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Distribution of Social Wasps in Two Metropolitan Cities (Busan and Daegu) of South Korea

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ABSTRACT

The objective of this study was to analyze social wasps' urban distribution tendency based on 10 species found in two metropolitan cities (Busan and Daegu) of South Korea. There 10 species included six species (*Vespa mandarinia, V. ducalis, V. crabro flavofasciata, Vespula koreensis koreensis, Parapolybia indica,* and *Polistes snelleni*) of forest dwellers that inhabited urban main forests and satellite forests, two species (*V. simillima simillima* and *V. analis parallela*) of facultative dwellers that nested at diverse sites of urban areas with greater preference for urban forest, and two species (*V. velutina nigrithorax* and *P. rothneyi koreanus*) of urban dwellers that nested at almost all sites, including urban and forest areas. These urban dwellers were found to adapt well to an urban environment based on their far higher rate of urban nesting compared to facultative dwellers. When distribution tendencies of facultative dwellers and urban dwellers in Busan and Daegu were compared, a regular distribution was mostly observed in Busan with a dense forest network. For Daegu that lacked forest connectivity, the greatest distribution of species was found in the nearby urban forest. For Daegu, a city further away from forests, urban dwellers occurred far beyond forest sites compared to Busan with a dense forest network.

Keywords: Distribution, Facultative dwellers, Forest dwellers, Metropolitan city, Urban dwellers, Vespidae

Introduction

Rapid increases in social hymenoptera in urban areas of South Korea have become a social problem due to the serious harm that they inflict. In Seoul, there has been a 4.5-fold increase in 119 emergency calls to remove nests of social wasps over the last 10 years. In 2009, there were a total 2,949 reports. This phenomenon has occurred similarly in other metropolitan cities (Choi *et al*., 2012a).

Habitat overlap of humans and social wasps during South Korea's rapid urbanization in the 1970s through 1990s has led to the destruction of social wasp nests. There were remarkable reductions in all social wasp species (Kim & Moon, 1994). Social wasps tend to increase in urban areas in line with conservation of forest areas and green parks according to recent shifts in urban green policies (Moon, 1998; Moon & Choi, 1999). Social wasps can easily adapt to various environments if a minimum habitat threshold for nesting is allowed. Although social wasps can cause serious harm to urban habitats, they can also be used as an index of nature in an urban ecosystem (Kim & Moon, 1994).

Previous studies have reported the predominance, invasion, and general distribution of social wasps in large cities of South Korea such as Busan (Choi & Moon, 2005; 2006; Choi *et al*., 2012b), Daejeon (Choi *et al*., 2006), and Seoul (Choi *et al*., 2012a). However, such studies were either limited to certain species or they merely discussed distributions according to forest without address comprehensive distribution characteristics, including distribution characteristics of diverse species and relations with forest.

Therefore, this study selected 10 species frequently dwelling in large cities and mapped their distributions, followed by analysis of distribution tendencies of each species. In addition, we analyzed distribution tendencies of

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social wasps based on distributional difference in urban forests between two cities: Busan and Daegu. It is crucial to preparing a countermeasure for public health and safety issues stemming from social wasps in urban areas for the future.

Materials and Methods

Categories of social wasps by habitat

In this study, social wasps were classified into three categories by habitat. 1) forest dweller, social wasps that not only nested but also foraged within an urban forest; 2) facultative dweller, social wasps that were able to nest and forage in urban areas apart from urban forest; and 3) urban dweller, social wasps that preferred urban areas to urban forest for nesting and foraging.

Types of urban forest

This study was divided urban forest into two types based on its size and function in the urban area (Oh *et al*., 2010): 1) urban main forest (UMF), large forest as a biogical source for small forests in urban areas (e.g., core forest, large urban forest, source forest); 2) urban satellite forest (USF), small and medium forests around UMF (e.g., city park, medium or small urban forest).

Survey area

The first survey area, Busan, is Korea's second largest metropolitan city. It is located at the southernmost part of the country. Daegu, is the third largest metropolitan city. It is located in the country's southern central part (Fig. 1). These two cities have quite different topographic features. Busan is equipped with a fragmented forest network consisting of UMF as well as USF. On the other hand, Daegu, which has a typical inland basin landform, is surrounded by forests in the outskirts with only 6-7 small forest parks within the city, lacking UMF within the city. Thus, the city structurally faces difficulty in proper formation of a forest network. As nesting of social wasps is largely affected by forest or green areas. These two cities are deemed as very appropriate sites for studying distribution characteristics of urban social wasps through comparison of their distributions (Fig. 1).

