score? or management or factor?)).tw,kf.	832441
19	(establishment or spread* or provenance or diversity or survival probabilit*).tw,kf.	617238
20	17 or 18 or 19	1634825
21	3 and 7 and 16 and 20	177
22	limit 21 to yr="2015 -Current"	102

Database: **Web of Science Core Collection: Science Citation Index Expanded (SCI-EXPANDED) --1987-present, Social Sciences Citation Index (SSCI) --1987-present, Arts & Humanities Citation Index (A&HCI) --1987-present, Emerging Sources Citation Index (ESCI) --2015-present**

Dato: 23.08.2021

Antall treff: 71

1	TS=(("Vespa velutina" or "Vespa mandarina" or "Murder hornet$" or "Japanese giant hornet$" or "Asian giant hornet$" or "Yellow legged hornet$" or "Asian predatory wasp$" or "Asian black hornet$" or "Vespa"))	944

2	TS= (("Honeybee$" or "Honey bee$" or "Solitary bee$" or "Apis mellifera" or "Hymenoptera$" or "Vespidae" or "Vespinae" or "European hornet$" or "Vespa crabro" or "beekeeping" or "apiculture"))	75,487
3	TS=(("ecolog*" or "impact population" or" climat*" or "invasi*" or "distribut*" or "rang$" or "thermotolerant*" or "thermo tolerant*" or "physiolog*" or "biodiversity" or "foraging activit*" or "interception$"))	7,627,961
4	TS=((("anti-predatory" or "antipredatory") NEAR/0 ("behaviour" or "behaviour")))	354
5	TS=((("thermal" or "heat") NEAR/0 ("adapti*" or "tolera*")))	10,280
6	(#3 or #4 or #5)	7,632,046
7	TS=(("risk" or "threat") NEAR/2 ("measur*" or "assessment$" or "effect$" or "analys*" or "score$" or "management" or "factor$"))	1,160,553
8	TS=(("establishment" or "spread*" or "provenance" or "diversity" or "survival probabilit*"))	1,245,579
9	#7 OR #8	2,408,968
10	#1 AND #2 AND #6 AND #9	82
11	#1 AND #2 AND #6 AND #9 and 2015 or 2016 or 2017 or 2018 or 2019 or 2020 or 2021 (Publication Years)	73

Database: **CABI (Crop Protection Compendium)**

Dato: 01.07.2021

Antall treff: 39 (pga grensenitet søkestrengen ble forenklet)

("Vespa velutina" OR "Vespa mandarina" OR "Murder hornet" OR "Murder hornets" OR "Japanese giant hornet" OR "Japanese giant hornets" OR "Asian giant hornet" OR "Asian giant hornets" OR "Yellow legged hornet" OR "Yellow legged hornets" OR "Asian predatory wasp" OR "Asian predatory wasps" OR "Asian black hornet" OR "Asian black hornets")

Appendix III

Modified GB-NNRA scheme for *Vespa velutina*

LIKELIHOOD OF ENTRY			
Important instructions: • Entry is the introduction of an organism into Norway. Not to be confused with spread, the movement of an organism within Norway. • In the context of this report, only entry through the crustacean aquarium trade is considered. Furthermore, this risk assessment should only be used for consideration of crustacean species that are regarded possible carriers. • For organisms that are already present in Norway, only complete the section for current active pathways of entry or, if relevant, potential future pathways. The entry section need not be completed for organisms that have entered previously and have no current pathways of entry.			
Question	**Response**	**Confidence**	**Comments**
1.1. How many active pathways are relevant to the potential entry of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	very few (1-3)	High	

1.2. List relevant pathways through which the organism could enter. Where possible give details about the specific origins and end points of the pathways. For each pathway, answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary).	Cargo (ship, truck, plane) or on private vehicles Dispersal/wind from Central Europe	High	

