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Assessment of an inexpensive trap design and survey method for vespine wasps (Hymenoptera, Vespidae, Vespinae)

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Abstract

The introduction of the predatory Giant Asian Hornet, *Vespa mandarinia* Smith, to North America in 2019 has motivated efforts to create early detection systems for this and other non-native social wasp species (Hymenoptera, Vespidae). Various trap and bait combinations have been used for this purpose, most of which require assembly and materials that are costly, reducing their usefulness in large-scale survey systems. This study tests an inexpensive and efficient trapping technique for detecting or surveying vespine wasps. Traps were made from reused plastic bottles containing a brown sugar and water bait. They were deployed at heights ranging from 0–6 m above ground in several configurations. Captures for traps suspended 1 m or greater above ground were, on average, nine times higher than the catch of ground-level traps. A rapid trap deployment method for large geographic areas was created, which captured seven different vespine wasp species along a 395 km east-west road transect from mountains to coastal plain in the Mid-Atlantic region of the United States. The trapping design and survey methodology described below is inexpensive and fast and could be used by land managers or citizen scientists to detect *V. mandarinia*, other exotic vespine, or conducted on a large-scale vespine diversity survey.

Keywords

Baited trap, detection, *Dolichovespula,* exotic species, trap deployment, *Vespula*

Introduction

Over the last several decades, there has been increased concern over the spread of exotic insect species due to international container shipping (Hulme 2009; Meurisse et al. 2019). Such species threaten native plant and insect communities both ecologically and economically. Vespid wasps are of particular concern because of the threat they pose to native pollinators. Until the appearance of *Vespa mandarinia* in the Pacific Northwest, there were no large-scale surveys for vespid species detection.

Fear over exotic wasp species introduction into North America spiked in 2019 with the arrival of the Giant Asian hornet. *V. mandarinia* is the largest bodied of any vespid (Hymenoptera, Vespidae) and is known for its ability to eradicate a bee colony in a matter of hours (Stankus 2020). Additionally, *V. mandarinia* can repeatedly deliver painful stings to humans which have caused extreme allergic reactions, resulting in 30–50 deaths per year in Japan (Stankus 2020). Models by Alaniz et al. (2020) predict damages between \$12 and \$102 million for bee-dependent products alone if *V. mandarinia* were to spread across the United States. Several established nests were found and eradicated in the Pacific Northwest, but other unverified sightings in the region have led many scientists and public officials to call for greater detection efforts (Stankus 2020; Animal and Plant Inspection Service 2021). There is a need for an inexpensive and reliable trap design that can be used for the coordinated detection of *V. mandarinia* over a large geographic range.

V. mandarinia has never been detected on the east coast of the United States, but other vespine species occupy the area and provide a proxy for testing *V. mandarinia* trapping methods. The most efficient way to detect vespine wasps related to *V. mandarinia* is through lethal trapping (Tripodi and Hardin 2020). Traps for vespine wasps often consist of a plastic bottle (usually a 1.5 L soda bottle or a gallon jug) filled with a liquid bait and hung from a tree branch (Dvorak 2007; Tripodi and Hardin 2020). Whether these traps are as effective when left on the ground is evaluated in this study.

Sugar-based foods are known to be effective bait for trapping some vespine species (Dvorak and Landolt 2006; Demichelis 2014; Tripodi and Hardin 2020). It is common for traps to contain a syrup or sugar mixture often with vinegar and fruit added, but a simple mix of dark brown sugar and water has proven effective if given enough time to ferment (Wegner and Jordan 2005; PDA 2020). Dark sugar bait was recommended by the Washington State Department of Agriculture in response to the first *V. mandarinia* detection (Tripodi and Hardin 2020).

In this study, a basic bottle trap with dark brown sugar bait was tested in the Mid-Atlantic region of the United States as an inexpensive and efficient method that could be used by seasonal technicians or citizen scientists to detect *V. mandarinia* or to survey other social wasp species that are attracted to fermented sugar baits. The bottle trap was tested at different heights, from ground level to 6 meters, and in different settings using a deployment method along roads in the region. Seven vespine species were detected from the genera *Vespula*, *Dolichovespula*, and *Vespa*.

