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Distribution, spread, and impact of the invasive hornet *Vespa velutina* in South Korea

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ABSTRACT

Hornets (*Vespa* spp) are top insect predators that can control pests, but their venomous stings and defensive behavior cause numerous human deaths throughout Asia. Hornets usually inhabit rural areas which reduces potential conflict with humans. In 2003, the invasive hornet, *Vespa velutina,* arrived in southern Korea (Yeongdo region) and became established. It is currently spreading northwards at a rate of 10–20 km per year. Despite originating in tropical/subtropical areas of Indo-China, its nesting biology and life cycle in South Korea are similar to those found throughout its native range, with mature colonies containing 1000–1200 adults. In 7 years, *V. velutina* has become the most abundant hornet species in Southern Korea by displacing native *Vespa* species such as *V. simillima,* which has a similar nesting biology. We also found a significant positive correlation between the abundance of *V. velutina* and the degree of urbanization, indicating that this invasive species was well adapted to urban environments. This was supported by our finding that 41% of emergency call-outs (119 Rescue Services) to deal with social wasps/hornet problems were due to *V. velutina,* which was twice as high as the number of calls about the next most abundant species. The rapid spread of *V. velutina* across southern Korea indicates that this species will continue to spread north-westward in the Korean peninsula and will become a major problem as more people and beekeepers come into contact with this aggressive invasive hornet.

Introduction

Climate change is predicted to alter the range of many species, including allowing the expansion of invasive species (Hill et al., 2010). A tropical/subtropical species of hornet, *V. velutina nigrithorax,* was recorded for the first time in South Korea in 2003 (Kim et al., 2006) and in France in 2004 (Haxaire et al., 2006). Both of these countries have a temperate climate. Their subsequent rapid spread has impacted human activities and the native fauna. *V. velutina* is now considered a serious invasive pest in France (Chauzat and Martin, 2009; Haro et al., 2010) and potentially in South Korea. The native range of *V. velutina* is the tropical and subtropical regions throughout most of Indo-China, Indonesia, and Taiwan (Archer, 1994; Martin, 1995; Carpenter and Kojima, 1997). *V. velutina* normally occurs in the cooler mountainous highland areas throughout its native range (Martin, 1995) and so may be pre-adapted to exploit temperate environments. The southern parts of South Korea are undergoing environmental (e.g. Kim, 2007) and vegetation (Park et al., 2010) changes, resulting in a more subtropical climate. Correspondingly, ten different subtropical butterfly species are now recorded in South Korea (Park et al., 2006) and the tropical cricket, *Lycorma delicatula,* has spread throughout the country since 2004 (Korea Forest Research Institute, 2007).

V. velutina adults can catch honeybees in flight as they return to the colony. The native Asian honeybees (*Apis cerana*) have evolved a 'heat-balling defense' warning behavior when hornets are patrolling near their nest entrance (Tan et al., 2005). However, European honeybees (*Apis mellifera*), which are commonly reared by Korean beekeepers, do not possess this behavior and are more susceptible to attack from *V. velutina* (Shah and Shah, 1991; Abrol, 1994; Tan et al., 2007). South Korea has six native hornet species, *V. analis, V. mandarinia, V. simillima, V. crabro, V. ducalis,* and *V. dybowskii*. The adult size, nest structure, nesting habits, and population size of *V. velutina* are very similar to *V. simillima,* a species that inhabits more temperate regions of Asia, including South Korea (Matsuura, 1973; Martin, 1995). Therefore, *V. simillima* may be in direct competition with *V. velutina*. Even in its native range, *V. velutina* is one of the most aggressive and feared hornets (Martin, 1995) and may pose a serious risk to humans if they move into more urban areas. The purpose of this study is to examine the spread of *V. velutina* across South Korea during the past 7 years, and its habitat preferences, damage, and impact on native *Vespa* composition.

Materials and methods

Study area

In 1997 to 2001, all native hornet colonies or adults were surveyed by trapping and netting in the Busan city area. After the arrival of *V. velutina* in 2003, nine cities (Yangsan, Ulsan, Jinhae, Masan, Gyeongju,

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Cheongdo-gun, Haman-gun, Gyeongsan and Daegu) within 200 km of Busan city were monitored by trapping adult hornets. During 2010, we conducted a detailed study in Busan city by trapping and netting adults at 75 locations throughout Busan city that represented all grades of urbanization. We also collected adults of all destroyed hornet nests collected by 119 Rescue Services (emergency call-outs) within the Geumjeong-gu region of Busan city. Busan city has a temperate climate that is strongly influenced by oceanic currents. It is located at the far southeastern end of the South Korean peninsula. It is a large city with a population of 3.5 million, and is home to the country's largest trading port. It is surrounded by mountains and forests and has many parks and green areas that provide excellent habitats for many species of hornets.

Classified urbanized grade

The distribution of hornets is greatly influenced by the availability of nesting sites, which fall into two main categories: (i) underground or enclosed (cavity) nests representative of *V. mandarinia* and *V. crabro*, and (ii) open nests typical of *V. analis*, *V. simillima,* and *V. velutina* (Matsuura, 1984; Martin, 1995). Because Busan city covers a region in which both forest and urban areas coexist, we classified the degree urbanization into five grades for each collection area. Grading was estimated by the percentage of green or urban coverage (modified percentage of vegetation and pavement/building cover [Zanette et al., 2005]) of a 100×100 m^2 area around the 75 collection sites. Grade 1 indicates nature forest regions with no artificial features; Grade 2 is the forest edges adjacent to city with <25% urbanization; Grade 3 is the urban areas with large wooded parks within the city or university campuses (urbanization 50%); Grade 4 is the regions such as small community parks, river terraces, or gardens with <75% urbanization; Grade 5 indicates downtown urban areas where no green areas exist.