Data collection and analysis

Individual social wasps used in this study were based on specimens collected since 2000 and stored at the Department of Biological Science, Kosin University, Busan and the School of Applied Biosciences, Kyungpook National University, Daegu. A supplementary survey was conducted during 2010-2012 at areas that were found to

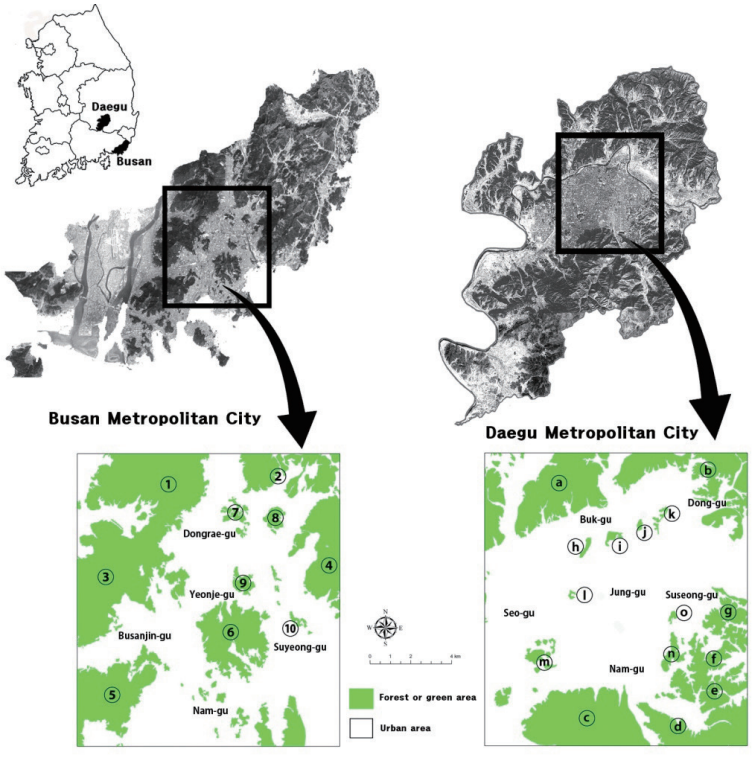

Fig. 1. Survey areas of social wasps and forests in Busan and Daegu
In Busan:
① Mt. Sanggyebong (N35°13′ 06.84" E129°03'38.03"),
② Mt. Yunsan (N35°14'01.53" E129°06'45.74"),
③ Mt. Baekyangsan (N35°10'53.90" E129°01'36.48"),
④ Mt. Jangsan (N35°10'22.09" E129°08'55.79"),
⑤ Mt. Eomgwangsan (N35°07'58.89" E129°02'09.02"),
⑥ Mt. Hwangryeongsan (N35°09'07.01" E129°06'03.58"),
⑦ Mt. Maansan (N35°12'36.87" E129°05'33.35"),
⑧ Mt. Okbongsan (N35°12'27.03" E129°06'43.97"),
⑨ Mt. Baesan (N35°10'46.67"E129°05'38.79"),
⑩ Mt. Baeksan (N35°09'43.27" E129°07'30.19")
In Daegu:
ⓐ Mt. Hamjisan (N35°54'46.21" E128°34'09.17"),
ⓑ Mt. Yongamsan (N35°55'48.70" E128°38'21.51"),
ⓒ Mt. Apsan (N35°49'42.33" E128°35'24.15"),
ⓓ Mt. Beopnisan (N35°49'05.76" E128°37'49.03"),
ⓔ Mt. Muhaksan (N35°49'41.13" E128°39'21.01"),
ⓕ Mt. Duribong (N35°50'43.63" E128°39'24.96"),
ⓖ Mt. Hyeongjebong (N35°51'35.79" E128°39'52.52"),
ⓗ Chimsan park (N35°53'38.31" E128°35'02.40"),
ⓘ Yeonam park (N35°53'55.12" E128°35'56.72"),
ⓙ Daebul park (N35°54'13.61" E128°36'53.71"),
ⓚ Geumho riverside (N35°54'33.72'E128°37'45.06"),
ⓛ Dalseong park (N35°52'21.09" E128°34'37.46"),
ⓜ Duryu park (N35°50'58.80" E128°33'35.35"),
ⓝ Beomeo park (N35°50'53.74" E128°37'51.63"),
ⓞ Beomeo citizen park (N35°51'45.79" E128°37'52.85")

provide poor information within the scope of this research according to the purpose of collection or difference of methods. As both cities had been surveyed for urban forests or large green parks, this study collected specimens mainly from houses and apartment complexes, small parks, flower beds, and street trees for urban landscapes located at Suyeong-gu, Yeonje-gu, Dongrae-gu, and Busanjin-gu in Busan and at Nam-gu, Jung-gu, and Buk-gu in Daegu. Every year, collection was carried out at different places to avoid overlapping of research areas.