Methods

Three experiments were run with identical bottle traps and sugar bait: 1) A hanging/ground experiment with paired and unpaired trials to compare the success of suspended and standing traps; 2) an elevated trap test that compared trap success at five heights from 0 to 6 m, and 3) a 395 km long transect, with traps deployed across multiple ecoregions.

Bottle trap design

The traps were made from recycled water or soda bottles, ranging from 0.47 to 1 L. The bottles were retrieved from recycling facilities and rinsed before use. Each trap was baited with a sugar-water mixture of the ratio of 0.47 L of dark brown sugar to 3.8 L of water. The bottles were filled halfway, to allow enough space for a large catch. For hanging traps, a string was knotted around the neck of the bottle and the trap was hung off the ground. Ground traps were placed on the ground. Over 2–4 weeks, the sugar mixture fermented, attracting wasps, hornets, and yellowjackets, which crawl through the bottle opening and are unable to navigate back out. Some by-catch of other insects occurred but was not quantified. By-catch primarily included ants, moths, and flies, with fewer than 10 individual bees trapped across all experiments. Bottles placed on the ground appeared to attract more by-catch than those that were hung. Bottle screw caps were retained for ease in transporting traps after collection. For a diagram and instructional video on trap construction, see Suppl. material 2: Fig. S1 and https://www.youtube.com/watch?v=AonF4bqs04k.

Survey area

This study was conducted in the Mid-Atlantic portion of the United States, primarily in the state of Maryland. The first two experiments were conducted at the United States Geological Survey's (USGS) Native Bee Inventory and Monitoring Lab (BIML) located on the United States Fish and Wildlife Service's Patuxent Research Refuge (Laurel, Maryland, USA). Some traps were also placed in the surrounding community of Laurel, Maryland. The east-west road transect was performed on a route that started in Pennsylvania near the Maryland border (39°45'06"N, 79°23'29"W), traversed west to east, and ended in New Castle, Delaware near the Delaware River (39°39'35"N, 75°33'50W), staying between the latitudes of 39.5°N and 39.8°N (Fig. 1). The total route was approximately 395 km long and primarily used two-lane country roads that ran parallel to larger highways.

Hanging/ground trap experiment

Two tests were conducted to compare the yield of traps placed on the ground versus hanging traps 1.25–1.5 m above the ground. Both a paired and unpaired trap test was conducted. The paired trap test examined vespine preference when both trap heights

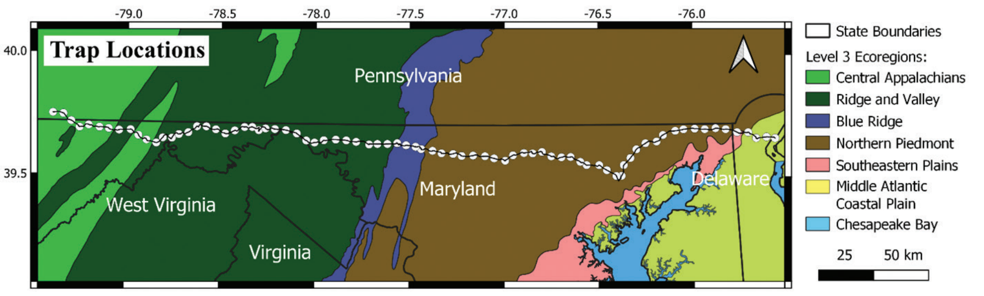

Figure 1. Trap locations and route of the east-west road transect. Trap locations (white dots) and route (black line) with state boundaries and level 3 ecoregions of the Environmental Protection Agency (Comeleo 2010).

are simultaneously present. The unpaired trap test shows differences in vespine attraction to traps at each height.

The paired trap test placed hanging and ground traps together, with ground traps directly under the hanging traps. Fifteen trap pairs were placed around Laurel, Maryland, primarily in the Patuxent Wildlife Refuge around the BIML. The same bottle type was used for each pair. They were left in place for three weeks between July 10th and August 16th of 2021.

