Flower-Visiting by the Invasive Hornet *Vespa Velutina Nigrithorax* (Hymenoptera: Vespidae)

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***Abstract*—**The Asian hornet or yellow-legged hornet *Vespa velutina nigrithorax* has recently been recorded as an invasive insect evoking environmental, apicultural and medical problems. Many aspects of the ecology, behavior and life history remain unknown, however. The present study focuses on flower-visiting by the hornet in the field. The foraging behavior of *V. velutina nigrithorax* on and around blooming plants was observed in Tsushima Island, Japan and Busan City, South Korea. The field observations confirmed that the hornet fed on floral nectar of 27 plant species scattering among 15 families. Pollen feeding was not observed. In addition, it was frequently found that *V. velutina nigrithorax* flew and hovered around a patch of flowers to predate hymenopteran bees and dipteran flies. Hunting behavior was recorded on 20 plant species belonging to 10 families. Field observations and mark-recapture experiments suggested that *V. velutina nigrithorax* played a role in pollinating at least some plant species. Although numerous hornet workers were found visiting flowers in the public area such as the park, school, hospital and home garden, none of them showed aggressive behavior against humans. Thus, flower-visiting *V. velutina nigrithorax* away from the nest did not pose a threat or risk associated with hornet stings.

***Keywords*—**foraging behavior, invasive species, honeybee, hornet stings, pollinator, predator, yellow jackets.

I. Introduction

HYMENOPTERAN insects such as bees and wasps are a well-known group of insects that visit flowers [1—4]. They are important pollinators, and flower-visiting bees and wasps obtain, as a reward of pollination, nectar and pollen from flowers [1, 4]. Nectar and pollen are nutritionally superior to other plant materials and are a main food source for many bees and wasps. Like other hymenopteran bees and wasps, hornets and yellow jackets (Vespidae) require carbohydrates as a key energy source; floral nectar is one of the major sugar resources for them [5, 6]. In fact, hornets and yellow jackets are frequently observed visiting flowers to feed on nectar [5, 7].

Because flower visiting is intimately associated with the ecology and life history of hornets and yellow jackets and because resources obtained from flowers should be a significant determinant of their reproductive success, flower-visiting behavior of hornets and yellow jackets is an important research subject in their ecology and life history evolution.

The present study focuses on flower visiting by the invasive hornet *Vespa velutina nigrithorax*. *Vespa velutina* has a wide range of distribution in Asia and is divided into several subspecies on the basis of the external morphology, *i.e.*, color and marking patterns [8]; the subspecies *nigrithorax* is natively distributed in southern China and northern India. However, in 2000's, this subspecies was unintentionally introduced into Europe and Korea, where it has been increasing the populations and expanding the range [9—11]. More recently, *V. velutina nigrithorax* has been found established in Tsushima Island of Japan in 2013 [12, 13]. Further, a nest of this hornet was discovered in Kitakyushu City, mainland Japan in 2015 [14]. Thus, the hornet has been extending its range in East Asia.

Vespa velutina nigrithorax is recognized as an invasive species [10, 11]. As with the case in many non-native introduced species, alien *V. velutina* in areas of invasion can evoke a number of problems. Currently it is believed that environmental, apicultural and medical problems may arise if invasive *V. velutina nigrithorax* is established and increases its population; (1) it can negatively affect native ecosystems because it is a powerful generalist predator; (2) the hornet may damage apiculture because it is a skillful and persistent hunter of honeybees; and (3) it should attack humans when disturbed as with other hornets and yellow jackets [10, 13]. Because of these problems, the management of *V. velutina nigrithorax* is on strong demand. However, many biological aspects of this hornet, *e.g.*, ecology, physiology and life history, are still unknown. The information is crucial to assessing the problems that the hornet will evoke and to developing the effective control methods.

In the present paper, I describe the flower-visiting behavior of *V. velutina nigrithorax*, an ecological aspect poorly reported previously, and reveal that the hornet visits flowering plants not only to feed on nectar but to hunt prey. The present paper provides a list of flowering plants that the hornet uses for feeding on nectar and for searching prey. Further, based on the field observations and mark-recapture experiments, I discuss that *V. velutina nigrithorax* plays a role as a pollinator.

II. Materials and Methods

A. Localities

Field surveys were made in Tsushima Island, Nagasaki Prefecture, Japan and Busan City, South Korea. Tsushima Island is situated off the northern Kyushu mainland of Japan. Busan Metropolitan City is the second largest city with the largest international port in South Korea. It is believed that the invasive hornet was unintentionally introduced from southern China into Busan in early 2000's and has been established in South Korea [11]. A population from Busan then invaded Tsushima in early 2010's [13, 15].