PATHWAY NAME: Cargo			
Question	**Response**	**Confidence**	**Comments**
1.3. Is entry along this pathway intentional (e.g., the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?	Accidental	High	
1.4. How likely is it that the organism will travel along this pathway from the point(s) of origin, multiple times (>10) over the course of one year?.	Very unlikely	Medium	Depends on the population density in the origin and the amount of cargo shipped.
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: Under comment, consider whether the organism could multiply along the pathway.	Moderately likely	Medium	Hibernating queens may survive a month or more hidden. Survival rate is unknown, but natural life cycle is hidden and hibernation from late fall to spring, thus, 4-6 months.
1.6. How likely is the organism to survive existing management practices during passage along the pathway?	Moderately likely	Low	Many goods can host hibernating queens. No existing management practice for this species?

1.7. How likely is the organism to enter Norway undetected?	Very likely	High	Hibernating queens are difficult to detect
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	Very likely	High	Passive transport occurs most likely during hibernation.
1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat?	Likely	Medium	Quite generalized nesting preferences and habitat use.
1.10. Summarized likelihood of the organism entering a suitable habitat in Norway through this pathway	Moderately likely	Medium	

PATHWAY NAME: Self dispersal			
Question	**Response**	**Confidence**	**Comments**
1.3. Is entry along this pathway intentional (e.g., the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?	Accidental	High	
1.4. How likely is it that the organism will travel along this pathway from the point(s) of origin, multiple times (>10) over the course of one year?	Very unlikely	High	Not present in any of the neighbouring countries
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: Under comment, consider whether the organism could multiply along the pathway.	Very unlikely	High	Self dispersal distance is estimated to be around 80km/year (REF). Can only reach Norway through Denmark and most probably further through Sweden. Need to multiply along the pathway.

1.6. How likely is the organism to survive existing management practices during passage along the pathway?	Likely	Medium	No management practices as of today, but will probably be subject to eradication-efforts if detected along the pathway (in Denmark or Sweden).
1.7. How likely is the organism to enter Norway undetected?	Very likely	High	
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	Very likely	High	Active transport while dispersing in spring.
1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat?	Very likely	High	Quite generalized nesting preferences and habitat use.
1.10. Summarized likelihood of the organism entering a suitable habitat in Norway through this pathway	Very unlikely	High	As long as it is not present in any of the neighbouring countries.

LIKELIHOOD OF ESTABLISHMENT			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
2.1. How likely is it that the organism will be able to establish in Norway, based on the similarity between climatic conditions in Norway and the organism's current distribution?	Unlikely	Low	Based on our own models and observations elsewhere in Europe. Low confidence based on discrepancy in the available data on current distribution. *V. velutina* has spread to South Korea, which has more similar climate conditions (very variable), but uncertain which genetic strain/morph this.
2.2. How likely is it that the organism will be able to establish in Norway, based on the similarity between	Very likely	High	No specific abiotic differences.

other abiotic conditions in Norway and the organism's current distribution?			
2.3. How likely is it that the organism will become established in protected conditions (in which the environment is artificially maintained, such as wildlife parks, glasshouses, aquaculture facilities, aquaria, zoological gardens) in Norway? Sub-note: gardens are not considered protected conditions	Very likely	Medium	Will probably be able to establish temporarily ion greenhouses, but can readily be eradicated upon detection.
2.4. How widespread are habitats or species necessary for the survival, development, and multiplication of the organism in Norway?	Moderately widespread (for Norway in total)	Medium	Exempt climatic conditions, the habitat (forest and rural areas) are widespread in some areas in Norway, specifically in the southern regions.
2.5. How likely is it that establishment will occur despite management practices (including eradication campaigns), competition from existing species or predators, parasites or pathogens in Norway?	Unlikely	Medium	Eradication campaigns in Western USA, Canada and France seems to work to a certain extent. Competition with native wasps seems not to be a problem but degree of pathogen spill over is unclear
2.6. How likely are the biological characteristics (including adaptability and capacity of spread) of the organism to facilitate its establishment in Norway?	Very likely	High	Its generalist lifestyle will enable it to utilize multiple sources of prey and other food items. Its use of nesting sites is also flexible.
2.7. How likely is it that the organism could establish in Norway despite low genetic diversity in the founder population?	Very likely	High	The species has established elsewhere, most likely from only a limited number of founders
2.8. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in Norway? (If possible, specify the instances in the comments box.)	Moderately likely	Low	The species has established several times elsewhere, with more or less similar climatic conditions as found in certain parts of Norway (*e.g.* Hamburg, Germany, South Korea, and UK)
2.9. Estimate the overall likelihood of establishment in Norway (mention any key issues in the comments box).	Moderately likely	Low	

