United States Department of Agriculture

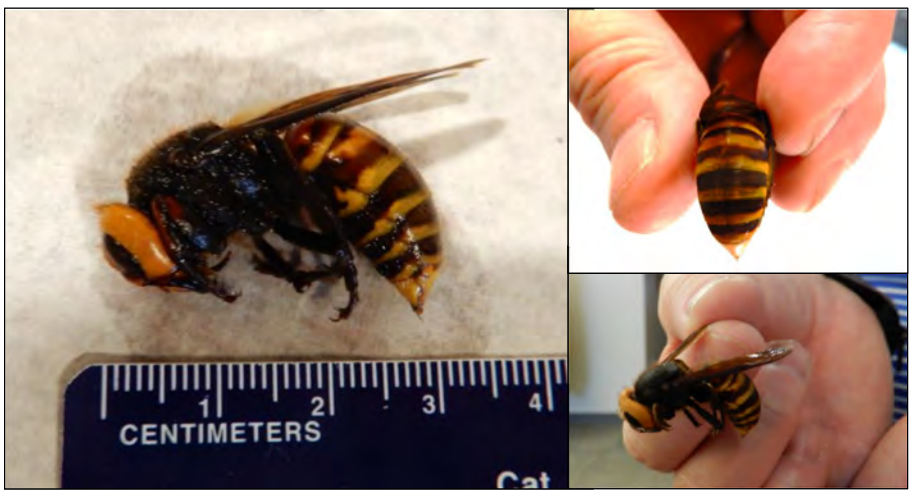
Animal and Plant Health Inspection Service

Plant Protection and Quarantine

New Pest Response Guidelines

Vespa mandarinia

Asian giant hornet



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Chapter 1

Introduction

On 8 December, 2019, a Blaine, Washington resident reported finding a large, dead hornet on his property (McGann, 2019). The Washington State Department of Agriculture (WSDA) identified this specimen as *Vespa mandarinia,* the Asian giant hornet, and the National Identification Services (NIS) confirmed the identification (AGH Response Team, 2020). The Washington detection followed the eradication of a *V. mandarinia* nest in Nanaimo on Vancouver Island, British Columbia, Canada on 18 September, 2019 (Ministry of Agriculture, 2019). These were the first detections of the Asian giant hornet in North America. Beekeepers have reported other observations dating back to October through public outreach campaigns by Washington State and British Columbia.

Vespa mandarinia is a quarantine pest for the United States. Plant Protection and Quarantine (PPQ) prepared these New Pest Response Guidelines (NPRG) to ensure we, at the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS), know the response options following the recent detection of *V. mandarinia* in the United States. The NPRG provides basic information to the response team for use during the first year of detection. The team can consider this information when it produces a site-specific action plan to detect, survey, monitor, control, contain, suppress, or eradicate an infestation of this pest. This NPRG was developed with informational support from the WSDA.

This document includes the following information:

- Summary of relevant pest biology and spread
- Guide to identification or screening for the pest in the field
- Preliminary method for delimiting the species distribution
- Summary of known potential control/management options
- Summary of knowledge gaps

Note: This document is based on the best information available at the time of development; however, new scientific and technical information may be identified after completion. As the pest situation evolves and new information is gathered, the response, including whether the response goals are achievable, may need to be revisited.

Chapter 2

Pest Overview

Pest Summary

Vespa mandarinia Smith (Hymenoptera: Vespidae), the Asian giant hornet, is the world's largest hornet and is a social insect native to Asia. The hornet is a pest of *Apis mellifera* L., the European honey bee, and causes losses to beekeepers in its native range. *Vespa mandarinia* is a social insect, with a large colony containing one queen and many workers.

Survey methods rely on passive traps that target flying adults. Although workers outnumber queens, only queens can disperse, thus control efforts must focus on eliminating queens and nests. The hornet nests underground, and locating nests is challenging and labor intensive.

Key Information

- *Vespa mandarinia* is a large hornet that is primarily a pest of honey bees.
- Population dispersal is restricted to the spread of queens.
- Eradication of this species focuses on eliminating queens. Strategies to achieve this vary depending on the time of season. Queens can be directly trapped and killed in the early spring and late fall. During the summer, nests can be located and destroyed.
- Nests are formed in the ground and are challenging to locate. Methods for locating nests involve labor intensive strategies.
- Some traps and baits for surveying *V. mandarinia* already exist. Other traps and baits have been used for closely related species. We recommend using traps and baits that have been previously successful for trapping *V. mandarinia.* However, we anticipate that resource constraints might dictate the best trap and bait combination.
- Typical protective clothing worn by beekeepers will not prevent *V. mandarinia* sting injuries. The material must be much thicker to protect the wearer from *V. mandarinia* stings.

Pest Information

Scientific Name

- *Vespa mandarinia* Smith, 1852

Taxonomic Position

- Animalia: Arthropoda: Insecta: Hymenoptera: Vespidae

Synonyms

- *Vespa japonica* Rad., 1857
- *Vespa latilineata* Cameron, 1903
- *Vespa magnifica* Smith, 1852
- *Vespa sonani* Matsumura, 1930

Common Names

- Asian giant hornet
- Japanese giant hornet
- Yak-killer hornet
- Suzumebachi (sparrow wasp)

Biology and Ecology

Colony Cycle

Vespa mandarinia are social hornets, with an annual colony cycle. Adult females are divided into two castes: queens that are responsible for starting a colony and laying eggs, and sterile workers that are responsible for gathering food and rearing larvae. A solitary queen will start a nest, then raise a colony of workers that take over foraging and many nest duties. **Figure 2-1** shows a summary of the colony cycle throughout the seasons in Japan (based on Matsuura, 1984, 1988; Matsuura and Sakagami, 1973). Although the specific timing of events might vary, the sequence of steps in the colony cycle would remain the same throughout the hornet's range.

Spring. The queen emerges from overwintering in the spring and enters a brief pre-nesting stage in which she feeds, develops her ovaries, and looks for a suitable nesting site (Matsuura, 1984).

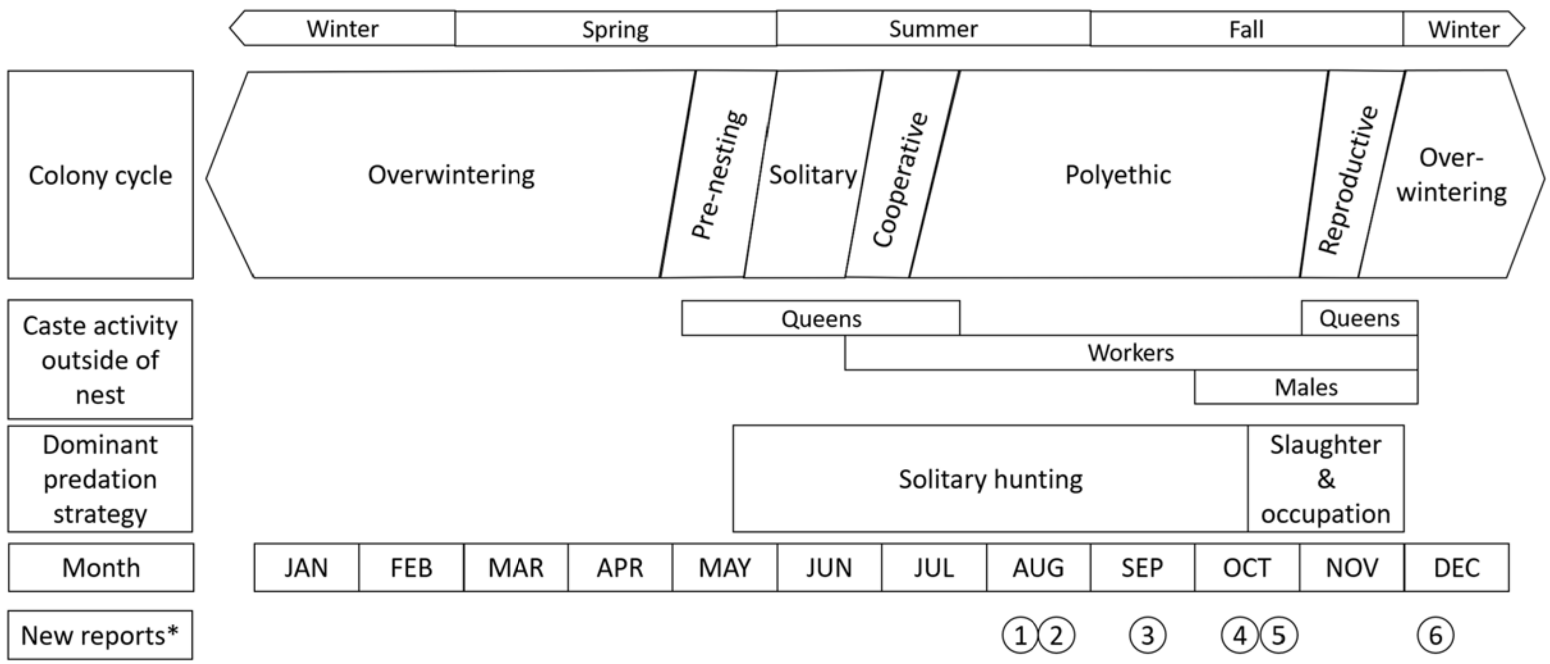

Figure 2-1. Ecological timing of *Vespa mandarinia* showing periods of adult activity outside of the nest by caste and colony cycle throughout the year. Vertical lines in the colony cycle show the first (left-most) and last (right-most) observation dates, with the duration of stages in between. Information based on data collected in Japan and presented by Makoto Matsuura (Matsuura, 1984; Matsuura and Sakagami, 1973). *New reports are based on observations in North America, and numbers refer to Codes in **Table 2-1** (AGH Response Team, 2020).

Summer. Upon selecting a suitable site, the queen enters a solitary phase in which she alone is responsible for building a nest, foraging, laying eggs, and caring for young. There is a brief cooperative phase in which some of her worker offspring have matured and assumed all duties aside from laying eggs, but the queen will still leave the nest to forage for her young. When there are about 40 workers in the nest, the colony enters the polyethic phase in which the queen becomes completely nest-bound and the workers assume all duties outside of the nest (Matsuura and Sakagami, 1973).

Fall. When there are many workers, the colony begins producing reproductives: males and next year's queens (Matsuura and Sakagami, 1973). Workers feed the new reproductives within the nest because reproductives do not forage (Matsuura, 1984). Males develop and leave the nest before females (in Japan, this is early October; **Figure 2-1**) and will perch at the entrance of nests waiting for the emergence of new queens about one month later (Matsuura and Sakagami, 1973). Mating takes place at the nest entrance, often with many males ambushing each new queen as she emerges (Matsuura, 1984). Males will remain alive and mobile for a few weeks after leaving their natal nest, and will feed on nectar from flowers, tree sap, and some mushrooms to maintain their energy (Matsuura, 1984). New queens must mate prior to overwintering, as males will not be present when they emerge the following spring.

Winter. After mating, a new queen will spend the colder months overwintering in a sheltered spot she has excavated in the soil, rotting wood, or piles of straw until the cycle begins again the following spring when new queens emerge from overwintering (Archer, 1995; Matsuura, 1984; Matsuura and Sakagami, 1973). Adult queens live nearly a year, whereas adult workers live for ~15 days (maximum ~35 days) (Archer, 1995). Males and workers will die before the onset of winter (Matsuura, 1984). Developmental time from egg to adult is about 40 days (approximate times for each stage- egg: 6 days, larva: 16 days, pupa: 18 days; Matsuura, 1984). Each egg is placed inside a cell within the comb of the nest, and larvae develop within a cell.

A queen produces an average of 2,712 cells, but this number can vary widely (SD ± 984.7) (Matsuura and Koike, 2002). Queens may reuse each cell two or three times, making estimates of colony production from the number of cells difficult, but each colony can produce a large number of new queens (Matsuura, 1984). One report estimates that the average colony will produce about 212 males and 205 new queens (Archer, 1995). One of the largest nests reported contained 540 active workers, and 4,677 constructed cells, 670 of which were queen cells (Matsuura and Koike, 2002). A *V. mandarinia* nest in Taiwan reached 6,000 cells, but the author gave no further details on this nest (Archer, 1995).

The social organization of the nest breaks down in late fall. Counting cells to predict the number of queens produced by a nest is likely to overestimate nest production. Workers cease foraging and feeding newly emerged adults, which might result in fewer new queens than cell numbers in a nest would predict (Matsuura and Sakagami, 1973). Additionally, males only have a single set of chromosomes. When the original queen is lost from the colony, workers commonly lay unfertilized eggs that will become functional males that can disperse and mate, increasing the reproductive potential of that colony (Matsuura, 1984).