The unpaired trap test placed 15 hanging and 15 ground traps at least 10 meters apart. The test was conducted in the area around the Native Bee Inventory and Monitoring Lab and the traps remained in place for three weeks, from August 2nd to August 23rd.

Elevated trap experiment

To test the catch yield of traps at different heights, 10 lines of paracord were hung around the BIML grounds, half of which were in open fields and the other half in a deciduous forest that was approximately 70 years old. Traps were tied to each line at heights of 6 m, 3 m, 1.5 m, .6 m, and ground level. The traps were left for 3-week periods between August 17th and September 21st.

395 km east-west road transect

During the trap deployment, the Gaia GPS app was used to track the distance from the start of the route. The surveyor stopped every five kilometers, or the closest possible pull-off point thereof, to deploy a trap. At each survey point, a waypoint was taken on the Gaia GPS app and the current location was saved in a folder on the Google Maps app. Each waypoint/location was named after the trap number, which was written on the trap before it was placed. Ground traps were placed in a sheltered area, (e.g., higher vegetation or at the base of signs, guardrails, or telephone poles). A marking flag was placed closer to the road so the ground traps would be easier to find during collection. Hanging traps were placed 1–1.5 m off the ground, usually on telephone poles or tree branches. For each trap, the surveyor recorded the trap number, distance from the start of the route, steps from the marking flag (for ground traps), and any additional notes for locating the trap.

The ground traps were deployed July 21st and 22nd and collected 21 days later on August 11th and 12th. The hanging traps were deployed in the same locations as the ground traps on August 19th and 20th and collected 21 days later, on September 9th and 10th. The locations saved on Google Maps were used to navigate from one trap to the next, with the surveyor spending no more than five minutes looking for the trap. During trap collection, the state of the trap was recorded as in-place, disturbed, or lost. Traps were capped and brought back to the USGS Native Bee Inventory and Monitoring Lab, Laurel MD for processing.

Sample processing

Trap catch was processed identically for all experiments. The catch of each trap was emptied into a mesh sieve and rinsed before being transferred to a wide, white tray filled with a few centimeters of water. Each species was counted and discarded. Uncertain identifications were retained for identification at the Native Bee Inventory and Monitoring Lab.

Data analysis

Non-parametric statistics were used for comparisons of trap results as the data weren't normally distributed. To compare the hanging/ground trap yields for statistically significant differences, non-parametric tests of two sample medians were conducted. A Mann-Whitney U test was performed to evaluate any statistical difference between two unpaired samples and a Wilcoxon test was performed to evaluate any statistical difference between two paired samples. For the hanging and ground trap comparison of the east-west road transect, paired traps included only trap locations with a usable hanging and ground trap result (thus paired by location) while unpaired traps included all usable traps from each group. To test the difference in total catch medians for the five heights of the elevated traps, a Kruskal-Wallis non-parametric ANOVA test was used. A Mann-Whitney pairwise test compared the overall catch of each combination of trap heights for statistically significant differences.

All test statistics were calculated using Paleontological Statistics Software Package (PAST), Version 4.07 (Hammer 2001), a data analysis software that performs a variety of statistical tests and data manipulation functions.

Results

Hanging/ground trap experiment

A Wilcoxon paired test of medians showed that hanging traps caught significantly more vespine individuals than the paired ground traps ($p \leq .001$). Likewise, a Mann-