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B. Field Survey

The field surveys were made between April 2014 and October 2015 to find flowering plants that *Vespa velutina nigrithorax* visited. Hornets were searched in the field where blooms were found. When *V. velutina nigrithorax* were found, the foraging behavior of individual hornets in a patch of flowers was observed to examine the purpose of visiting plants that were blooming, and their behavior on or around flowers was noted. The species of plants that had been visited were also recorded. When possible, photographs were taken as evidence.

C. Mark-Recapture Experiment

To further confirm whether *V. velutina nigrithorax* could contribute pollination at least in some circumstances, a mark-recapture experiment was conducted under a field condition in Yongdusan Park, Busan, South Korea in November 2014, when *Camellia sasanqua* and a cross variety between *C. sasanqua* and *C. japonica* (Theaceae) were in full bloom. Numerous workers and occasionally males of *V. velutina nigrithorax* were observed visiting the flowers (Fig. 1a). Thirteen wasps (workers) of the hornet visiting *Camellia* flowers were captured with an insect net and were marked carefully on the thorax with a spot of quick drying yellow or blue paint. The marked wasps were then liberated; none of them immediately returned to the place of capture, and they flew to go somewhere. In all, 15 wasp workers were marked in the field experiment. The observation was continuously made to confirm whether the marked wasps returned to the same place to visit *Camellia* flowers.

III. Results

The invasive hornet *V. velutina nigrithorax* was commonly found in the park, school, hospital, parking lot and home garden that were adjacent to forests as well as in the forests in Busan City. It was also common at least in rural areas of northern Tsushima. Considerable time was spent to search plants that *V. velutina nigrithorax* visit the blooms. As the result, the hornet was recorded from 36 species of plants belonging to 17 families (Table I). The field surveys and observations showed that *V. velutina nigrithorax* visited flowering plants to collect floral nectar from 27 species of plants belonging to 15 families (Table I, Fig. 1). In any of these plants, the hornets were not found feeding on the pollen.

The queens and workers of the hornet often carried the pollen of flowers that they had been visiting (Fig. 1). Also, the majority of the hornet visited flowers of the same plant species sequentially during a single trip. Repeated or sequential visiting on the same flowering species was observed for Camellia (n = 31 in Busan), buckwheat (n = 22 in Tsushima), Porcelain berry (n = 8 in Tsushima), bushkiller (n = 4 in Tsushima), loquat (N = 9 in Tsushima), and Canna (n = 22 in Busan). Flower visit by *Vespa velutina nigrithorax* could therefore help pollinating the flower.

TABLE I
PLANTS THAT *VESPA VELUTINA* VISITED AND THE PURPOSE OF VISITS

Plant family	Scientific name	Purposes/ Caste*
Amaryllidaceae	*Allium fistulosum*	N/W
Anacardiaceae	*Rhus javanica* var. *roxburgii*	H/W
Asteraceae	*Aster tripolium*	H/W
	Chrysanthemum x *morifolium*	H/W
	Dendranthema indicum	H/W
	Farfugium japonicum	H, N/W
	Solidago altissima	N/W, M
Araliaceae	*Aralia cordata*	H/W
	Aralia elata	H/W
	Eleutherococcus sp.	N/M, W
	Fatsia japonica	H, N/W, M
	*Hedera helix (?)***	H, N/W
	Hedera rhombea	H, N/W
Cannaceae	*Canna* x *generalis*	N/W
Clethraceae	*Clethra barbinervis*	H/W
Elaeagnaceae	*Elaeagnus multiflora*	N/Q
Euphorbiaceae	*Mallotus japonicas*	H/W
Lamiaceae	*Caryopteris incana*	H/W
	Elsholtzia ciliate	H, N/W
	Mentha suaveolens	H/W
Lauraceae	*Litsea japonica*	N/W
Mytraceae	*Callistemon speciosus*	N/W
	Melaleuca leucadendron	N/W
Oxalidaceae	*Oxalis corniculata*	H, N/W
Pittosporaceae	*Pittosporum tobira*	N/Q
Polygonaceae	*Fagopyrum esculentum*	H, N/W
	Reynoutria japonica	H, N/W
Rosaceae	*Eriobotrya japonica*	N/W, M
	Rhaphiolepis umbellata var.*integerrima*	N/Q
	Rubus crataegifolius	N/Q
	Rubus hirsutus	N/Q
Rutaceae	*Zanthoxylum ailanthoides*	H, N/W
Theaceae	*Camellia japonica* x *sasanqua (=hiemalis)*	N/W, M
	Camellia sasanqua	N/W, M
	Camellia sinensis	N/W
Vitaceae	*Ampelopsis brevipedunculata* var. *heterophyla*	N/W
	Cayratia japonica	H, N/W

* Purpose of visits are shown as H (hunting) and N (nectar feeding), and the caste of visitors as Q (queen), M (male) and W (worker).
**Difficult to correctly distinguish from hybrid varieties.