The life history and colony cycle of social hymenopteran insects, such as *V. mandarinia*, can inform response efforts. The colony cycle drives levels of activity and foraging strategies outside of the nest, and therefore, surveys that we tailor to the colony cycle are more likely to be successful. Population levels are low during the pre-nesting, solitary, and cooperative stages and detection of individuals outside of the nest is more difficult during the spring and early summer. Workers are numerous in the late summer and fall when the nest enters the polyethic and reproductive stages (**Figure 2-1**). If North American phenology resembles Japanese records, hornets are easiest to detect in July through November when workers are active (**Figure 2-1**). Although surveys are more likely to detect workers, only mated queens can start nests and establish new populations. This implies that killing queens and eradicating nests before they reach the reproductive stage would more successfully control the hornet than management tactics that merely kill workers.

Nesting

Vespa mandarinia usually nest in pre-existing underground cavities with a narrow opening, such as rodent burrows (**Figure 2-2**; Matsuura and Sakagami, 1973). Queens will spend days to weeks searching for a suitable site during the pre-nesting stage (**Figure 2-1;** Matsuura, 1984). Entrance tunnels can measure up to 60 cm from the exterior opening to the entrance of the nest envelope within the cavity (Matsuura and Sakagami, 1973). The hornets also build nests in hollowed trunks or roots of dead trees, but these are usually no more than one to two meters above the surface of the soil (Matsuura and Koike, 2002; Yamane and Makino, 1977). Aerial nests are rare. Out of 1,756 nests examined in Japan, only three were aboveground nests and these were placed in human-built structures (Matsuura and Koike, 2002). Nests consist of cells, interlocking chambers for larval development, and are constructed from chewed bits of wood fibers harvested from living trees or decaying wood (**Figure 2-2**; Matsuura, 1984; Yamane and Makino, 1977). Subterranean nests can be difficult to locate but as the colony grows, workers will excavate soil to increase the size of the cavity, depositing soil near the nest entrance (Matsuura and Sakagami, 1973). Soil pellets placed near the nest entrance can aid in locating colonies (Lee, 2010).

Once workers are present in large enough numbers, *V. mandarinia* regulate the temperature within the nest, keeping it close to 32°C (Matsuura, 1984). Similar to many other social insects, *V. mandarinia* will fiercely defend their nests from perceived threats (Lee, 2010).

Figure 2-2. *Vespa mandarinia* nesting. A. Nest in a cavity within a soil embankment; **B**. Workers harvesting wood fibers for nest construction. Photo credits: Kim, Hyun-tae (A), Wikimedia Commons; Alpsdake, Wikimedia Commons (B).

Feeding Strategies

Plant Associations

In Japan, queens that have emerged from overwintering habitats visit oak (*Quercus* spp.), such as *Q. acutissima, Q. serrata,* and *Q. glauca* to eat fermenting sap that seeps from wounds (**Table 2-1;** Matsuura, 1984). They fiercely defend feeding areas from other insect competitors, including other *V. mandarinia* queens (Matsuura and Sakagami, 1973). In Japan, fermenting oak sap is available throughout the active season of *V. mandarinia,* but is less common in early spring or late fall (Suetsugu et al., 2019; Yoshimoto and Nishida, 2009). An individual patch of oak sap can last as long as five months (Yoshimoto et al., 2005). Workers will defend occupied patches from all unrelated intruders (Matsuura, 1984). Although oaks are the most commonly used source of sap in Japan, researchers have recorded *V. mandarinia* from sap patches on Satsuma mandarins (*Citrus unshiu*), elms (*Ulmus parvifolia*), and pussywillows (*Salix gracilistyla*) (**Table 2-1;** Matsuura, 1984). Although we provide a list of trees in Japan that produce attractive sap, it is likely that many other tree species in North America could produce equally attractive sap resources.

Vespa mandarinia seldom visit flowers but are occasionally observed feeding on flowers of banana (*Musa* spp.) (Lee, 2010), camellia (*Camellia japonica*), fennel (*Foeniculum vulgare*), and porcelain berry (*Ampelopsis glandulosa* var. *brevipedunculata*) (Matsuura, 1984). In the fall, *V. mandarinia,* particularly males, also consume the fruiting bodies of the fungus *Protubera nipponica* and are attracted to the odors emitted by the fungus that resemble volatiles from fermenting sugars (e.g., isobutyric acid, 3-methylbutyl acetate, and 2-phenylethanol) (Matsuura, 1984; Suetsugu et al., 2019). *Vespa mandarinia* workers also chew ripe or overripe fruits to extract the sugary juice, which can result in crop damage (Matsuura, 1984).

Table 2-1. List of reported sap sources for *Vespa mandarinia* in Japan

Scientific name	Common name	References
Castanopsis cuspidata	Japanese Chinquapin	Matsuura, 1984
Citrus unshiu	Satsuma mandarin	Matsuura, 1984
Quercus acutissima	sawtooth oak	Matsuura, 1984
Quercus glauca	ring-cup oak	Matsuura, 1984
Quercus serrata	ko-nara	Matsuura, 1984
Quercus spp.	oaks	Matsuura, 1984
Salix gracilistyla	rose-gold pussy willow	Matsuura, 1984
Ulmus parvifolia	Chinese elm	Matsuura, 1984

Predation Strategies

Similar to other hornets, *V. mandarinia* is predatory and hunts primarily arthropod prey, such as scarab and longhorn beetles (Matsuura, 1988), mantids (Matsuura, 1984), large caterpillars, and spiders (Matsuura and Sakagami, 1973). After catching its prey, a hornet will decapitate it, chew the more muscular portions of the thorax into a ball, and then fly back to the nest (Matsuura, 1984). Hornets usually hunt alone, but *V. mandarinia* are unusual in that, late in the season, they organize mass attacks against nests of other social Hymenoptera. This is called the slaughter and occupation phase of the colony cycle (**Figure 2-1**; Matsuura and Sakagami, 1973).

Vespa mandarinia specialize in mass attacks on nests of other species of *Vespa*, yellowjackets (*Vespula* spp.), various paper wasps (*Polistes* spp.), and honey bees (*Apis* spp.) (Lee, 2010; Matsuura and Sakagami, 1973). Some prey species recorded in Japan are *A. cerana, A. mellifera, V. analis, V. crabro, V. simillima,* and *Vespula flaviceps* (Ono and Sasaki, 1987). Hornets begin mass attacks when a single foraging worker excretes a recruiting pheromone from her van der Vecht glands on a targeted nest or hive. The pheromone then recruits her nest mates to the targeted colony (Ono et al., 1995). Two to fifty nest mates will participate in the attack (Matsuura, 1984, 1988). Once the targeted colony's defenses are overwhelmed, *V. mandarinia* will occupy the nest and harvest the protein-rich brood for approximately ten days (Ono et al., 1995). This group attack behavior occurs late in the season when nests are large and workers are rearing reproductives (**Figure 2-1**). *Vespa mandarinia* will usually target nests that are within one kilometer of their own nest (Matsuura and Sakagami, 1973).

Apiaries suffer heavy losses when hornets switch to the slaughter and occupy strategies (**Figure 2-1**) and target *A. mellifera* (Matsuura and Sakagami, 1973). During a slaughter event, hornets quickly kill thousands of honey bees, and instead of returning to the nest with balls of meat after each kill, they leave the bee carcasses in place (**Figure 2-3**; Matsuura and Sakagami, 1973). Hornets are efficient bee killers. For example, each hornet killed one bee about every 14 seconds during one recorded slaughter event (Matsuura, 1984). A slaughter event can last from one to six hours, with an average duration of 105.4 minutes (Matsuura, 1984, 1988). After overcoming the honey bee defenses, hornets occupy the hive and harvest the bee brood, staunchly defending their new conquest from other wasps and beekeepers over the next few days to weeks (Matsuura and Sakagami, 1973). The colony cannot recover from these attacks and is lost (Matsuura, 1984). Wild honey bee colonies are also vulnerable to attack, but because wild nests are dispersed in the landscape, the concentrated resources in an apiary are likely more attractive and easier for the hornets to locate (Matsuura, 1988).

Figure 2-3. Decapitated bees from an apiary in Custer, Washington. This damage is characteristic of *V. mandarinia* mass attacks. Photo credit: Teddy McFall, courtesy of WSDA.

Dispersal

Foraging Range and Natural Dispersal

Vespa mandarinia are powerful, large-bodied fliers. While foraging, *V. mandarinia* workers typically fly one to two kilometers from their nest, although they are capable of foraging at a radius of up to eight kilometers (Matsuura and Sakagami, 1973). The height of their flight varies with the distance they are going to travel. Toh and Okamura (2003) recorded *V. mandarinia* at heights of six meters or less when travelling short (90 meter) distances, and at heights of over 25 meters when traveling more than one kilometer. Abe, et al. (1995) reported that *V. mandarinia* can fly at speeds of over 30 kilometers per hour and cover ~100 kilometers in a single day. However, these reports remain unverified.

Data on queen dispersal is unknown in this species, although we expect that *V. mandarinia* queens can fly long distances. A capacity for long distance dispersal would increase the chance that this species could effectively spread by natural means. Queens of *V. velutina*, a slightly smaller hornet, can fly about 30 kilometers in a single day (Beggs et al., 2011).

Pathways

Vespa mandarinia populations can only be established by mated queens. They are exclusively capable of starting a nest and breeding new queens. Unmated queens can only have male offspring, and their nests would quickly fail. Pathways by which *V. mandarinia* could establish or spread must allow for the entry of either 1) one or more mated queens or 2) at least one virgin queen ***and*** one male. Workers cannot establish a population.

Since hornet colonies can only establish from an inseminated queen and queens are unlikely to be present in honey bee hives, live honey bee commodities are not a pathway for the introduction of *V. mandarinia*. Furthermore, queens are not associated with mass attacks on honey bee hives. We found reports of solitary queens hunting bee prey in apiaries, but hornets in the hunting stage do not enter honey bee hives (Matsuura and Sakagami, 1973). Worker hornets are responsible for raiding honey bees, and the slaughter and occupy stages occur late in the season when hornet colonies have large numbers of workers and are rearing the larger-bodied reproductive brood (August through October in Japan, July through December in India and South Korea) (Choi and Kwon, 2015; Matsuura and Sakagami, 1973; Mattu and Sharma, 2017).

Queens mainly overwinter alone in chambers that they excavate in soil, but they have also been found overwintering in rotting logs and straw (Archer, 1995; Matsuura, 1984; Matsuura and Sakagami, 1973). *Vespa* queens do not overwinter in pre-existing cavities and prefer north-facing sites that are dark and remain moist (Matsuura, 1984). Researchers think that international cargo containing pots for bonsai trees was responsible for the introduction of a similar species, *V. velutina*, into France (Arca et al., 2015). The imported pottery was empty and did not contain bonsai trees or soil, but it is unclear if the queen excavated an overwintering cell in packing material or was just associated with the pots themselves. Genetic evidence suggests that a single *V. velutina* queen that had mated multiple times, or a very small number of overwintering queens that had mated singly, started the French population (Arca et al., 2015). This scenario further underscores the introduction risk posed by hornet queens.

Throughout Asia, humans consume *V. mandarinia* as food and traditional medicine. Larvae and pupae are prepared much like seafood and other meats and are both nutritious and culturally valued (**Figure 2-4**; Ho, 2019; Nonaka, 2008; Ying et al., 2008). Nests containing larvae and pupae are excavated and sold in markets in China, Thailand, and elsewhere in Asia (**Figure 2-5**; Nakamura and Sonthichai, 2004; Ying et al., 2008). In Japan, hornet hunters seek wild nests late in the season to harvest the ample larvae and pupae as a seasonal delicacy (Ho, 2019). In 2008, the market price for a *V. mandarinia* nest in Japan was ~$100 per kilogram, and nests can be an important income source for rural villagers (Nonaka, 2008). Live adult hornets are added to liquor (shōchū or awamori), which is then fermented to make an alcoholic beverage (**Figure 2-4B**), or into jars of honey (**Figure 2-4C**) (Baseel, 2019; Ho, 2019; Kotzer, 2017; Tackett, 2013). Both are thought to have medicinal properties from the venom excreted by the hornets as they drown (Baseel, 2019; Ho, 2019; Kotzer, 2017; Tackett, 2013).