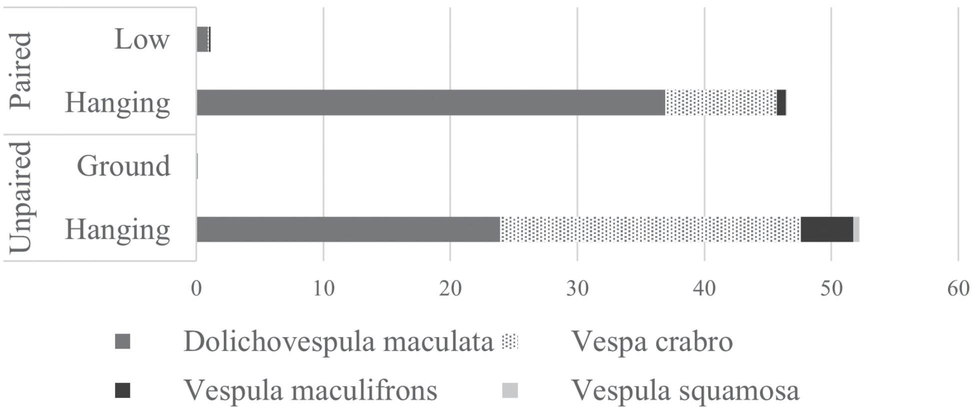

Figure 2. Average yield of hanging/ground trap experiment. Results are separated into paired and unpaired tests and average yield is categorized by species.

Table 1. Summary statistics of hanging and ground traps on the east-west road transect.

Statistics	Ground	Hanging
Number of traps set	79	77
Count of traps collected	59	72
Traps lost (%)	25	5
Minimum catch	0	0
Maximum catch	45	61
Total catch	145	942
Mean catch per trap	2.5	13.1
Std. error	0.9	1.9
Median catch per trap	0	6

Whitney U test showed the same result for the unpaired trap results ($p \leq .001$). Summing across both paired and unpaired test results, hanging traps caught 98.8% of all individuals, while ground traps caught 1.2% (Fig. 2). There was a large amount of variability in overall yield amongst the hanging traps, with captures ranging from 0 to 162 individuals per trap. Four different species were found in the hanging/ground trap experiment. For more summary statistics, see Suppl. material 1: Table S1.

Elevated trap experiment

The ground level (0 m) traps had the lowest average catch, followed by the 6 m trap, while the three highest traps averaged within two individuals of each other (Fig. 3). A Kruskal-Wallis non-parametric ANOVA test showed a statistically significant difference between the total catch sample medians ($p = .001$). A Mann-Whitney pairwise test showed the total catch at the ground level was significantly lower than all other heights. There was no significant difference in total catch between the other heights.

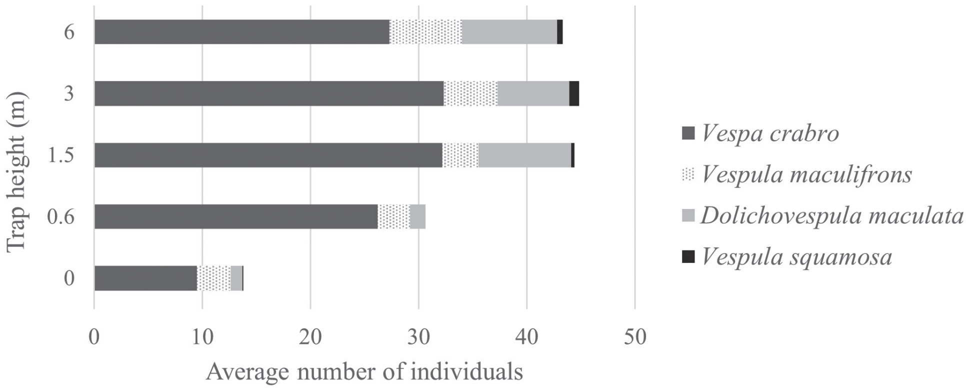

Figure 3. Average catch at each height of the hanging line traps. Includes the average number of individuals from each of the four species detected.

395 km east-west road transect

The east-west road transect intersected five EPA Level III ecoregions (Comeleo 2010), traversing from a high of 800 meters down to just above sea level, and sampled a varied landscape calculated predominantly as forested (41.1%), agricultural (29.3%), or developed (26.0%) using the 2019 National Land Cover Database.