Hunting behavior was also observed on 20 plant species belonging to 10 families (Table I). *Vespa velutina nigrithorax* evidently selected the flowering stage of the plants to visit because the hornet was not found around non-flowering stages of the same plant species. With no exception, *V. velutina nigrithorax* searched prey insects while flying and hovering around flowers (Fig. 2). When they found potential prey, they chased and tackled the prey that had been visiting the flowers. The prey insects were mostly, hymenopteran bees (including European and Japanese honeybees) and dipteran flies. When the hornets successfully captured prey, they flew up to find a place that was ideal to handle the prey to chew up (Fig. 2 last photo). Then they carried the prey back to the nest.

In buckwheat flowers, individual *V. velutina nigrithorax* workers were occasionally observed to land on the flowers to feed on nectar during a single hunting trip. Also, some individuals evidently concentrated to search prey while the others visited the flowers exclusively to feed on nectar.

Among the 34 plant species recorded in the present study, 8 were planted for ornamental or horticultural purposes in the park, school, hospital, home garden, etc. Also, many other plants recorded were commonly found in those places. Thus, the general public was likely to commonly encounter the invasive hornet in the public place in the area of invasion.

The mark-recapture experiment confirmed that 10 out of the 15 marked workers returned to the same place where they visited the same flowering plant species again. The return was mostly observed within 20 min of release. This result indicated that the hornet memorized the place where nectar-producing flowers were available and visited the place repeatedly to collect floral nectar.

IV. Discussion

A. Flower Visiting by Vespa velutina

The present study has confirmed that *Vespa velutina nigrithorax* visits blooming 37 plants species, scattering among 18 families. The hornet *V. velutina* has already been recorded as a flower visitor but the purpose of visit was not recorded [16, 17]. The current paper has shown that the hornet visits the flowering plants with two distinct purposes: nectar feeding and prey hunting.

Fig. 1. Flower-visiting by *Vespa velutina nigrithorax* to feed on nectar. From left to right: on *Eleutherococcus* sp., *Canna generalis, Elaeagnus multiflora, Elsholtzia ciliate, Fagopyrum esculentum, Eriobotrya japonica, Camellia sasanqua, C. japonica x sasanqua*, and *C. sinensis.* Note that some hornets carried the pollen on their body.

On 27 species belonging to 15 plant families, the queen, male and/or worker of *V. velutina nigrithorax* feed on the nectar (Table 1; Fig. 1). Although there are no apparent taxonomical trends in plant species used by the hornet, many of flowers that are visited have rather exposed nectaries easily accessible, *e.g.*, umbellate flowers. This is evidently because the members of Vespidae, including *Vespa* spp., generally have a short proboscis, which does not enable the wasps to feed on nectar deep inside the flower [18]. The notable exception is found on Canna flowers whose nectary glands are concealed deep inside. However, *V. velutina nigrithorax* shows robbing behavior to feed on the nectar (Ueno, submitted). Hornets depend largely on carbohydrate food, and they often use tree sap as the main source [5]. Floral nectar is another important source of carbohydrates for them though the dependency may be weak [5]. In the present study, *V. velutina nigrithorax* has been found on flowers most frequently in autumn. This may be because tree sap is poorly available in the season.

The present study did not confirm pollen feeding by queens

and workers of *V. velutina nigrithorax* though pollen is known as an important, nutritionally rich food source for many hymenopterans visiting flowers [4, 19]. At least, several wasps belonging to Vespidae are demonstrated to consume pollen [19]. To exactly confirm whether *V. velutina* does not consume pollen, dissection experiments are needed to see the gut contents, and this will be done in a future study.

The foraging behavior of flower-visiting Hymenoptera has been well studied in the context of optimal foraging [20, 21]. Basically, the flower-visiting behavior is not random and bees are strongly selective to reduce foraging time, risk and cost while maximizing foraging efficiency. However, no available studies have focused on flower visiting behavior of the hornet *Vespa* spp. in terms of optimal foraging. It is unclear whether *V. velutina nigrithorax* selects the recorded plants on the basis of nectar-collecting efficiency. How the hornet chooses to visit blooming plants will be an interesting subject in future studies.