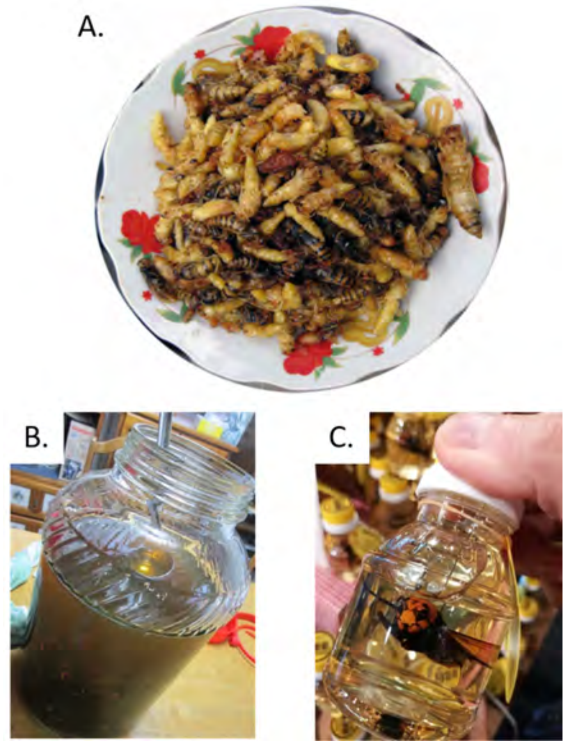

Figure 2-4. Different ways that people consume foods made from *Vespa mandarinia*. A. traditional wasp dish from Yunnan Province, China; **B**. hornet liquor from Japan; **C**. hornet honey from Japan, Photo credits: Ying et al., 2008 (A); Tackett, 2013 (B); @yusai00 courtesy of SoraNews24, Baseel, 2019 (C).

Figure 2-5. Methods used in rural Japan to find and collect *Vespa mandarinia* nests to sell or eat. A. Tagging a worker with a streamer to follow it back to the nest; **B.** Hornet-hunters wear protective gear to excavate nests at night and use smoke to sedate the hornets. Photo credits: Payne, 2016 (A); Nonaka, 2008 (B).

Smuggling is a potential pathway since *V. mandarinia* are not available in the United States and have cultural value as food and as traditional medicine. A package with a *V. mandarinia* nest containing live larvae and pupae was intercepted at a U.S. port of entry (Smith-Pardo, 2020). Foods containing live immature hornets could allow hornets to be introduced; however, products such as liquor and honey containing dead hornets could not. Hornet-hunters usually harvest nests late in the season when workers are rearing reproductives. Thus, it is likely that hornets harvested for consumption would contain high-risk castes. Humans consume larvae and pupae fresh, leaving them alive within the comb of the nest until they are ready to be prepared (Nonaka, 2008). While larvae are likely to perish in the absence of adult hornet caretakers, pupae are likely to remain alive and viable for an extended period. These have the potential to mature into adults and escape to establish a population. Thus, hornet comb containing pupae for consumption is a likely pathway for introduction.

Geographic Distribution

World Distribution

Vespa mandarinia are native to Asia They have records in China, India, Bhutan, Japan, Korea, Laos, Malaysia, Myanmar, Nepal, Russia, Taiwan, and Thailand (**Figure 2-6**; GBIF, 2020; Kumar and Srinivasan, 2010; Nguyen et al., 2006; Rafi et al., 2017; van der Vecht, 1959). The record of *V. mandarinia* from Sri Lanka was based on an error, and the species is not known to be present there (Kumar and Srinivasan, 2010). To our knowledge, *V. mandarinia* is not distributed throughout all of China but is concentrated in the southern portion of the country (van der Vecht, 1959). Similarly, in India, only the northern states have records of *V. mandarinia*, which ranges throughout the Himalayas (Kumar and Srinivasan, 2010). There is a single record of its occurrence in northwestern Vietnam, in Hoa Binh Province (Kumar and Srinivasan, 2010). In Russia, researchers have only collected *V. mandarinia* in the Primor'ye region (Nguyen et al., 2006), and it is unclear how common it is there.

Basing the potential distribution of *V. mandarinia* on geo-political units with collection records will certainly overestimate areas of suitable habitat. For example, in Hong Kong, the hornet is present but rarely observed (Lee, 2010). Although the species is widely recorded throughout Japan, it is more common in the south, between temperate and tropical zones (Yamane and Makino, 1977). Local microclimates, such as those driven by elevation, are more likely to predict the potential distribution of *V. mandarinia* than its recorded presence in geo-political units.

We did not find elevation tolerances for this species in the primary literature, but it does seem to be generally associated with lowlands rather than high elevations (Yamane and Makino, 1977). Although many of the regions from which the hornets are recorded are mountainous (e.g., the hornets are widely distributed throughout the Himalaya ranges; Kumar and Srinivasan, 2010), they are described as "rare or absent" from higher elevations within regions in which the hornets are common (Yamane and Makino, 1977). Three specimens were collected at 2,134 meters elevation in Myanmar (as Burma), but other specimens recorded from that country occurred at much lower elevations (between 400 and 1,400 meters; van der Vecht, 1959). Of the 530 specimen records in the Global Biodiversity Information Facility that have elevation recorded, one record in Pakistan occurred at 1,155 meters, but the rest are under 700 (average 123 ± 98.6 (SD) meters) (out of a total of 1,789 records; GBIF, 2020). The species does not seem to be commonly associated with high elevations.

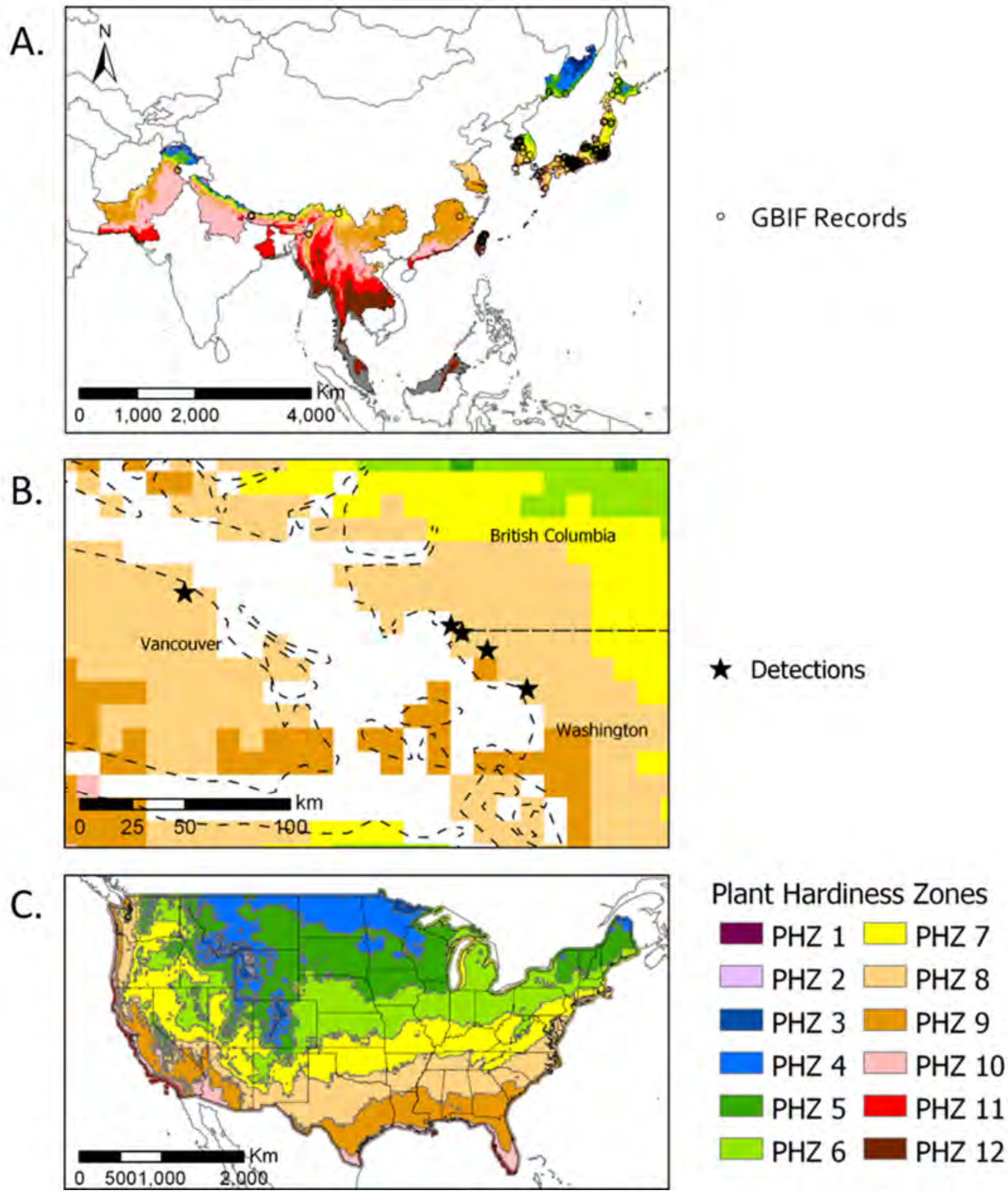

Figure 2-6. Plant Hardiness Zone maps of **A**. the known distribution of *Vespa mandarinia* in the Old World; **B**. recent detections in North America; and **C**. the lower 48 United States. In A. open circles indicate specimen records (GBIF, 2020); in B. stars indicate recent detections in Washington and British Columbia.

Current Distribution in the United States and Canada

Although there has been a detection of *V. mandarinia* in Washington, we do not know if this species is established there. Reports of *V. mandarinia* from British Columbia have also been confirmed by provincial authorities, but other U.S. reports from Washington remain unconfirmed (**Table 2-2**). Reports of *V. mandarinia* in North America are recent, few, and span a short period. This suggests that this is an early potential invasion. On the other hand, these recent detections could indicate that populations of the hornet have increased enough to be detectable and that it has already established in the area. If confirmed, the recent reports of *V. mandarinia* in Northern Bellingham, Washington, 27 kilometers away from the initial detection in Blaine, would suggest that there is more than one nest in the United States. It is early in our understanding of this species and its invasion potential, and we have little data available on its presence here.

Table 2-2. Reports of *Vespa mandarinia* from North America. Codes are unique identifiers and reference symbols on the diagram in **Figure 2-1**

Event Date	Event	Location	Code
Mid-August 2019	Three adult specimens collected after beekeeper reports. Canada genetically confirmed identification.	Nanaimo, British Columbia, Canada	1
August 2019	Beekeeper (below, Code #5) first saw hornets near house.	Northern Bellingham, Washington (27.3 kilometers from 8 December detection in Washington)	2
18 September, 2019	Nest located. One queen and about 200 workers in nest. No new adult queens present, but a few males were present.	Robin's Park Nanaimo, British Columbia, Canada	3
23 October, 2019	Single specimen photographed, not collected.	White Rock, British Columbia, Canada	4
October 2019	Beekeeper (above, Code #2) saw hornets attacking hive.	Northern Bellingham, Washington (27.3 kilometers from 8 December detection in Washington)	5
8 December, 2019	Homeowner collected a dead specimen, and NIS confirmed identification as *V. mandarinia*. Live specimen spotted by same homeowner near hummingbird feeder.	Southeast of Blaine, Washington	6

Potential Distribution in the United States

We compared the plant hardiness zones (PHZ) that encompass the native range of *V. mandarinia* with zones in the United States. This gave us a rough assessment of the areas at risk within the United States (**Figure 2-6**). The distribution of *V. mandarinia* encompasses PHZ 3 through 13, which include all areas in the lower 48 States (**Figure 2-6**). Although the Primor'ye region of Russia contains zones 3 and 4, specimen records from the Primor'ye are limited to zones 5 and 6; similarly, records from northern Japan do not include zone 5 (**Figure 2-6**; Archer, 1995; GBIF, 2020). This suggests that *V. mandarinia* might be limited to warmer areas than our zone matching would predict. Using PHZ to determine suitable areas for *V. mandarinia* likely overestimates their potential range in the United States, and a more accurate prediction would require an analysis beyond the scope of this document.

Vespa mandarinia preferentially build nests in forested habitats throughout their natural range, and their abundance is associated with forests and urban green spaces (Azmy et al., 2016; Choi et al., 2012). Forested areas are common throughout the United States, as are honey bees, one of the main food sources targeted by the hornets.

Chapter

3

Pest Identification

Species ID/Diagnostic

Morphological

Adults

Vespa mandarinia is the largest hornet species in the world (Ono et al., 2003). Workers range from 25 to 40 millimeters in length (**Figure 3-1**), and queens can exceed 45 millimeters (Lee, 2010; Toh and Okamura, 2003). Worker body size increases through the season as the nest grows larger. In late summer and in fall, the overlap in size between large workers and new queens can make caste determination difficult (Matsuura and Koike, 2002). Males superficially resemble females but lack a stinger (**Figure 3-1**).