LIKELIHOOD OF SPREAD			
Important notes: • Spread is defined as the expansion of the geographical distribution of an alien species within an area.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
3.1. How likely is it that this organism will spread widely in Norway by *natural means*? (Please list and comment on the mechanisms for natural spread.)	Likely	High	Based on studies of the spread in France, the species seems to be able to spread easily if the climate conditions are suitable and it is able to establish. Urban areas and forests are suitable habitat (if climate conditions are met)
3.2. How likely is it that this organism will spread widely in Norway by *human assistance*? (Please list and comment on the mechanisms for human-assisted spread.)	Moderately likely	Low	Model studies suggest the species might do long distance spread by human assistance but assume that the likelihood is correlated with human population densities, again correlated with amounts of transported goods. Since Norway's population is scattered the probability of spread is most likely among the larger cities in the south (Robinet et al. 2019).
3.3. How likely is it that spread of the organism within Norway can be completely contained?	Very unlikely	Medium	Norwegian climate will most likely be at the edge of the species tolerance limits. However, eradication efforts in other countries have shown that this species is very difficult to completely eradicate if established, as it only takes one surviving queen to make a new colony.
3.4. Based on the answers to questions on the potential for establishment and spread in Norway, define the area endangered by the organism.	Southeast and West coast	Medium	Based on climate suitability modelling.
3.5. Estimate the overall potential for future spread for this organism in Norway (using the comments box to indicate any key issues).	Likely	Medium	

MAGNITUDE OF ENVIRONMENTAL IMPACT			
Important instructions: • When assessing potential future environmental impacts, climate change should not be taken into account. This is done in later questions at the end of the assessment. • Each section starts with the impact elsewhere in the world, then considers impacts in Norway separating known impacts to date (*i.e.*, past and current impacts) from potential future impacts.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
4.1. How much environmental harm is caused by the organism within its existing geographic range, excluding Norway?	Minor to Moderate	Medium	Based on studies from Asia and Europe showing competition with native species. Minor in regard to impact on biodiversity and moderate impact on honey bees.
4.2. How much impact would there be if genetic traits of the organism were to be transmitted to other species, modifying their genetic makeup and making their environmental effects more serious?	Minimal	High	Not known to hybridize.
4.3. How much impact do other factors (which are not covered by previous questions) have? (Specify these other factors in the comments box)	Moderate	High	Primary concern is the predation on European honey bees
4.4. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in Norway?	Moderate	Medium	May compete with *V. crabro* and may prey on honey bees, but most likely with minor to moderate effects. Effects on other insect populations unclear. I expect limited nest sizes (number of individuals) due to climate limitations in Norway.
4.5. Indicate any parts of Norway where environmental impacts are	Southeastern and west coast – see map	Medium	

particularly likely to occur (provide as much detail as possible).			
4.6. Estimate the expected ecological impacts of the organism if it is able to establish and spread in Norway (despite any natural control by other organisms, such as predators, parasites, or pathogens that may already be present).	Moderate	Medium	Harassment of people, feeding on honey bees and wild insects are the main impacts. Negative effects on pollinating insects in particular. Possibly Moderate effects on honey bee apiaries

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
6.1. What aspects of climate change (up to the year 2100), if any, are most likely to affect this risk assessment?	Temperature and precipitation	High	The species is climate limited at northern latitudes and a warmer and wetter climate will favour its likelihood for establishment and spread.
6.2. What aspects of the risk assessment are most likely to change as a result of climate change? • Establishment • Spread • Impact on biodiversity • Impact on ecosystem services and functions	Establishment and spread	High	May become locally abundant if local conditions become favourable (See above).