Collection period was from July to September when social wasps showed robust activity. Collection was carried out by annually installing 50 pieces of social wasp-inducing traps used by Choi *et al*. (2012b). Individual social wasps found during collection were additionally collected using netting. Individuals found during the supplementary survey were kept at Pest Ecology Lab at the School of Applied Biosciences, Kyungpook National University. For distribution mapping, the Point Pattern Analysis (PPA) method of Geographical Information System (GIS) per Choi *et al*. (2012a) was used. The map used was the 4th forest cover map of the Korea Forest Service. The distance from each forest boundary was measured using an algorithm of buffering in ArcMap v.9.3 (copyright at ESRI) that could create a new feature containing a set of buffer distances. The distance in the map appeared at intervals of 100 meters. The number of each species was counted based on this interval.

Results and Discussion

Social wasps surveyed in both cities

Social wasps surveyed in both cities comprised a total of 19 species belonging to two subfamilies (Vespinae and Polistinae). Of these, *Vespa dybowskii, Polistes chinensis antennalis, P. yokahamae, P. djakonovi, P. japonicus japonicus, P. mandarinus,* and *P. nipponensis* showed very poor distribution. Thus, they were excluded from this study due to difficulty in explaining their distribution characteristics. *Parapolybia varia* and *Vespula flaviceps flaviceps* that showed almost the same nesting nature as *Pa. indica* and *Vl. koreensis koreensis* were also excluded from this study. Thus, this study conducted analysis of distribution characteristics for 10 species (Figs. 2 and 3).

Distribution of social wasps in both cities

Six species are typical forest dwellers inhabiting interior and edges of UMF and USF in Busan and Daegu (Fig. 2). Above all, *V. mandarinia* nests in the underground of open forests and forages for large insects with less agility. As it needs sufficient green space for its feeding sources, it inhabits UMF and larger USF (Figs. 2E and 2F). *V. ducalis, V. crabro flavofasciata,* and *Vl. koreensis koreensis* forage for small, medium insects. *V. ducalis* in particular forages for paper wasps, inhabiting small and medium USF as well as UMF (Figs. 2A-2D, 2G, 2H). *V. crabro flavofasciata* and *Vl. koreensis koreensis* are sometimes found in urban areas near urban forests. As their foraging distances are in the upper 100-1000 m and 100-400 m, respectively (*Matsuura & Yamane*, 1990), they often fly near urban residence areas and parks if necessary and feed on carbohydrate and protein sources from wastes or small flower beds. However, because most of them are nesting in urban forests, they do not actually pose a direct threat to urban areas. *Pa. indica* and *P. snelleni* inhabit UMF and sporadically appear in some USFs (Figs. 2I~2L). *Pa. indica nests* on branches. *P. snelleni has been observed in various places such as among bushes as well as eaves and walls of houses. Polistes species*, which has a short foraging distance of around 20-150 m (Hibino, 1981; Kasuya, 1980; Prezoto & Gobbi, 2005), rarely flies out of forest like Vespinae and forages for small insects with soft skin like Lepidoptera larva around its nests. Thus, it has almost no urban activity with little harmful effects.

On the other hand, the rest four species are facultative dwellers that can nest and forage in urban forest as well as urban area. *V. simillima simillima* and *V. analis parallela* have a higher nesting rate in urban forests with regard to their distribution. They tend to nest on diverse sites from edges of urban forests to inner parts of cities. They commonly nest on open spaces such as walls in urban buildings, canopies, and under eaves from a hanging nest. They frequent fly from urban nests to nearby forest or from forest to near cities in order to take in carbohydrate sources from nearby waste or obtain protein sources from small, medium insects near urban parks or from large insects (e.g., large cicadas among street trees in summer) in cities (Park, 2010). Accordingly, they are able to inhabit urban environments easier than forest dwellers nesting on a natural matrix.