The hornet's color varies throughout its range, and varying amounts of dark brown, yellow, and red led early taxonomists to split the species into numerous subspecies (e.g., *bellona*, *japonica*, *latilineata*, *magnifica*, *nobilis*; Lee, 2010; Nguyen et al., 2006; van der Vecht, 1959). Recent literature has mostly abandoned these synonyms, but a few color forms seem geographically restricted (Archer, 1995), which might help determine the origin of the specimens in North America (**Figure 3-1**).

Based on the coloration of the specimen found in Washington (**Figure 3-1D;** Spichiger, 2019), we estimate that this specimen most closely resembles the description of *V. m. mandarinia/V. m. japonica* in Archer (**Figure 3-1A,B**; Archer, 1995). This color form is distributed throughout the eastern part of the hornet's range, which includes Japan, Korea, Primor'ye (Russia), and the Chinese provinces Sichuan, Hebei, Hunan, Jiangxi, Fujian, and Zhejiang (Archer, 1995); thus these are potential source locations.

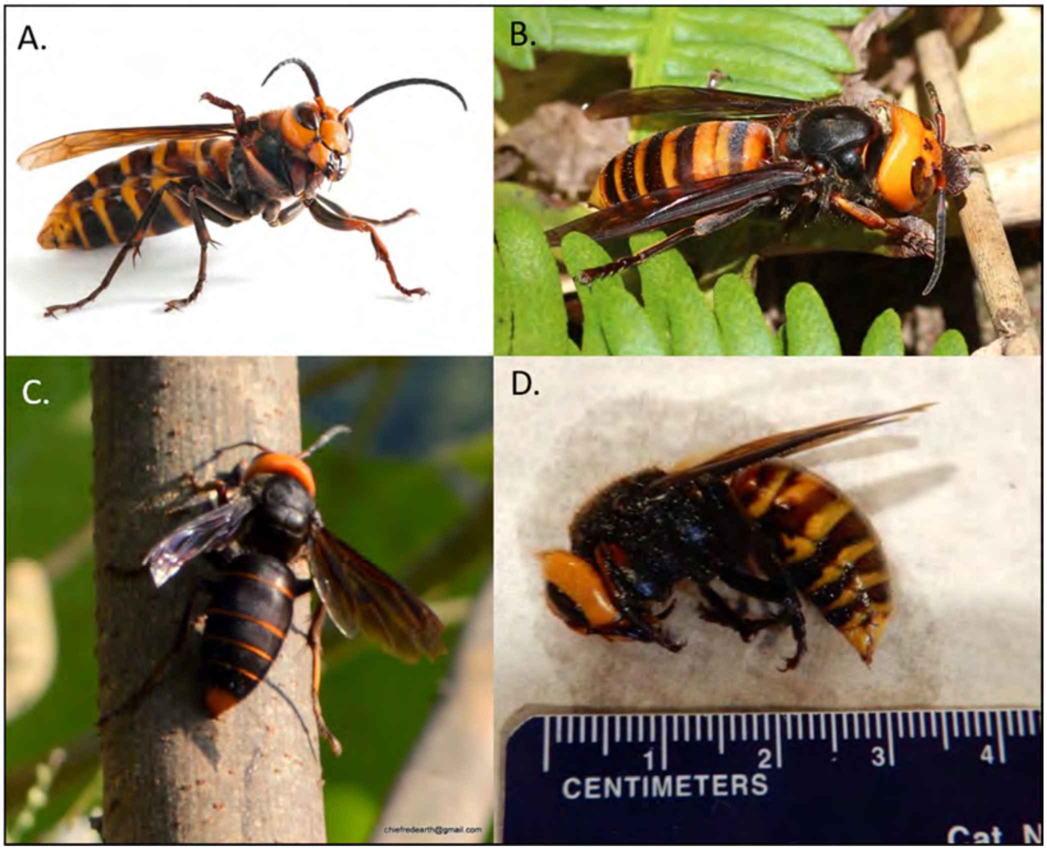

Figure 3-1. *Vespa mandarinia* from Japan, India, and Washington. A and **B**. *V. m. mandarinia/V. m. japonica* color form from Japan; **C**. *V. m. magnifica* color form from India **D**. *V. mandarinia* specimen from Washington. Photo credits: Yasunori Koide, Wikimedia Commons (A); Alpsdake, Wikimedia Commons (B); Chief Red Earth, https://indiabiodiversity.org (C); Sven-Erik Spichiger, Washington State Department of Agriculture (D).

Larvae and Pupae

Larvae and pupae cannot survive outside of the confines of nest cells. Pupae resemble adults. **Figure 3-2** shows both stages within nest cells and removed from nest cells.

Molecular

Both the United States and British Columbia are genotyping samples of *V. mandarinia* collected from these detections to verify their identification, investigate potential origins, and better understand the population dynamics of the hornets present in North America (AGH Response Team, 2020; Spichiger, 2019). No details have been released on which molecular markers are being used to aid in identification. Researchers have developed eight microsatellite markers for *V. mandarinia,* five of which could be informative for population genetic studies (Hasegawa and Takahashi, 2002).

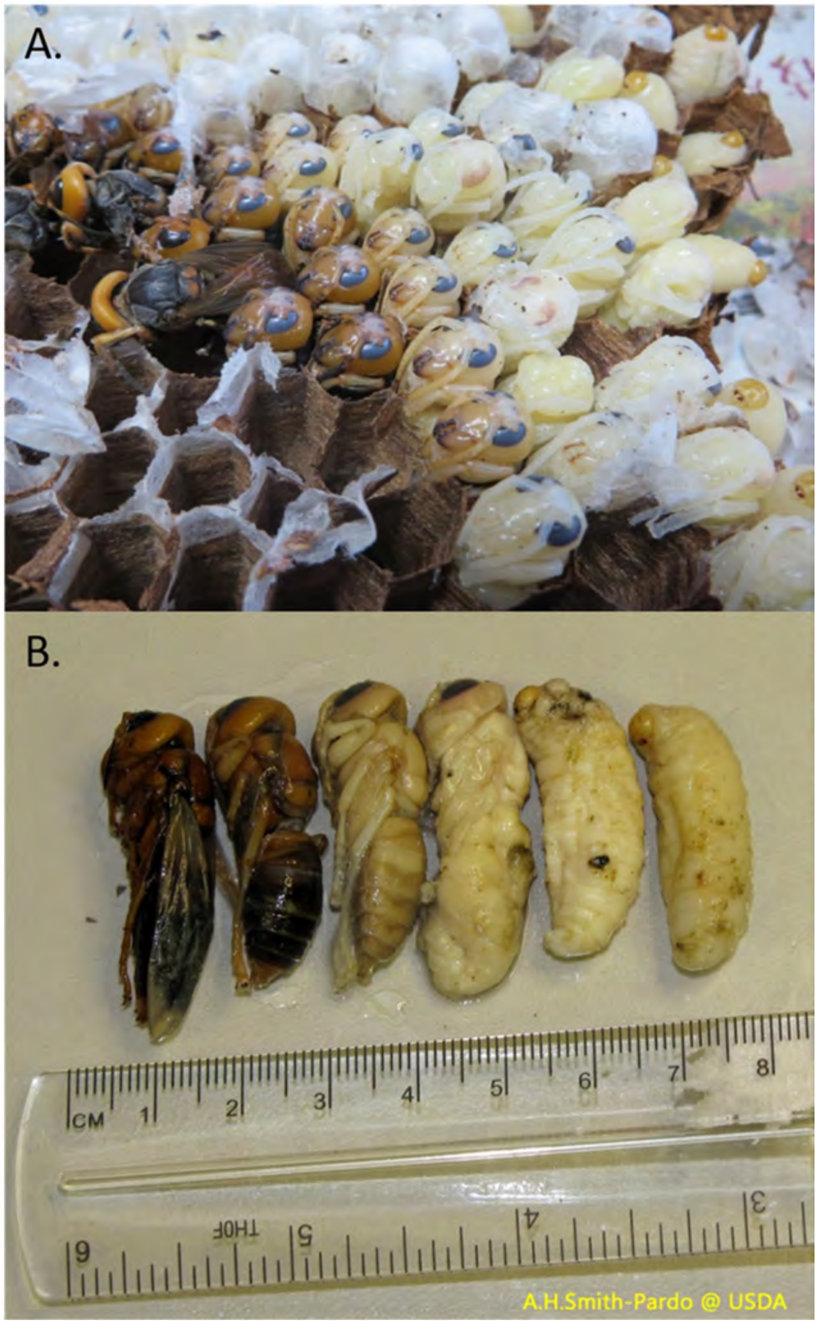

Figure 3-2. *Vespa mandarinia* larvae and pupae A. within the comb; **B**. removed from the comb and showing stages of development from larva to adult (right to left). Photo credits: www.libertyruth.com (A); Allan Smith-Pardo, USDA (B).

Similar Species

Vespa mandarinia is easily distinguished from most other large hornets by its distinctive size; large, yellow to orange head with black eyes; and a distinctively cleft clypeus (**Figure 3-3;** Kumar and Srinivasan, 2010; Lee, 2010; Nguyen et al., 2006). *Vespa crabro*, the European hornet, is the only *Vespa* species established in North America. *Vespa crabro* is easily distinguished from *V. mandarinia* by head characters and general coloration (**Figures 3-3** and **3-4**). *Vespa crabro* was released in the 1800s for biocontrol of forest pests (Beggs et al., 2011). Its distribution is limited to all states east of the Great Plains except the most southern reaches of eastern North America (GBIF, 2020). *Vespa mandarinia* most closely resembles *V. analis*, a co-occurring Asian species with a yellow head that is slightly smaller, but *V. mandarinia* has wider genae, a distinctive clypeus, and appears stockier and more robust (**Figure 3-3;** Lee, 2010).

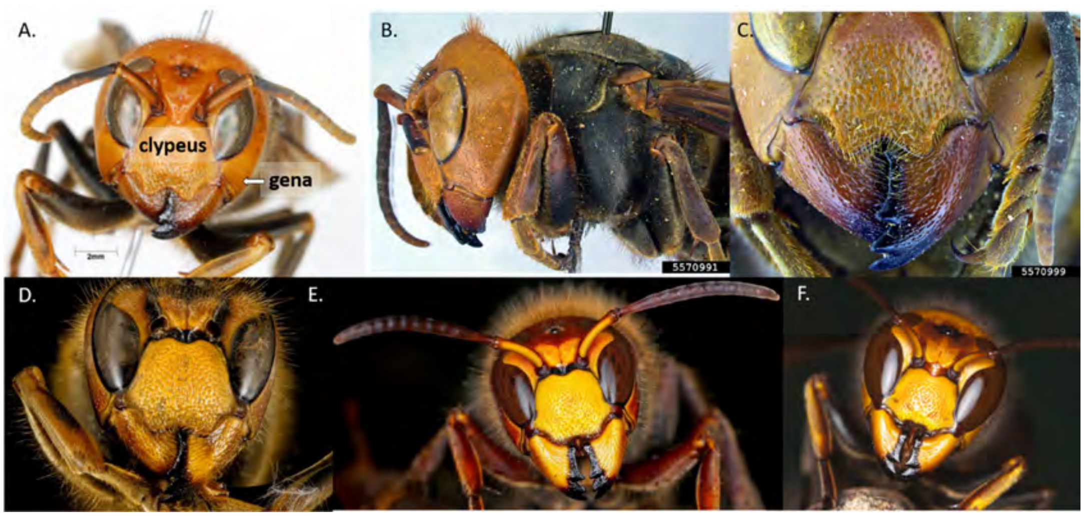

Figure 3-3. Heads of *Vespa* species showing the distinctively cleft clypeus and wider genae that distinguish *V. mandarinia* from other large *Vespa* spp. **A**. *Vespa mandarinia*; **B**. *V. mandarinia* (side view of gena); **C**. *V. mandarinia* (detail of clypeus); **D**. *V. crabro*; **E**. *V. velutina*; and **F**. *V. analis*. Photo creditss: Lee, 2010 (A and F); Allan Smith-Pardo, USDA APHIS PPQ (B and C); USGS, Flickr (D); and Philippe Garcelon, Flickr via Natural History Museum (E).