RISK SUMMARIES for *V. velutina*			
	RESPONSE	**CONFIDENCE**	**COMMENTS**
Summarise Entry	Unlikely (0-10 years perspective) Moderately likely (10–30 years?)	Medium	Human mediated entry is unlikely, and the natural spread of the species is unlikely to bring it to Norway in several years
Summarise Establishment	Moderately likely	Medium	If able to enter Norway some areas in the southeast and west seems suitable for the species establishment and survival

Summarise Spread	Moderately likely	Medium	It can spread by own means along the coast and potentially with cargo over the mountains
Summarise impact from pathogens/ parasites	Minor	Medium	The species can host pathogens that might spill over to native Hymenoptera. The effect seems to be strongest for *V. crabro* and other hornets, but there is potential for interspecific infections also to other social species (honey bees and bumble bees)
Summarise Ecological Impact	Moderate	Medium	The species can compete with native wasp species (three genera) and consumes other native insect species.
Conclusion of the risk assessment	Moderate risk	Medium	

Appendix IV

Modified GB-NNRA scheme for *Vespa mandarinia*

LIKELIHOOD OF ENTRY			
Important instructions: • Entry is the introduction of an organism into Norway. Not to be confused with spread, the movement of an organism within Norway. • In the context of this report, only entry through the crustacean aquarium trade is considered. Furthermore, this risk assessment should only be used for consideration of crustacean species that are regarded possible carriers. • For organisms that are already present in Norway, only complete the section for current active pathways of entry or, if relevant, potential future pathways. The entry section need not be completed for organisms that have entered previously and have no current pathways of entry.			
Question	**Response**	**Confidence**	**Comments**
1.1. How many active pathways are relevant to the potential entry of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	very few (1-3)	High	
1.2. List relevant pathways through which the organism could enter. Where possible give details about the specific origins and end points of the pathways. For each pathway, answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary).	Cargo (ship, truck, plane) Dispersal (need to enter Europe first)	High	

PATHWAY NAME: Cargo			
Question	**Response**	**Confidence**	**Comments**
1.3. Is entry along this pathway intentional (e.g., the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?	Accidental	High	
1.4. How likely is it that the organism will travel along this pathway from the point(s) of origin, multiple times (>10) over the course of one year? Subnote: Under comment, discuss how likely the organism is to get onto the pathway in the first place.	Very unlikely	Medium	Depends on the population density in the origin and the amount of cargo shipped
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: Under comment, consider whether the organism could multiply along the pathway.	Moderately likely	Medium	Hibernating queens may survive a month or more hidden. Survival rate is unknown, but natural life cycle is hidden and hibernation from late fall to spring, thus, 4-6 months.
1.6. How likely is the organism to survive existing management practices during passage along the pathway?	Moderately likely	Low	Many goods can host hibernating queens. No existing management practice for this species?
1.7. How likely is the organism to enter Norway undetected?	Very likely	High	Hibernating queens are difficult to detect
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	Very likely	High	Passive transport occurs most likely during hibernation.

1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat?	Likely	Medium	Quite generalized nesting preferences and habitat use.
1.10. Summarized likelihood of the organism entering a suitable habitat in Norway through this pathway	Unlikely	Medium	

PATHWAY NAME: Self dispersal			
Question	**Response**	**Confidence**	**Comments**
1.3. Is entry along this pathway intentional (e.g., the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?	Accidental	High	
1.4. How likely is it that the organism will travel along this pathway from the point(s) of origin, multiple times (>10) over the course of one year? Subnote: Under comment, discuss how likely the organism is to get onto the pathway in the first place.	Very unlikely	High	Not present in Europe
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: Under comment, consider whether the organism could multiply along the pathway.	Very unlikely	High	Self dispersal distance is estimated to be around 80km/year (REF). Can only reach Norway through Denmark and most probably further through Sweden. Need to multiply along the pathway.