Hanging traps had a significantly higher overall yield than ground traps for a paired test ($p \leq .001$) and an unpaired test ($p \leq .001$). Five percent of the hanging traps were lost (4 of 77) compared to 25 percent of the ground traps (20 of 79) (Table 1). Hanging traps had an average overall catch that was approximately five times larger than ground traps, containing seven different species compared to the five caught by ground traps (Table 2). The seven species detected include *Vespula maculifrons* (du Buysson), *Vespa crabro* (Linnaeus), *Dolichovespula maculata* (Linnaeus), *Vespula flavopilosa* (Jacobson), *Vespula germanica* (Fabricius), *Vespula squamosa* (Drury), and *Dolichovespula arenaria* (Fabricius). For more summary statistics and the original data of the east-west road transect including trap locations, landscape attributes, and catch results, see Suppl. material 1: Table S2, S3.

Discussion

The results of this study demonstrate that a 1–1.5 m hanging trap design, consisting of a re-used plastic bottle and a dark brown sugar bait mixture, is effective at trapping a diverse group of vespine wasps. Hanging traps performed, on average, nine times better than ground-based traps in overall catch across all experiments, and five times better in trap loss as shown by the east-west road transect, with an overall trap loss of only 5%. The elevated trap test demonstrated that ground-level placements perform significantly worse than all other heights, with traps 1.5 m and above performing similarly in their total catch.

Table 2. Summary statistics of species found on the east-west road transect. This includes the mean number of individuals per trap (standard error in brackets), maximum in one trap, and percent occurrence, which is the percent of traps with at least one individual from that species. The median catch for all species is zero except for the *V. crabro* and *V. maculifrons* in the hanging traps, which had median values of 1 and 2 respectively.

Species	Ground			Hanging		
	Mean per trap	**Max**	**Occurrence (%)**	**Mean per trap**	**Max**	**Occurrence (%)**
Vespula maculifrons	0.83 (0.29)	12	22.0	4.96 (1.09)	56	70.8
Vespa crabro	1.14 (0.63)	32	8.5	4.36 (0.93)	35	51.4
Dolichovespula maculata	0.15 (0.09)	5	8.5	1.31 (0.29)	17	47.2
Vespula flavipolosa	0.07 (0.05)	3	3.4	1.06 (0.42)	26	23.6
Vespula germanica	0	0	0	0.74 (0.33)	18	13.9
Vespula squamosa	0	0	0	0.64 (0.20)	11	25.0
Dolichovespula arenaria	0.27 (0.14)	6	10.2	0.03 (0.02)	1	2.8

The road transect captured seven of the ten vespine species recorded in the Maryland Biodiversity Project, a non-profit citizen science project that has cataloged over 11,000 insect species in Maryland (Maryland Biodiversity Project 2021). The vespine species captured includes all but one of the species listed with more than one confirmed sighting.

The biggest asset of this trap design and deployment technique is its accessibility and cost. Assuming bottles are freely collected from a recycling facility or receptacle, as these were, the only material expenses are for the dark brown sugar and string. For those materials, we estimate the per trap cost to be approximately $0.15. The only major expenses are gas and time. Approximately six traps spaced five km apart can be deployed or collected in an hour.

This trap design and a road transect deployment could be used to detect *V. mandarinia* and other exotic vespine species or as an inexpensive assessment of the component of regional vespine species that are attracted to fermenting sugar bait. This study demonstrated how many traps can be deployed inexpensively over a large geographic range. A small group of technicians could survey a large area using these traps and a methodology similar to the Breeding Bird Survey (Dunn et al. 2000). One example of this would be to divide the survey area into a grid of equal cell size or with cells oriented around physiographic strata. A point randomly generated within each cell and traced to the nearest road could be used as a starting point for a 25 km transect, with traps hung on the side of the road every kilometer. Two of these transects could be deployed or collected per day, meaning one technician could complete approximately 48 of these transects (1200 traps) in three months, given pick-up after three weeks and one day per week for sample transfer and storage into a freezer for later identification.