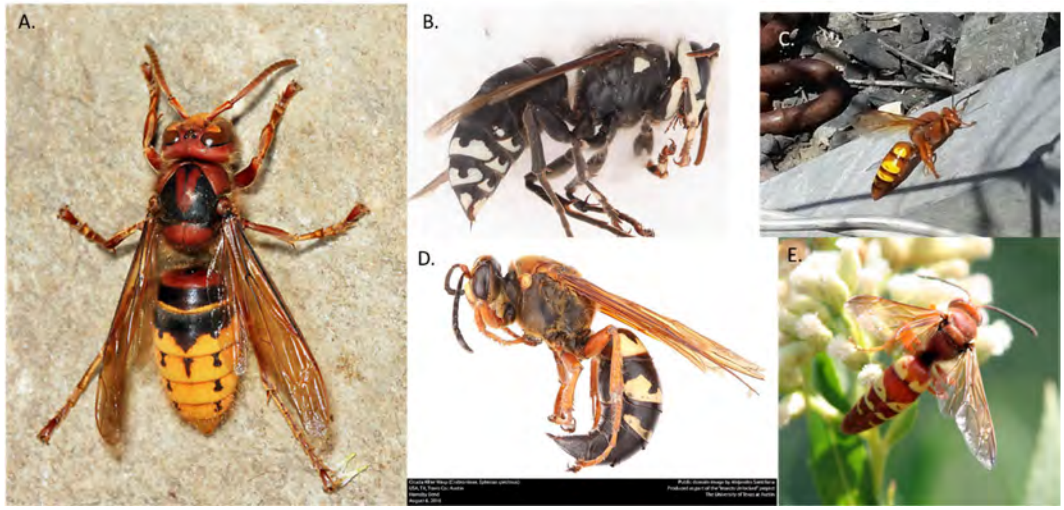

Figure 3-4. Species of social vespids in North America that look similar to *Vespa mandarinia*. **A**. European giant hornet (*Vespa crabro*); **B**. Bald-faced hornet (*Dolichovespula maculata*); **C**. Western cicada killer (*Sphecius grandis*); **D**. Eastern cicada killer (*Sphecius speciosus*); **E**. Pacific cicada killer (*Sphecius convallis*). Photo creditss: Tom Murray, BugGuide (A); Marci Hess, BugGuide (B); Jason R. Eckberg, BugGuide (C); Alejandro Santillana, Wikimedia Commons (D); Matthew Reynolds, WSDA, BugGuide (E).

Chapter

4

Survey and Eradication

Approach Overview

Because we have only one confirmed detection to date, we do not know the extent of the incursion. Delimiting the extent of the area occupied by *V. mandarinia* will help define where resources should be focused and help assess whether eradication is feasible.

There is also the possibility that the hornet is widespread in the region, so additional detection efforts are warranted. These efforts could include engaging beekeepers or other members of the general public to increase the possibility of detecting the hornet. The population spread of *V. mandarinia* is dependent upon the dispersal of queens, therefore eradication efforts should focus locating nests and trapping queens.

The response to any new detection resulting from trapping efforts of *V. mandarinia* depends on the time of year that the specimen was caught. During the pre-nesting, solitary, and cooperative stages, population levels are low and detection of individuals outside of the nest is more difficult than later in the season when the nest enters the polyethic and reproductive stages (**Figure 2-1**).

If North American phenology resembles the Japanese records, hornets are easiest to detect from July to November when workers are numerous (**Figure 4-1**). Early season detections, during the pre-nesting and solitary stages of the colony (**Figure 2-1**; April - June) are more likely to be queens, but not all queens active in the spring have started nests. Efforts spent locating nests during this period are likely to be unfruitful. However, lethal trapping of queens may reduce the overall population size.

Detections of *V. mandarinia* during the cooperative or polyethic stages of the colony (**Figure 2-1**; July - October) are more likely to be workers. These detections would require further trapping in the vicinity of each detection to locate the queen within her nest. Furthermore, when the colony transitions to the reproductive phase (**Figure 2-1**; November) it is difficult to distinguish between the castes, and trapped specimens could be either reproductives or workers. Since reproductives likely travel much farther than workers, it becomes unclear whether there is a nest near the detection site.

Given these factors, we recommend the following approach:

1. **Targeting Queens**: Using lethal traps during the early (pre-nesting and solitary stages) and late seasons (reproductive stage) to kill queens in areas where *V. mandarinia* has been detected.
2. **Targeting Nests**: Using active methods to locate and eliminate nests during the cooperative and polyethic stages.
3. **Public Outreach**: Using volunteers, particularly beekeepers, to determine if the population extends beyond where we currently know it to be.

Survey Approaches

The timing of the proposed approach is based on seasonal data from Japan. Although the colony cycle is expected to remain the same, the timing might change in a new location. Careful observations of caste activity can inform efforts to properly match survey methods to hornet activity.

Targeting Queens (April - June, and November)

The most effective approach to take during this period is to use lethal, passive traps baited with an attractant (**Figure 4-1**).

Queens are the most likely caste collected in traps during these months. Males may also be caught in November. Therefore, the goal of these traps is to reduce the overall population of *V. mandarinia* by catching and killing queens. Any subsequent trapping in the targeted area during this period is unlikely to help surveyors detect a nest.

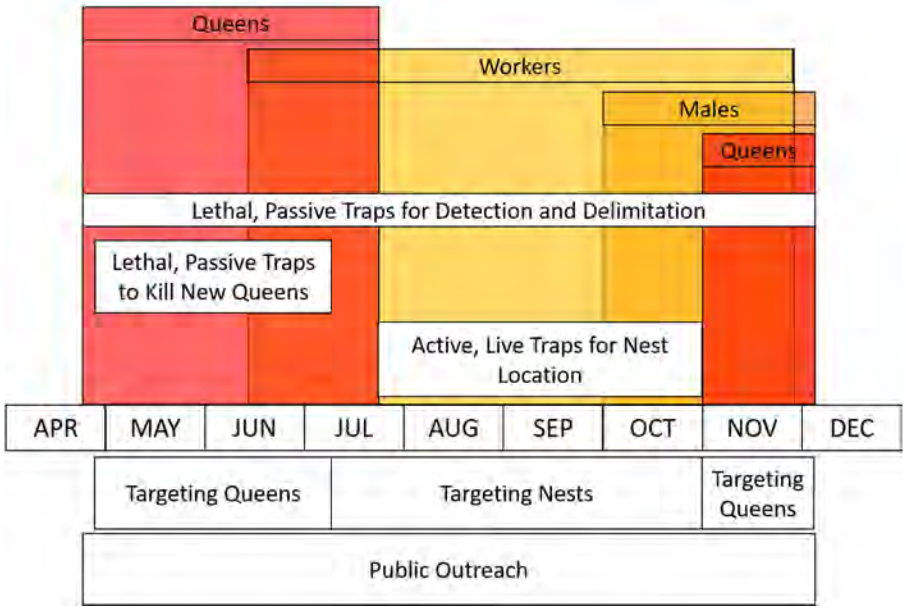

Figure 4-1. Recommended survey timing based on caste activity.

Targeting Nests (July – October)

Nest detection is important for control efforts (Kennedy et al., 2018), but the subterranean habits of *V. mandarinia* make locating nests challenging (**Figure 2-2**). A worker hornet encountered in the field is likely to return to her nest, which is typically within 2 kilometers. Surveyors can use this behavior to locate nests. Teams of people coordinate to harvest hornet's nests for food or to sell in local markets in Japan (Nonaka, 2008). They use sugar or meat baits to attract workers, and then follow the worker as she flies back to her nest. The hunters will return at night in special protective suits to excavate the entire nest, using smoke to sedate the adults within (**Figure 2-5**, Nonaka, 2008).

Because covering distances as far as 2 kilometers on foot can be difficult, live trapping might take place over multiple days, with new traps placed at the point at which watchers lose sight of the hornet. The most effective visual method of tracking *V. velutina* in Europe is executed over multiple days and involves noting the direction in which a worker flies, then setting baited traps in a series, each one closer to the nest (Kennedy et al., 2018). Because live trapping is labor intensive, it should only be employed at sites that have confirmed detections of worker activity.

Once a *V. mandarinia* detection has been confirmed, a delimiting survey can be initiated to determine the extent of the area occupied by the hornet (**Figure 4-2**). Additionally, trap data from the delimiting survey can be used to determine the ideal areas to implement live trapping techniques for nest location. Lethal traps can be set up for the survey, with trapping densities higher near the site of the detection and up to 2 kilometers radius surrounding the site (**Figure 4-2**). Because the maximum foraging range of workers is 8 kilometers, the trapping zone should include the area enclosed by a circle of this radius (**Figure 4-2**).

A delimiting survey is adaptive. Trap locations and densities can be altered as more data are available. When additional hornets are detected, the concentration of traps will change, removing traps from areas without activity and adding traps to areas with known hornet activity (**Figure 4-2**). Multiple detections of *V. mandarinia* in a sub-section of the delimited area might warrant the use of live trapping techniques.

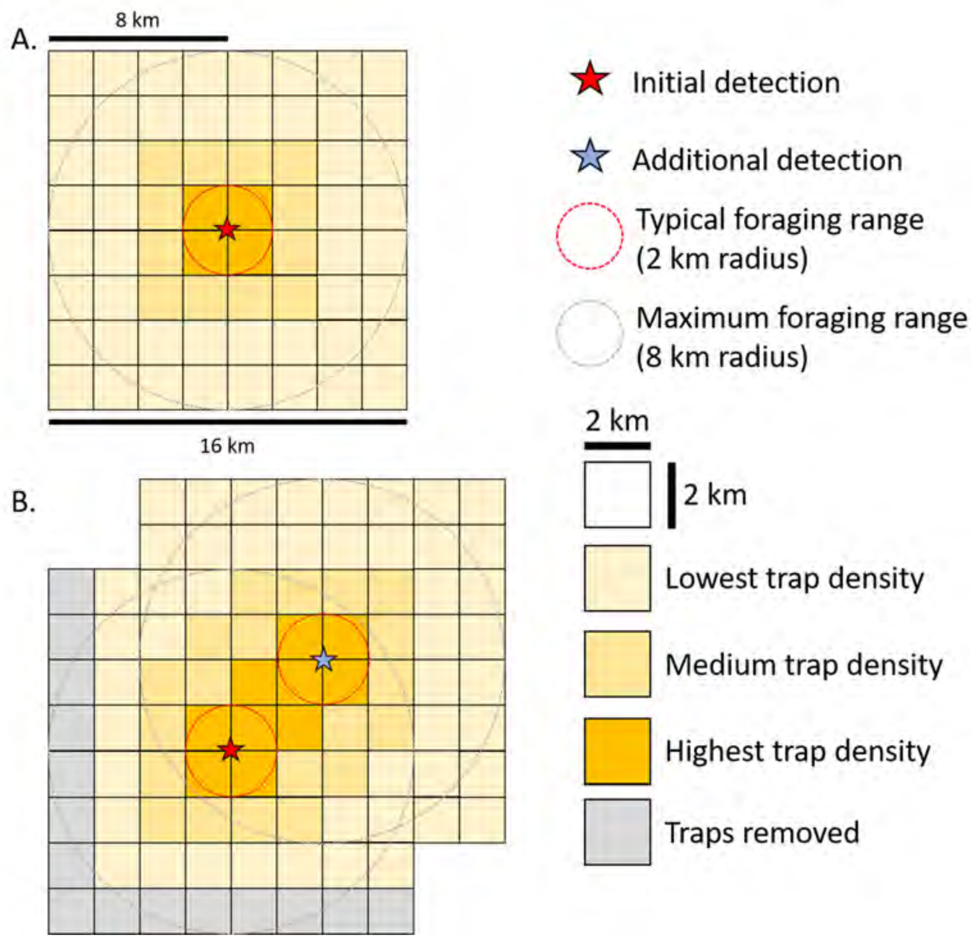

Figure 4-2. Diagram of a post-detection delimiting survey scheme. A. Schematic of initial passive trap placement for a delimiting survey. The red star indicates an initial detection site. The red circle shows the typical 2-km radius foraging range, and the grey circle shows the maximum 8-km foraging range. Traps would be placed at a higher density near the initial detection site, as indicated in orange, compared to those placed near the perimeter in light yellow. **B**. Schematic of passive trap placement for a delimiting survey after a hypothetical additional detection (blue star). An additional grid has been added, and traps have been redistributed.

Public Outreach (April-December)

Requesting the assistance of the public to make and deploy low-tech passive traps is an effective method to broaden the survey and can increase the chance of detection. Because *V. mandarinia* target bees, beekeepers should be informed of hornet biology and asked to deploy homemade traps in their apiaries (**Figure 4-3**). The United Kingdom's Animal and Plant Health Agency employed the assistance of citizen scientists and beekeepers in their battle against the invasive *V. velutina* with a simple homemade live trap (**Figure 4-3**; National Bee Unit, 2019). This trap has a mesh bottom designed to reduce by-catch. Although live traps were used in the United Kingdom, they require more resources to maintain and are likely unnecessary at this stage. The City of Nagoya distributes plans for a simple homemade lethal trap that beekeepers could deploy to passively monitor for hornet presence (**Figure 4-3;** City of Nagoya, 2020). These are baited with a mixture of 300 mL liquor, 100 mL vinegar, and 125 g of sugar (City of Nagoya, 2020).