1.6. How likely is the organism to survive existing management practices during passage along the pathway?	Likely	Medium	No management practices as of today, but will probably be subject to eradication-efforts if detected along the pathway (in Denmark or Sweden).
1.7. How likely is the organism to enter Norway undetected?	Very likely	High	
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	Very likely	High	Active transport while dispersing in spring.
1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat?	Very likely	High	Quite generalized nesting preferences and habitat use.
1.10. Summarized likelihood of the organism entering a suitable habitat in Norway through this pathway	Very unlikely	High	As long as it is not present Europe

LIKELIHOOD OF ESTABLISHMENT			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
2.1. How likely is it that the organism will be able to establish in Norway, based on the similarity between climatic conditions in Norway and the organism's current distribution?	Likely	Medium	Based on the modelling of habitat suitability model in Zhu et al., 2020.
2.2. How likely is it that the organism will be able to establish in Norway, based on the similarity between other abiotic conditions in Norway and the organism's current distribution?	Very likely	High	No specific abiotic differences.
2.3. How likely is it that the organism will become established in protected conditions (in which the environment is artificially	Very likely	Medium	Will probably be able to establish temporarily in greenhouses, but can readily be eradicated upon detection.

maintained, such as wildlife parks, glasshouses, aquaculture facilities, aquaria, zoological gardens) in Norway? Sub-note: gardens are not considered protected conditions			
2.4. How widespread are habitats or species necessary for the survival, development, and multiplication of the organism in Norway?	Moderately widespread (for Norway in total).	Medium	Exempt climatic conditions, the habitat (forest and rural areas) are widespread in some areas in Norway, specifically in the southern regions.
2.5. How likely is it that establishment will occur despite management practices (including eradication campaigns), competition from existing species or predators, parasites or pathogens in Norway?	Moderately likely	Low	Given that it enters Norway. Eradication campaigns in Western USA and Canada seems to work to a certain extent. Competition with native wasps seems not to be a problem but degree of pathogen spill over is unclear
2.6. How likely are the biological characteristics (including adaptability and capacity of spread) of the organism to facilitate its establishment in Norway?	Very likely	High	Its generalist lifestyle will enable it to utilize multiple sources of prey and other food items. Its use of nesting sites is also flexible.
2.7. How likely is it that the organism could establish in Norway despite low genetic diversity in the founder population?	Very likely	High	The species has established elsewhere, most likely from only a limited number of founders
2.8. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in Norway? (If possible, specify the instances in the comments box.)	Likely	Low	The species has established in US and Canada, with more or less similar climatic conditions as found in certain parts of Norway.
2.9. Estimate the overall likelihood of establishment in Norway (mention any key issues in the comments box).	Likely	Low	Primarily low likelihood due to the very unlikely event that it should enter Norway in the first place.

LIKELIHOOD OF SPREAD
Important notes: • Spread is defined as the expansion of the geographical distribution of an alien species within an area.