Sampling of Vespa species

In this study, *Vespa* species were sampled by a combination of netting flying adults, collecting nests, and using traps. The trap consisted of a 2 L plastic container containing a solution of 1:1:1 sugared water, acetic acid, and ethanol that is attractive to hornets and widely used by beekeepers to control hornets. The traps were hung throughout the Busan city area and monitored every 2 weeks. During 1997–2001, sampling was conducted via 50–60 traps and netting in Busan between July and September of each year. During 2003–2009, the spread of *V. velutina* was monitored in Busan city by installing 20 traps in all major habitats. This was supplemented by 1–2 days of trapping and netting in other regions outside Busan. In 2010, one trap was installed at each of 75 locations, i.e. 15 locations for each Grade of urbanization. In addition, three traps each were installed in the urban and forest areas in Haman-gun, Gyeongsan city, Masan city, and Yeongyang-gun. The Geumjeong-gu region of Busan city 119 Rescue Services emergency call-out reports dealing with social wasp/hornet nests problems during August–September 2010 were also studied to investigate the scale of the problem.

The 1997–2001 samples were deposited in the Forensic & Conservation Biology Lab at the Department of Biological Science, Kosin University, and all other samples are at the Animal Systematics Lab at the Department of Life Sciences, Yeungnam University, South Korea. Statistical analyses were analyzed with correlation analysis by Pearson's Correlation Coefficient at $p<.005$ using software SPSS V.16.

Results and discussion

Distribution and spread of Vespa velutina in South Korea

Since the first report in 2003, *V. velutina* has spread north and west from the point of origin at a rate of 10–20 km per year (Fig. 1), as indicated by the arrival in 2010 of *V. velutina* in Daegu city, 110 km from Busan city. It has been speculated that this species has spread via the movement of goods before colonies first appeared around the Busan port area (Fig. 1), the largest trading port in South Korea. Further weight is given to this idea because the arrival of *V. velutina* in France is believed to be via imported pots from China (Chauzat and Martin, 2009). Furthermore, the same distinctive subspecies, *V. velutina nigrithorax,* that occurs in Indo-China has invaded both France and South Korea suggesting a similar point of origin.

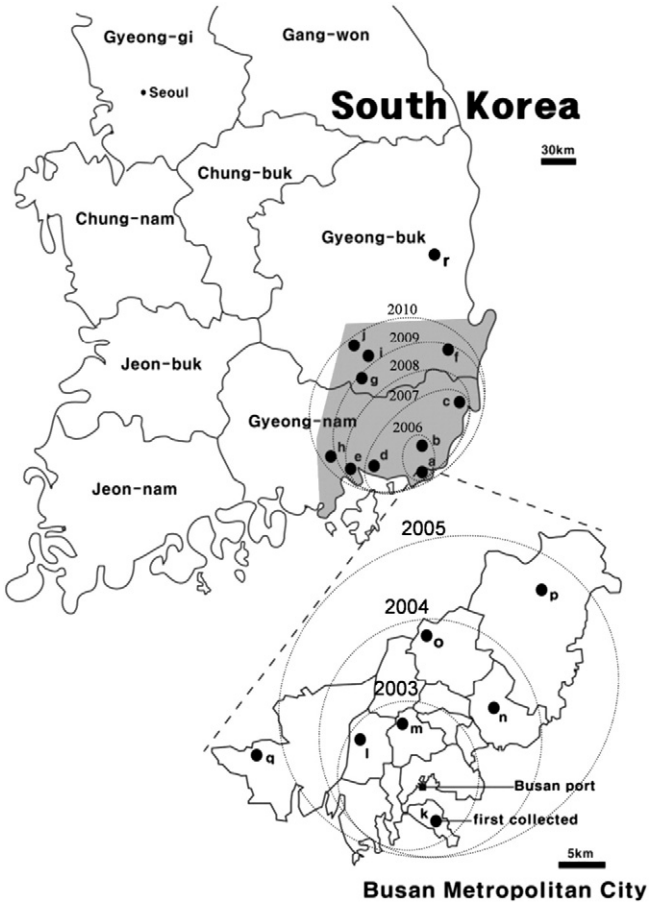

Fig. 1. Spread and distribution of *V. velutina* between 2003 and 2010 both within the Busan metropolitan city (insert) and across southern regions of South Korea. Key: a, Busan metropolitan city; b, Yangsan city; c, Ulsan city; d, Jinhae city; e, Masan city ; f, Gyeongju city ; g, Cheongdo-gun ; h, Haman-gun ; i, Gyeongsan city j, Daegu city; k, Yeongdo-gu (Mt. Bongraesan); l, Seo-gu (Mt. Seunghaksan); m, Busanjin-gu (Mt. Baekyangsan); n, Haeundae-gu (Mt. Jangsan) o, Geumjeong-gu (Mt. Geumjeongsan); p, Gijang-gun ; q, Gangseo-gu; r, Yeongyang-gun (points on map are sampling sites).

Biology of V. velutina nigrithorax

In South Korea, *V. velutina* queens were observed each year searching for sap and nest material during May (Fig. 2A), and mating (Fig. 2D) was observed during November, indicating a 7 month nesting cycle that is comparable to the native hornets *V. simillima* and *V. mandarinia*. Like *V. simillima* the embryo colony of *V. velutina* is built in an enclosed space and the entire colony later relocates to an open nest-site where the colony is free to expand rapidly. During August–September, *V. velutina* colonies in South Korea were 40–50 cm in height and 25–30 cm in length, with 4–5 combs. Mature colonies located in November were 60–90 cm in height and 40–70 cm in length, with 6–7 combs and containing 1000–1200 adult workers, which makes them the most populous species of hornet now in