For a citizen science campaign to be effective, a system must be in place to distribute educational materials and to receive and process reports from the public. Observers should be encouraged to submit photographs that show a side view of the head (**Figure 3-3**) and include a ruler or other means of determining the size of a specimen to aid in identification.

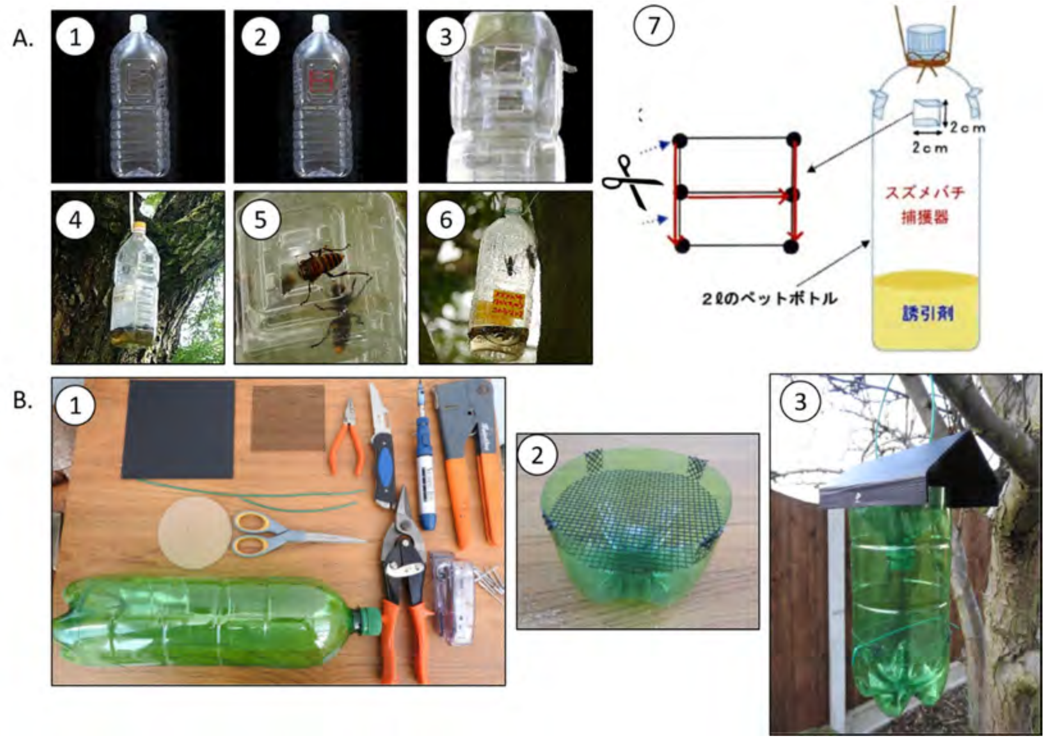

Figure 4-3. Homemade trap designs. A. Nagoya design: 1) 1.5 to 2 L plastic bottle; 2) cuts in an "H" shape, to 3) create openings; 4) baited and deployed in a tree; 5) hornets entering the trap; 6) hornets trapped; 7) schematic illustrating construction and bait level; **B.** UK design: 1) supplies needed; 2) detail of the screen separating the bait from the trap interior; 3) trap constructed and deployed in a tree. Photo credits: Wasp in the City, 2020 (A1-6); City of Nagoya, 2020 (A7); National Bee Unit, 2019 (B).

Trapping and Baits

Lethal, Passive Trapping

Lethal, passive traps are a useful means of detecting hornets in new locations and delimiting the occupied area. Passive traps are baited with an attractant, and lure hornets into a chamber that contains a fluid that will drown them (**Figure 4-4**). At this time no synthetic chemical lures are available for *V. mandarinia,* and the same fluid that is used as an attractant is also used to kill trapped insects. Lethal, passive traps can be left in the field unattended for extended periods, although they should have appropriate labeling to reduce disturbances from curious onlookers. Typically, spoilage rates of the attractant and the insects trapped in the attractant will determine how often traps need to be checked and refreshed, as hornets can be deterred by the odor of decaying insects. These traps can be used to detect adult hornets during any part of the colony cycle. There are many trap designs that might be useful for trapping *V. mandarinia,* and these are described in **Appendix A**.

Figure 4-4. Bucket trap baited with diluted fermented milk drink to monitor for hornets in Nagoya, Japan. Photo credit: Wasp in the City, 2020.

Live Trapping and Tracking

Live traps must hold trapped insects in a chamber that is separate from the attractant chamber or else the insects will drown. There is not a readily available trap that holds a fair volume of liquid attractant in a separate chamber, but the easily assembled traps used for monitoring *V. velutina* in the United Kingdom (**Figure 4-3**; National Bee Unit, 2019) are likely to suffice for *V. mandarinia* as well. Live traps must be checked daily by a crew of watchers who can devote the time to tag and follow a worker back to her nest, an activity that might take days. Because live trapping is labor intensive, it should only be employed at sites where there are credible reports of worker activity.

Tracking is difficult considering that a hornet can fly above the tree canopy and travel for several kilometers (Matsuura and Sakagami, 1973). The unaided eye can spot and follow a worker as far as 100 meters (Toh and Okamura, 2003), but flagging can help surveyors visually track the hornet. Trackers often use lightweight flagging to increase the visibility of tracked workers (Sharma et al., 1979; Toh and Okamura, 2003). These can be constructed from plastic shopping bags cut into strips (40 mm x 5 mm) or, if longevity is not an issue, tissue paper (20 mm x 20 mm) tied to the constriction between the thorax and the abdomen or the hind leg of captured foragers (**Figure 2-5**; Sharma et al., 1979; Toh and Okamura, 2003). Although Japanese hornet hunters commonly employ this technique, one group of researchers reported difficulty in following *V. mandarinia* to their nests over uneven terrain (Sharma et al., 1979).

It is important to immobilize workers while tagging them because of their capacity to sting. Individual *V. mandarinia* anesthetized with ethyl acetate and marked with paint markers exhibit normal behaviors at sap feeding sites upon recovery (Yoshimoto, 2009). Coolers filled with ice will likely immobilize workers, but we found no data on how long a hornet needs to be chilled before it is incapacitated. It is important to tag and release the hornet where it is captured and not in a new location to maintain data integrity.

We can gather more data about *V. mandarinia* by individually marking captured hornets with a paint marker or writing a serial number on the streamer before releasing them. If we record the GPS location of each hornet capture, we may gain a better idea of the species' foraging radius and the proximity of the individual colonies. Once the surveyors discover the nest and dispatch the hornets, we can account for all of the tagged workers. This will help us determine if there are additional nests in the area.

Live traps should be clearly labeled as hazardous and placed in locations that are not likely to attract the attention of the public. Surveyors working with live hornets will need adequate protective gear (**Figure 4-5**) and safety training.

Attractive Baits

Fermentation odors are attractive to *V. mandarinia.* In Japan, the typical baits used to attract hornets capitalize on the attractiveness of fermentation odors and many use a combination of sugar, alcohol, and vinegar to trap *V. mandarinia* (**Appendix A**). The city of Nagoya, Japan has been monitoring hornets, including *V. mandarinia,* since 2011 and uses a diluted commercially available, lactic-acid fermented, dairy drink to bait plastic bucket traps. These are placed at a height of one to three meters (**Figure 4-4; Appendix A;** Wasp in the City, 2020). Officials check traps and replace the bait weekly from April or May through November

(Azmy et al., 2016; Wasp in the City, 2020). The fluid itself acts as a drowning agent.

Both sugar- and protein-based baits are used by Japanese hornet hunters to attract workers that can be followed back to their nests (Nonaka, 2008; Payne, 2016). in India, decaying fish and an unspecified decaying meat bait were more attractive to *V. mandarinia* (as *V. magnifica*) than rotten apples (Sharma et al., 1979). Protein baits, made of mashed raw fish or other meat diluted to 25% solution, are attractive to *V. velutina* late in the season when the colony's growth rate is high and there is a need for additional protein (National Bee Unit, 2019). Meat-based baits decay quickly and should be replaced every three days (National Bee Unit, 2019).

Figure 4-5. Protective gear designed to protect the wearer from hornet stings. The suit is made from a material that is slick on the outside to prevent hornets from being able to hold on to the suit. This material is made of multiple layers and thick enough to prevent the sting from penetrating. Unlike a beekeeper's mesh veil, the visor on a hornet suit is made of hard plastic and the back is a thick, reinforced material. Photo credits: asuka21.blue.coocan.jp and www.dic-corp.co.jp/contents/raptor.html.

Trap Placement

Behavior research demonstrates that *V. mandarinia* has a preference for oak sap and honey bees (Suenami et al., 2019). Therefore, placing traps in oak woodlands and apiaries might be more successful. Survey guidelines for *V. velutina* in the

United Kingdom suggest placing traps in sunny locations, rather than shady ones, in oak trees and honey bee hive stands (National Bee Unit, 2019). We do not have comparable information for *V. mandarinia* trap placement. Traps in Japan are typically placed 3 meters high (Wasp in the City, 2020).

Handling Samples for Identification

Sample Collection

Specimens should be stored in at least 70% ethanol to preserve them for morphological verification and potentially for genetic testing. Vials should be labeled with all available collection data (e.g., date, location, trap style, bait type, etc.).

Sample Shipping

Surveyors should ship specimens to the identifier designated by the APHIS State Plant Health Director (SPHD) and follow shipment protocols provided by the SPHD.

Identifiers will confirm a positive occurrence by submitting the specimen(s) to the proper APHIS authority.

Environmental and Health Considerations

Non-target By-catch

Traps should target *V. mandarinia*, and avoid trapping non-target insects such as honey bees and other pollinators. It is important to deploy traps that do not attract honey bees, particularly for surveys in apiaries. Sugar-based traps are likely to attract and kill non-target insects, including pollinating insects foraging for nectar (Monceau et al., 2012). Traps that use odors of decaying fruits can also attract honey bees, but those with an alcohol component are likely to repel them (Rojas-Nossa et al., 2018). Trap attractants based on fermentation odors are not known to attract honey bees (Landolt and Zhang, 2016; Oliver et al., 2014). Further research on baits specific to *V. mandarinia* would help improve the specificity of traps. Color can also be an important stimulus for pollinators. Blue vane traps are very attractive to wild bees, particularly bumble bees (*Bombus* spp.), as was discovered accidentally during a study employing Asian ladybeetle traps (Stephen and Rao, 2005). Blue traps should be avoided.

Sting Hazards

It is important to note that *V. mandarinia* has a powerful sting, which is a hazard to human health. *Vespa mandarinia* will fiercely defend their nests, and people without protective gear (**Figure 4-5**) should stay at least three meters away from a nest entrance (Lee, 2010). Protective gear should be specific for hornet work. Materials used in beekeeping suits will not prevent sting injury.

Vespa mandarinia is responsible for an estimated 30 to 50 deaths a year in Japan (Yanagawa et al., 2007). Not all persons killed by *V. mandarinia* stings are allergic to hornet venom. Direct causes of death include anaphylaxis and sudden cardiac arrest, which are normally associated with an allergic reaction. Reactions also include rare complications associated with serve toxicity, such as rhabdomyolysis (disintegration and release of muscle fiber tissues into the blood stream), kidney failure, liver dysfunction, respiratory failure, and the formation of deadly blood clots (Yanagawa et al., 2007).

Chapter 5

Control Options

Overview

This chapter presents known options available for controlling this pest and summarizes how they are used in the United States.

This information can be used by decision-makers after a detection to assess the suitability of potential actions to eradicate, contain or suppress *V. mandarinia* populations. The efficacy and feasibility of each control option will depend on the pest situation at the time of detection. Factors such as detection location (e.g., natural or urban environment, agricultural crops, apiaries, orchards), area of spread, the climatic region, the time of year, and current practices already in place contribute to determining whether a particular control option is appropriate.

Chemical Control Options

Chemical Controls

Eradicating nests is a more effective population control measure than killing individual foraging workers and is the best tactic for minimizing the spread of invasive hornets (Kennedy et al., 2018; Kishi and Goka, 2017). Hornet chemical-control typically follows one of two modes of action based on chemistry and formulation: 1) fast knockdown sprays that are immediately lethal and 2) slower acting residual formulations designed to be spread among nest mates. Chemists designed fast knockdown sprays to kill hornets on contact. This is beneficial to applicators who must approach the nest entrance to apply insecticide, but hornets protected within the nest are unlikely to be killed. Conversely, slower acting chemicals with longer residuals are formulated as dusts or foam. These attach to hornets, who then carry the insecticide inside of the nest exposing nest mates and larvae. These are more effective in eliminating nests than fast knockdowns. Applying a slow-acting formulation inside the nest entrance is effective but requires locating nests prior to application and specialized protective gear (**Figure 4-5**).