QUESTION	RESPONSE	CONFIDENCE	COMMENTS
3.1. How likely is it that this organism will spread widely in Norway by *natural means*? (Please list and comment on the mechanisms for natural spread.)	Likely	High	*V. mandarinia* has been less successful at spreading (in US and Canada) than *V. velutina* in Europe, but this is presumably due to the early detection and massive eradication efforts in the US/Canada rather than less effective natural means of spreading.
3.2. How likely is it that this organism will spread widely in Norway by *human assistance*? (Please list and comment on the mechanisms for human-assisted spread.)	Moderately likely	Low	Model studies suggest the species might do long distance spread by human assistance but assume that the likelihood is correlated with human population densities, again correlated with amounts of transported goods. Since Norway's population is scattered the probability of spread is most likely among the larger cities in the south, as predicted for *V. velutina.*
3.3. How likely is it that spread of the organism within Norway can be completely contained?	Very unlikely	Medium	*V. mandarinia* has only been in US/Canada for about three years, so experience is very limited, but the eradication efforts there has shown that this species is very difficult to completely eradicate if established, as it only takes one surviving queen to make a new colony.
3.4. Based on the answers to questions on the potential for establishment and spread in Norway, define the area endangered by the organism.	Forested coastal areas from Sweden to north of Trondheim, and some inland forested areas.	Low	Based on climate suitability model in Zhu et al., 2020, large parts of Norway appear to be suitable for Norway. However, as there is no data for *V. mandarinia* In Europe, this model has higher uncertainty than the model used for *V. velutina*.
3.5. Estimate the overall potential for future spread for this organism in Norway (using the comments box to indicate any key issues).	Likely	Medium	Should it enter Norway and establish

MAGNITUDE OF ENVIRONMENTAL IMPACT			
Important instructions: • When assessing potential future environmental impacts, climate change should not be taken into account. This is done in later questions at the end of the assessment. • Each section starts with the impact elsewhere in the world, then considers impacts in Norway separating known impacts to date (*i.e.*, past and current impacts) from potential future impacts.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
4.1. How much environmental harm is caused by the organism within its existing geographic range, excluding Norway?	Minor to Moderate	Low	Same as for *V. velutina*, but less data on this species as an invader. Minor in regard to impact on biodiversity and moderate impact on honey bees.
4.2. How much impact would there be if genetic traits of the organism were to be transmitted to other species, modifying their genetic makeup and making their environmental effects more serious?	Minimal	High	Not known to hybridize.
4.3. How much impact do other factors (which are not covered by previous questions) have? (Specify these other factors in the comments box)	Moderate	High	Primary concern is the predation on European honey bees
4.4. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in Norway?	Moderate	Medium	May compete with *V. crabro* and may prey on honey bees, but most likely with minor to moderate effects. Effects on other insect populations unclear. I expect limited nest sizes (number of individuals) due to climate limitations in Norway.
4.5. Indicate any parts of Norway where environmental impacts are particularly likely to occur (provide as much detail as possible).	Forested costal areas from Sweden to north of Trondheim, and some inland	Low	

	forested areas.		
4.6. Estimate the expected ecological impacts of the organism if it is able to establish and spread in Norway (despite any natural control by other organisms, such as predators, parasites, or pathogens that may already be present).	Moderate	Medium	Harassment of people, feeding on honey bees and wild insects are the main impacts. Negative effects on pollinating insects in particular. Probably slightly stronger effect on the native *V. crabro* than *V. velutina* due to its size. Possibly Moderate effects on honey bee apiaries

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENTS**
6.1. What aspects of climate change (up to the year 2100), if any, are most likely to affect this risk assessment?	Temperature and precipitation	Medium	The species is climate limited at northern latitudes and a warmer and wetter climate will favour its likelihood for establishment and spread.
6.2. What aspects of the risk assessment are most likely to change as a result of climate change? • Establishment • Spread • Impact on biodiversity • Impact on ecosystem services and functions	Establishment and spread	Medium	May become locally abundant if local conditions become favourable (See above).

RISK SUMMARIES for *V. mandarinia*			
	RESPONSE	**CONFIDENCE**	**COMMENTS**
Summarise Entry	Very unlikely (0-10 years perspective)	Medium	Human mediated entry is unlikely, and the natural spread of the species is very unlikely

	Unlikely (10–30 years?)		to bring it to Norway in the foreseeable future.
Summarise Establishment	Likely	Low	If able to enter Norway many areas appear to be suitable for the species establishment and survival
Summarise Spread	Likely	Medium	It can spread by own means along the coast and potentially with cargo over the mountains
Summarise Ecological Impact	Minor	Medium	The species can compete with native wasp species (three genera) and consumes other native insect species.
Conclusion of the risk assessment	Low	Low	