B. Hunting Behavior

The present study has confirmed that *V. velutina nigrithorax* hunt for insects on and around plants that are blooming. Hornets are among predatory wasps that prey a variety of arthropods, mainly insects [5].

Fig. 2. Flower-visiting by *Vespa velutina nigrithorax* to hunt the prey. From left to right: on *Elsholtzia ciliate*, *Chrysanthemum* x *morifolium*, *Mentha suaveolens*, *Rhus javanica* var. *roxburgii*, *Fatsia japonica*, and *Farfugium japonicum*. Note that *V. velutina* basically searches the prey while flying or hovering.

The prey is returned to the nest as food for their larvae. *Vespa velutina* is a well-known, skillful hunter of honeybees and is frequently observed hunting for honeybees in front of beehives [13, 22, 23]. It is also a predator of many other insects [24] but its foraging behavior, other than that in front of beehives, is relatively unknown. The present study has recorded 20 plant species around which the hornet searches prey. Evidently, there are no taxonomical or morphological tendencies of the plants recorded. The only shared feature among the plants that the observer can notice is that they attract many hymenopteran and dipteran insects, which are the main prey of *V. velutina nigrithorax*. Although the hornet may initially be attracted to the odor of flowers, it may select the hunting site on the basis of the abundance of potential prey gathering on the flowers. Curiously, on buckwheat, some workers exclusively fly around the flowers to find prey while the other individuals only visit and land on the flowers for collecting nectar. The individual role of *V. velutina* workers may be divided among them.

C. Hornets as a Pollinator

The mutualistic relationship between nectar producing plants and social bees (*e.g.*, honeybees and bumble bees) has been well documented [4, 21]. In general, social bees greatly contribute to pollination whereas they obtain nectar and pollen as a reward. The relationship between plants and hornets has received little attention but it appears that hornets are an opportunist visitor of flowers, and, under this condition, the relationship with flowering plants would be weak. Even so, hornets will pollinate flowering plants, at least in some degree.

No published literatures have confirmed whether *V. velutina nigrithorax* can contribute as a pollinator. The present study provides some evidence that the hornet plays a role in pollinating; in this study, it is found that (1) pollens are commonly attached on the body of *V. velutina*; (2) individual hornet workers sequentially visit the same flowering plant species during a single nectar-collecting trip; and (3) they individually visit the same flowering plant species repeatedly.

First, in the field observations, it was often found that queens and workers of *V. velutina nigrithorax* were with pollens

on their thorax and abdomen (Fig. 2). The observations indicated their potential contribution to pollination. Second, each *V. velutinal nigrithorax* was found repeatedly visiting flowers of the same plant species during any single flower-visiting trip. The individual hornets, which were often with pollens on their body, were likely to pollinate the flowers during the trip. Third, the mark-recapture experiment confirmed that the individual hornets repeatedly travel to the same place where they visited the same plant species that were flowering. Taken together, it is concluded that *V. velutina nigrithorax* can contribute pollination at least in some circumstances.

D. Threat and Risk to Humans

Many people recognize hornets as frightening creatures that may attack and sting them. Hornet stings are not only painful and scary but also could be fatal if a severe allergy reaction called anaphylaxis is evoked [5]. In Japan, around 10-20 people die every year due to hornet stings [13] though the incidence caused by *V. velutina nigrithorax* has not occurred yet in the country. However, the number of people stung by this invasive hornet has been increasing in Tsushima Island, Japan (Ueno, unpublished), and a great care should be taken to avoid the stings.

It is widely known that hornets are not aggressive when they are away from the nest [5, 6]. In fact, *V. velutina nigrithorax* foraging around flowers did not show any aggressive behavior during the current study. They did not attack the observer and just flew away when disturbed or even after captive workers had been released. In the present study, numerous workers of the hornet were found in the public areas close to forests in the city of Busan (park, hospital, school, street, *etc*.). This was particularly true in the place where plants that were blooming were present. Among the 35 plant species recorded in the present study, 10 were planted ornamental or horticultural purposes in the public place like the park, school, hospital, and home garden. However, none of the hornet showed aggressive behavior against humans; in fact, people appeared not to recognize the presence of *V. velutina nigrithorax* even when they were flying near them. Thus, unless *V. velutina nigrithorax* are near the nest, they will not pose a threat or risk to the general public.

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