We found no chemical controls specific for *V. mandarinia*, but there are many pesticides available for use against close relatives of *V. mandarinia* that are present in the United States, such as *Vespula* spp., *Dolichovespula* spp., and *V. crabro* (**Table 5-1**). Honey bees are likely to be vulnerable to many chemical controls, so beekeepers should carefully consider any pesticides used near apiaries.

Chemicals Registered in the United States

Although the chemicals listed below are registered in the United States, they have not been tested on this pest and efficacies might not be the same. Any mention of trade names or commercial products does not imply endorsement or recommendation by the USDA. This list is not all-encompassing, and additional products are likely to be available.

Table 5- 1. A selection of pesticide products for hornet control that are available in the United States

Trade Name	Active Ingredients	Description
Bonide ® Wasp and Hornet Killer	0.1% Tetramethrin 0.25% Permethrin 0.50% Piperonyl butoxide (Bonide Products, 2008)	Home use. Knockdown with residual action. Aerosolized spray reaches up to 20 feet. (Bonide Products, 2008)
Champion Sprayon ® Wasp, Bee and Hornet Killer	0.2% Tetramethrin 0.125% d-Phenothrin (Chase Products Co., 2006)	Home use. Knockdown with residual action. Aerosolized spray reaches up to 20 feet. (Chase Products Co., 2006)
Demand ® CS Insecticide	9.7% Lambda-cyhalothrin (Syngenta, 2018)	Professional use. Residual. Microencapsulated, synthetic pyrethroid. (Syngenta, 2018)
EcoSmart ® Jet Wasp and Hornet Killer	0.5% 2-Phenethyl propionate 1.0% Peppermint oil (Kittrich Corp., 2020)	Home use. Knockdown. Registration not required. (Kittrich Corp., 2020)
Enforcer ® Instant Knockdown Wasp and Hornet Killer	0.1% Tetramethrin 0.25% permethrin 0.5% piperonyl butoxide (Zep, 2016)	Home use. Knockdown with residual action. Aerosolized spray reaches up to 20 feet. (Zep, 2016)
EverGreen ® Crop Protection EC 60-6 Valent U.S.A.	6% Pyrethrins 60% Piperonyl butoxide (CDMS, 2020)	Professional use. Knockdown. Liquid concentrate. (CDMS, 2020)
EverGreen ® Pro 60-6 MGK	6% Pyrethrins 60% Piperonyl butoxide (CDMS, 2020)	Professional use. Knockdown. Liquid concentrate. (CDMS, 2020)

Trade Name	Active Ingredients	Description
Nufarm ® Chlorpyrifos SPC 2	24.66% Chlorpyrifos (CDMS, 2020)	Professional use. Knockdown. Liquid concentrate. (CDMS, 2020)
Nufarm ® Chlorpyrifos SPC 4	44.7% Chlorpyrifos (CDMS, 2020)	Professional use. Knockdown. Liquid concentrate. (CDMS, 2020)
Optigard ® Flex Liquid	21.6% Thiamethoxam (Syngenta, 2018)	Professional use. Residual. Liquid or foam. (Syngenta, 2018)
Ortho ® Home Defense® MAX Termite & Destructive Bug Killer	2.4% Bifenthrin (Ortho, 2020)	Home use. Residual. Liquid. (Ortho, 2020)
Ortho ® Hornet and Wasp Killer[7]	0.2% Tetramethrin 0.2% Sumithrin (Ortho, 2020)	Home use. Knockdown and residual. Encapsulating aerosol foam reaches up to 20 feet. (Ortho, 2020)
PT ® Wasp-Freeze ® II Wasp and Hornet Insecticide	0.1% Prallethrin (BASF, 2018)	Home use. Knockdown and residual. Aerosolized spray reaches up to 15 feet. (BASF, 2018)
Stinger ® Wasp, Hornet & Yellow Jacket Foam	0.2% Tetramethrin 0.2% Sumithrin (Bonide Products, 2008).	Home use. Residual. Foam reaches up to 20 feet. (Bonide Products, 2008)
Tempo ® SC Ultra Bayer	11.8% Beta-cyfluthrin (CDMS, 2020)	Professional use. Knockdown and residual. Liquid concentrate. (CDMS, 2020)
Tempo® Ultra WP Bayer	10% Beta-cyfluthrin (CDMS, 2020)	Professional use. Knockdown and residual. Wettable powder. (CDMS, 2020)

Labeling

Although a proposed formulation may be approved by APHIS in an effective eradication or chemical control program, it may not be labeled at the time of pest detection for the specific use site or rate required. If a formulation is not labeled for the necessary use, there may be several options. One can request a quarantine exemption from the U.S. Environmental Protection Agency under section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act, or a special local needs registration under Section 24(c) from the state where the product will be applied. The prescribed formulation must be labeled both for use on the site at which it is to be applied and at the desired rate and must be registered for use in the state in which the eradication program is occurring. All applicable label directions must be followed, including but not limited to requirements for personal protection equipment, maximum treatment rates, storage and disposal.

Alternative Control Options

Cultural Controls

Since the introduction of *A. mellifera* to Japan in 1876, Japanese beekeepers have employed several mechanical methods to manage hornets in apiaries (Matsuura and Sakagami, 1973). These methods include traps installed at hive entrances and entrance screens to deter hunting hornets (Matsuura and Sakagami, 1973). Killing workers at hives by beating them with sticks is a popular control method used by both Japanese and Indian beekeepers (Matsuura and Sakagami, 1973; Sharma et al., 1979). One study in India found that hornet visitation to apiaries was reduced by 48 percent after a campaign of killing wasps with wooden sticks (Sharma et al., 1979). This is a labor-intensive practice and the loss of a few workers is not likely to be an effective control measure.

Hornet traps placed at honey bee hive entrances are also not likely to control a population, but the traps do seem capable of protecting hives from succumbing to attacks by *V. mandarinia.* In one Japanese study, hornet traps at hive entrances in an apiary caught an average of 69.2 *V. mandarinia* per hive over the hornet season of July through November (Matsuura, 1988). No honey bee hives were lost during a 10-year study of the efficacy of hornet traps at the entrances of 20 hives in an apiary subject to frequent *V. mandarinia* attacks (Matsuura, 1988). This is in stark contrast to the loss of 100% of unprotected hives in a nearby apiary and all wild honey bee colonies in the region that were observed to have been attacked (Matsuura, 1988).

Behavioral Control

Mass trapping

Given the social structure of this species, mass trapping efforts that target queens are likely more effective than those that target the non-reproductive workers (Oliver et al., 2014; Rojas-Nossa et al., 2018). Although workers are the most frequently encountered caste, only mated queens can start nests and pose an introduction risk. Males and queens are active outside of the nest for a brief period; therefore, management efforts targeting reproductive castes are likely to be effective from April through July and in November (**Figure 4-1**). Reports from Japan suggest that mass trapping has little effect on *V. mandarinia* populations in apiaries (Sharma et al., 1979). In France, *V. velutina* populations seem to be impacted by mass trapping queens when they emerge in the spring, but it is not seen as an effective control measure (Monceau et al., 2012; National Bee Unit, 2019).

Chapter 6

Research Needs

New technology, research or assessment is needed to:

- Estimate the efficacy of various attractants, baits, and trap body designs (**Appendix A**).
- Determine the seasonal cycle of *V. mandarinia* in the Pacific Northwest.
- Develop pheromone-based baits. *Vespa mandarinia* virgin queens produce an uncharacterized pheromone that is attractive to males; researchers can extract this with ethyl ether, but not non-polar n-hexane (Ono and Sasaki, 1987). There is an additional aggregation pheromone secreted by workers that males use to locate nests from which virgin queens will soon emerge (Ono and Sasaki, 1987). These chemicals show promise as trap attractants but have not been characterized or synthesized.
- Determine if poisoned baits can be used to kill colonies. Field tests of using insecticide-laced meat baits to kill *V. tropica* (as *V. cincta*) nests were successful (Mishra et al., 1989). Poisoned baits were found to be attractive to *V. velutina* (as *V. auraria*), but no results on their efficacy in killing nests were reported (Sharma et al., 1979). No toxic bait research is available for *V. mandarinia,* although Matsuura (1973) has discussed the possibility of its effectiveness. Studies on toxic baits targeting *Vespula* species are available and show that the method holds promise for controlling ground nesting wasps (Kishi and Goka, 2017).
- Determine if *V. mandarinia* carry parasites that can infect honey bees. We only found data on a single natural enemy of *V. mandarinia,* the Strepsipteran parasite *Xenos moutoni* (Maeta et al., 1998). *Vespa velutina* carry detectable levels of honey-bee viruses in their tissues, including *Deformed wing virus*, *Acute bee paralysis virus*, *Black queen cell virus*, and two new, unclassified viruses (Dalmon et al., 2019).
- Examine nest location methods that are less labor-intensive. Unmanned aerial vehicles have been used to track *V. velutina* flights in Korea, (Kim et al., 2019). Harmonic radar, radio-frequency identification tags, and radio-telemetry are other options used to track *V. velutina* (Kim et al., 2019; Milanesio et al., 2016, 2017).
- Explore the potential of an in-hive remote detection system. Researchers

in Korea have developed a prototype of an in-hive alert system to detect and report *V. mandarinia* intrusions based on matching the wing-beat frequency of attacking wasps and transmitting an alert to a cell phone (Kim et al., 2017). This system could be useful for monitoring at-risk apiaries late in the season and could provide an early warning that an apiary is situated near a colony of *V. mandarinia*. To our knowledge, this device has not yet been field tested.

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V. mandarinia

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Appendix

A Untested Traps and Baits

Introduction

We do not know the best trap, bait, or combination to use for the detection of *V. mandarinia* in the United States. Other countries use some traps and baits specifically to capture *V. mandarinia*, but it is unclear if the components from those traps would be readily available and cost efficient in the United States. Similarly, there are traps and components that might be readily available, but researchers have only used them on related species, so it is unclear whether they would be effective for *V. mandarinia*. This appendix covers all the traps (**Table A-1**) and baits (**Table A-2**) that we encountered in our research. We provide these options to give surveyors options among trap-bait combinations.

Table A- 1. Traps identified in the literature that may be effective at luring *V. mandarinia.* Image code refers to images in Figure A-1.

Image Code	Trap Name	Description	References
A	Bottle Trap (a.k.a. Nagoya design)	**Type** Lethal, passive trap, but it could be adapted as live trap by adding screen or float device **Pros** Trap is used by the public to kill *V. mandarinia* queens in Japan Easy to assemble from inexpensive materials Can be used by citizen scientists **Cons** Might not be durable **Usage** The City of Nagoya recommends that beekeepers use this trap to kill *Vespa* spp., including *Vespa mandarinia*, queens in their apiaries throughout spring	City of Nagoya, 2020; Wasp in the City, 2020
B	CAPS Plastic Bucket Trap (a.k.a. Funnel Trap)	**Type** Lethal, passive, but it could be adapted as live trap by adding screen or float device **Pros** CAPS users are familiar with and might already have these traps Trap has been used to monitor *V. mandarinia* in its native range **Cons** CAPS users might have added drain holes **Usage** The City of Nagoya uses this trap for monitoring *Vespa* spp., including *V. mandarinia,* in Japan	Brambila et al., 2014; City of Nagoya, 2020; Wasp in the City, 2020

Image Code	Trap Name	Description	References
C	Jug Trap	**Type** Lethal, passive **Pros** Easy to assemble from inexpensive materials Surveyors likely experienced with use **Cons** Never tested on *V. mandarinia* **Usage** Deployed by WSDA after the first detection of *V. mandarinia.* Used by the Pennsylvania Department of Agriculture in trap testing, but we do not know if this trap worked for catching *V. crabro*	PDA, 2020b; Spichiger, 2019
D	Merrill Fruit Fly Trap (a.k.a. Plastic McPhail trap)	**Type** Lethal, passive **Pros** USDA has many of these on hand Surveyors likely experienced with use **Cons** Never tested on *V. mandarinia* or close relatives **Usage** USDA has used this in fruit fly detection programs	USDA-APHIS-PPQ, 2004; Wood, 1996
E	Rescue! W.H.Y. ® Trap	**Type** Two-chamber model has both lethal and live chambers **Pros** Specifically developed to attract wasps, hornets, and yellowjackets and not non-target insects Proprietary attractants included **Cons** Traps are commercially produced and might be costly to purchase or refresh attractants Attractants were developed for North American Hymenoptera have not been tested on *V. mandarinia* Hole size was developed for North American Hymenoptera and might be too small for *V. mandarinia* **Usage** This trap has been used by the public for trapping nuisance Hymenoptera in the United States	Rescue, 2020
F	U.K. Asian Hornet Monitoring Trap	**Type** Live, but it could be adapted as lethal trap by removing screen **Pros** Easy to assemble from inexpensive materials Can be used by citizen scientists **Cons** Never tested on *V. mandarinia* Live trapping likely requires safety training **Usage** The Animal and Plant Health Agency of the United Kingdom encourages beekeepers to use these traps to monitor for *V. velutina,* an Asian hornet that may or may not be established in the United Kingdom	National Bee Unit, 2019

Figure A- 1. Trap designs. A. Bottle trap; **B**. CAPS plastic bucket trap; **C**. Jug trap; **D**. Merrill trap; **E**. Rescue! W.H.Y. Trap; **F**. U.K. Asian hornet monitoring trap. Photo credits: Wasp in the City, 2020 (A); Brambila et al., 2014; Wasp in the City, 2020 (B, inset); PDA, 2020b (C); www.novagrica.com (D); Rescue, 2020 (E); National Bee Unit, 2019 (F).