Additionally, the trap design would be ideal for a citizen science-based protocol for more large-scale surveys. Citizen science is growing in popularity as a method for surveying plants and wildlife, including exotic species. Pusceddu et al. (2019) used a verified citizen science program to monitor the spread of an invasive vespid species (*Vespa crabro*) on the island of Sardinia (Italy). The program reported high data accuracy and civil engagement.

Citizen science-based reporting could be a valuable tool for detecting and exterminating any *Vespa mandarinia* that find their way to North America. The US Department of Agriculture (USDA) called on scientists of the Pacific Northwest to assist with the detection of *V. mandarinia* after they first arrived in 2019 (Tripodi and Hardin 2020). The

Washington Department of Agriculture has launched a 2021 Asian Giant Hornet Public Dashboard to continue these efforts using citizen scientist reporting (WSDA 2021).

The hanging trap and sugar-based bait tested in this study have shown to be effective at catching vespine wasps in high densities, and they would likely be effective as a passive, lethal trap for *V. mandarinia*. We recommend that this method of trapping be explored further as a widespread, citizen scientist approach for the detection of *V. mandarinia*. Unlike similar citizen science methodology, our trap design doesn't require that land managers ship trap materials to participants (PDA 2020).

While inexpensive and accessible, these traps may not equally attract all vespine species (Dvorak 2007) and there could be high variance throughout the summer due to changes in dietary preferences (Stankus 2020; Tripodi and Hardin 2020). Similar traps have reportedly been used by Japanese farmers to capture and kill dispersing *V. mandarinia* queens in the spring and late fall (Tripodi and Hardin 2020), however future study is required to confirm the effectiveness of this trap design for *V. mandarinia*, and specifically for *V. mandarinia* queens if the design is to be used as a lethal capture to prevent species dispersal from year to year. Additionally, in any future study, we recommend that species and numbers of by-catch be recorded to assess the impact on non-target species.

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Supplementary material 1

Tables S1–S3

Authors: Grady O. Jakobsberg, Jacqueline R. Sanchez

Data type: Tables and figures.

Explanation note: Table S1. Summary statistics of trap results for unpaired and paired hanging and ground traps, including the mean catches for the four species found. Table S2. Trap location statistics of east-west road transect. Landscape statistics are given as the percentage of each type within one kilometer of the trap location. Wetland/open water and grassland/shrubland classifications are not included due to low median percentage values of 0.20 and 0.40 respectively. Elevation data were obtained from the Gaia GPS trap location waypoints. Landscape statistics were derived in QGIS using the 2019 National Land Cover Data (Dewitz 2021), the 2016 Tree Canopy Cover (USDA Forest Service, 2019), and the EPA's Level III Ecoregions of North America (Comeleo 2010). Table S3. Trap locations, attributes, and catch statistics. Includes (from left to right): latitude coordinates, longitude coordinates, trap number, deployment date for ground traps, collection date for low traps, deployment date for high traps, collection date for high traps, usable low traps (1 means usable, 0 means unusable), usable high traps (1 means usable, 0 means unusable), elevation (in meters), level 3 ecoregion of the trap, the percentage of water/wetland within 1 km of the trap, percentage of developed land within 1 km of the trap, percentage of forested land within 1 km of the trap, percentage of grass or shrubland within 1 km of the trap, percentage of cropland or pasture within 1 km of the trap, percentage of tree canopy within 1 km of the trap, species counts for low traps (separated by species), total catch for low traps, species count for high traps, and total catch for high species. Elevation data were obtained from the Gaia GPS trap location waypoints. Landscape statistics were derived in QGIS using the 2019 National Land Cover Data (Dewitz 2021), the 2016 Tree Canopy Cover (USDA Forest Service, 2019), and the EPA's Level III Ecoregions of North America (Comeleo 2010).

Link: https://doi.org/10.3897/jhr.89.80284.suppl1

Supplementary material 2

Figure S1

Authors: Gabrielle A. Jakobsberg, Grady O. Jakobsberg

Data type: Image.

Explanation note: Illustrated diagram of hanging and ground trap placement for educational purposes. Not to scale.

Link: https://doi.org/10.3897/jhr.89.80284.suppl2