Table A- 2. Bait types identified in the literature that might be attractive to *V. mandarinia*

Bait type	Formulations	Notes	References
Artificial Sap	• Black sugar, shōchū, and distilled water at a 1:2:2 ratio	**Pros** Known to be an effective *V. mandarinia* attractant Fermentation odors are not likely to attract honey bees **Cons** Not tested for trapping efficiency **Usage** This bait was used in a behavioral study to attract sap feeding insects, including *V. mandarinia* **Notes** Black sugar is an Asian product that is similar to brown sugar, but more strongly molasses flavored	Yoshimoto et al., 2005

Bait type	Formulations	Notes	References
Dark Sugar	• Light or dark brown sugar: 1 cup, diluted in ½ gallon of water	**Pros** Replace weekly **Cons** Not tested for trapping efficiency Without the addition of fermentation odors, this bait might attract bees **Usage** Dark sugar baits were deployed by WSDA in response to the first *V. mandarinia* detection **Notes** Non-target by-catch was reported with this bait	PDA, 2020a; Spichiger, 2019
Lactic-acid Fermented Beverage	• Fermented milk drink at 60%, water at 40% • Grape variant: 3 parts grape Calpis ® and 2 parts water • Yeast variant: Calpis ® solution with "a few spoons of dry yeast" added	**Pros** Known to be an effective *V. mandarinia* attractant Replace weekly **Cons** There may be some non-target by-catch associated with this bait Not tested for trapping efficiency **Usage** The City of Nagoya, Japan uses Calpis ® bait to monitor and trap hornets, including *V. mandarinia* Yeast added to Calpis ® bait attracted many *V. velutina* **Notes** Calpis ® is a dairy-based beverage produced through lactic-acid fermentation, sold as Calpico® outside of Japan	Azmy et al., 2016; Kishi and Goka, 2017; Wasp in the City, 2020
Orange Juice and Alcohol	• Equal parts orange juice and clear liquor distilled from sweet potatoes at 25% alcohol • Equal parts shōchū and orange juice • Equal parts makgeolli and orange juice	**Pros** Known to be an effective *V. mandarinia* attractant Replace weekly **Cons** Not tested for trapping efficiency **Usage** This bait has been used for trapping hornets, including *V. mandarinia* in Japan and South Korea **Notes** Shōchū is an Asian liquor made from distilled rice wine typically at about 25% alcohol Makgeolli is an unfiltered Asian rice wine that is usually at about 6 to 9 percent alcohol	Tatsuta and Makino, 2003; Wasp in the City, 2020

Bait type	Formulations	Notes	References
Protein	• Raw fish, chicken, or frog • Mashed raw meat, prawns or trout diluted to 25% with water • Canned cat food containing chicken, tuna, or sardine	**Pros** Perhaps effective during the late season when nests are large Not attractive to honey bees **Cons** Has only been used in labor intensive live trapping Needs to replaced frequently (every 3 days) or decay odors will become repellant **Usage** Meat baits are used by hornet hunters in Japan to catch workers to tag and follow back to a nest, and in the United Kingdom for trapping *V. velutina* Fish was more attractive than meat in one study in India Cat food has been used to trap a variety of predatory Hymenoptera	Kishi and Goka, 2017; Matsuura and Sakagami, 1973; National Bee Unit, 2019; Nonaka, 2008; Sharma et al., 1979
Sweet Vinegar and Alcohol	• Sake (rice wine at ~15 percent alcohol): 1,800 ml, vinegar: 250 ml, sugar: 500 g • Sake, vinegar, sugar in a ratio of 2:1:1 • Sake: 180 ml, vinegar: 60 ml, sugar: 75 g • Liquor: 300 ml, vinegar: 100 ml, sugar: 125 g • Equal parts sugar water, acetic acid, and ethanol • Grape variant: 10 parts grape juice, 3 parts sake, 2 parts vinegar, 2 parts sugar	**Pros** Known to be an effective *V. mandarinia* attractant Replace weekly or every other week **Cons** Not tested for trapping efficiency **Usage** This bait has been used by beekeepers for trapping hornets, including *V. mandarinia,* in Japan and Korea Researchers have used this bait for monitoring *Vespa* spp, including *V. mandarinia,* in South Korea **Notes** Non-target by-catch was reported with this bait. Authors did not report the concentration of sugar used to prepare sugar water.	Choi et al., 2012; City of Nagoya, 2020; Wasp in the City, 2020
Synthetic Lures	• Heptyl butyrate • Acetic acid and 2-methyl-1-butanol • Acetic acid with isobutanol	**Pros** Attractive to many social wasps and hornets Not attractive to honey bees Some available as commercial products **Cons** Never tested on *V. mandarinia* **Usage** Acetic acid with isobutanol or 2-methyl-1butanol is attractive to a large variety of social wasps in the United States, including *V. crabro* Heptyl butyrate is effective for trapping yellowjackets (*Vespula squamosa*, *Vespula pensylvanica*, and several species in the	Beggs et al., 2011; Landolt and Zhang, 2016; Oliver et al., 2014

Bait type	Formulations	Notes	References
		Vespula rufa group) **Notes** Concentrations are not often reported in review literature, but they are likely available in original reports	

Appendix

B

Environmental Compliance

Introduction

Use **Appendix B** as a guide to environmental regulations pertinent to *V. mandarinia*.

Overview

Program managers of Federal emergency response or domestic pest control programs must ensure that their programs comply with all Federal Acts and Executive Orders pertaining to the environment, as applicable. Two primary Federal Acts, the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA), often require the development of significant documentation before program actions may begin. APHIS' Policy and Program Development Staff (PPD), Environmental and Risk Analysis Services (ERAS) is available to provide guidance and advice to program managers and prepare drafts of applicable environmental documentation. In preparing draft NEPA documentation, PPD ERAS may also perform and incorporate assessments that pertain to other Acts and Executive Orders, described below, as part of the NEPA process. The Environmental Compliance Team (ECT), a part of PPQ's Plant Health Programs, sometimes assists ERAS in development of documents and implements environmental monitoring. Program leadership is strongly advised to consult with PPD ERAS and/or ECT early in the development of a program in order to conduct a preliminary review of applicable environmental statutes and to ensure timely compliance.

Environmental monitoring of APHIS pest control activities may be required as part of compliance with environmental statutes, as requested by program managers, or as suggested to address concerns with controversial activities. Monitoring may be conducted with regards to worker exposure, pesticide quality assurance and control, off-site chemical deposition, or program efficacy. Different tools and techniques are used depending on the monitoring goals and control techniques used in the program. Staff from ECT will work with the program manager to develop an environmental monitoring plan, conduct training to implement the plan, provide day-to-day guidance on monitoring, and provide an interpretive report of monitoring activities.

The following is list of pertinent laws and Executive Orders:

National Environmental Policy Act (NEPA) – NEPA requires all Federal agencies to examine whether their actions may significantly affect the quality of the human environment. The purpose of NEPA is to inform the decision-maker prior to taking action and to inform the public of the decision. Actions that are excluded from this examination, actions that normally require an Environmental Assessment, and actions that normally require Environmental Impact Statements are codified in APHIS' NEPA Implementing Procedures located in 7 CFR 372.5.

The three types of NEPA documentation are:

1. **Categorical Exclusion**

   Categorical exclusions are classes of actions that do not have a significant effect on the quality of the human environment and for which neither an environmental assessment (EA) nor an environmental impact statement (EIS) is required. Generally, the means through which adverse environmental impacts may be avoided or minimized have actually been built into the actions themselves (see 7 CFR 372.5(c)).

2. **Environmental Assessment (EA)**

   An EA is a public document that succinctly presents information and analysis for the decision-maker of the proposed action. An EA can lead to the preparation of an environmental impact statement (EIS), a finding of no significant impact (FONSI), or the abandonment of a proposed action.

3. **Environmental Impact Statement (EIS)**

   In the event that a major Federal action may significantly affect the quality of the human environment (adverse or beneficial), or, the proposed action may result in public controversy, an EIS is prepared.

Endangered Species Act (ESA) – This statute requires that programs consider their potential effects on federally protected species. The ESA requires programs to identify protected species and their habitat in or near program areas and documentation of how adverse effects to these species will be avoided. The documentation may require review and approval by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service before program activities can begin. Knowingly violating this law can lead to criminal charges against individual staff members and program managers.

Migratory Bird Treaty Act – This statute requires that programs avoid harm to migratory bird species, eggs, and their nests. In some cases, permits may be available to capture birds, which require coordination with the U.S. Fish and

Wildlife Service.

Clean Water Act – This statute requires various permits for work in wetlands and for potential discharges of program chemicals into water. This may require coordination with the Environmental Protection Agency, individual states, and the Army Corps of Engineers. Such permits would be required even if the pesticide label allows for direct application to water.

Tribal Consultation – This Executive Order requires formal government to government communication and interaction if a program might have substantial direct effects on any federally-recognized Indian Nation. This process is often incorrectly included as part of the NEPA process, but must be completed prior to general public involvement under NEPA. Staff should be cognizant of the conflict that could arise when proposed federal actions intersect with tribal sovereignty. Tribal consultation is designed to identify and avoid such potential conflict.

National Historic Preservation Act – This statute requires programs to consider potential impacts on historic properties (such as buildings and archaeological sites) and requires coordination with local State Historic Preservation Offices. Documentation under this Act involves inventorying the project area for historic properties and determining what effects, if any, the project may have on historic properties. This process may require public involvement and comment prior to the start of program activities.

Coastal Zone Management Act – This statute requires coordination with states where programs may impact Coastal Zone Management Plans. Federal activities that may affect coastal resources are evaluated through a process called “federal consistency”. This process allows the public, local governments, Tribes, and state agencies an opportunity to review the federal action. The federal consistency process is administered individually by states with Coastal Zone Management Plans.

Environmental Justice – This Executive Order requires consideration of program impacts on minority and economically disadvantaged populations. Compliance is usually achieved within the NEPA documentation for a project. Programs are required to consider if the actions might disproportionally impact minority or economically disadvantaged populations, and if so, how such impact will be avoided.

Protection of Children –This Executive Order requires federal agencies to identify, assess, and address environmental health risks and safety risks that may disproportionately affect children. If such a risk is identified, then measures must be described and implemented to minimize such risks.

Appendix

C

Comments and Feedback

Considerations

The NPRG production team focuses on the technical scientific methods found in the literature that may be useful to the agency when taking action on a new pest. We attempt to balance scientific rigor with program feasibility but are not involved in the decision making processes. In order to improve our ability to balance what we find in the literature with what is possible in the field, we would like you to answer the following questions after using this document. Please email a copy of the NPRG after answering the questions below to PPQ.NPRG@usda.gov.

Name:

Organization:

Contact (please include contact information if you would like us to reach out to you in response to your comments):

Which parts of the NPRG did your group find most useful?

Which parts of the NPRG were not useful, or were unclear?

What could be added to future NPRGs to make them more useful?

If there is not enough space for your responses to the questions above, or if you have specific feedback about this NPRG, please use track changes or insert comments into the document itself.

Thank you!

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V. mandarinia

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Cover Image

Vespa mandarinia found in Washington State, December, 2019. Photos by Sven-Erik Spichiger, Washington State Department of Agriculture.