V. simillima simillima shows up near urban forest. It may fly up to around 400-600 m of the city from urban forest (Figs. 3C, 3D; 4A, 4B) and nest on various artificial structures. It has the highest rate of urban inhabitation among native *Vespa* species (Choi & Moon, 2005). *V. analis parallela* also appears in urban areas (Figs. 3A, 3B; 4A, 4B). Under eaves, it mainly nests on bushes in urban forest with relatively less diversity of urban nesting sites and lower ratio compared to *V. simillima simillima*. They have a smaller nesting size than natural nests. They mostly appear within 1 km of forest. They are most likely to pose harm to central parts of cities with a foraging distance of 1000-2000 m (Matsuura & Yamane, 1990). Particularly, taking *Vespa* species like paper wasps (*Polistes* or *Parapolybia*) into account, their aggression may threaten human life. Thus, urgent countermeasures are required

from the perspective of urban public health.

V. velutina nigrithorax and *P. rothneyi koreanus* were found to nest on most sites, including urban areas and forests. They have a far higher rate of urban nesting than facultative dwellers (Figs. 3E~3H).

Since its first invasion to Busan in 2003, *V. velutina nigrithorax*, a subtropical species, has quickly spread across the country and urban areas (Choi *et al*., 2012b; 2013; Jung *et al*., 2009; Jung, 2012a; 2012b; Kim *et al*., 2006). It mainly nests on walls and under eaves of urban buildings. It prefers to nest on street trees and trees in urban parks. It has the highest agility among *Vespa* species. It seems to have the greatest advantage of foraging in an urban environment. Its distribution in Busan is the greatest,

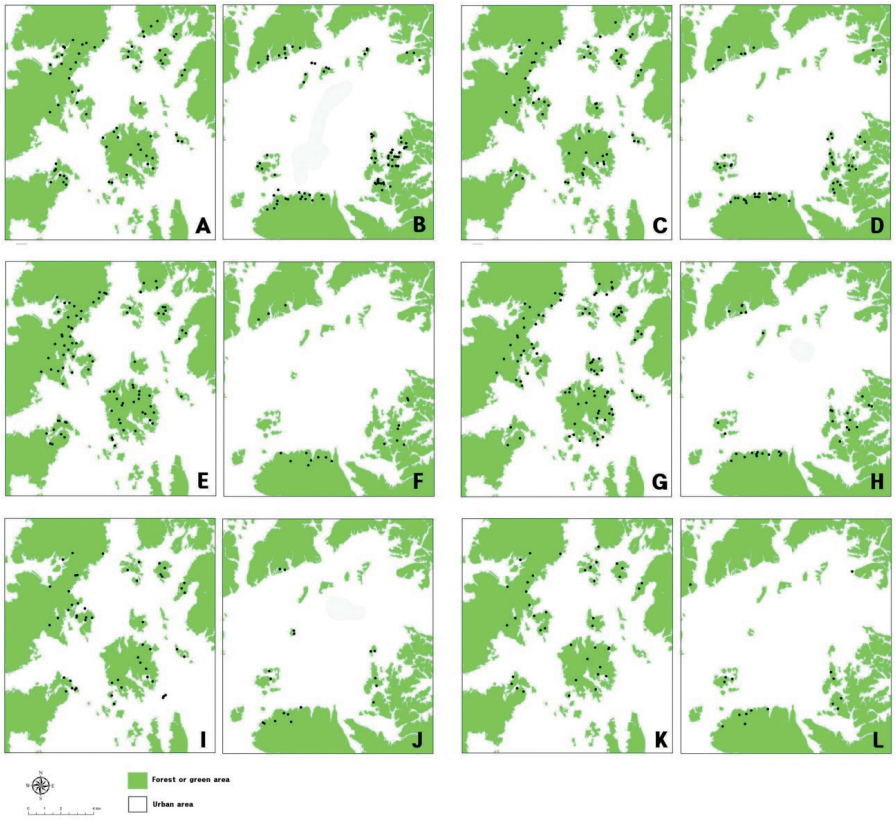

Fig. 2. Distribution of six forest dwellers in Busan and Daegu
A: *V. crabro flavofasciata* (Busan); B: *V. crabro flavofasciata* (Daegu); C: *V. ducalis (Busan)*; D: *V. ducalis* (Daegu); E: *V. mandarinia* (Busan); F: *V. mandarinia* (Daegu); G: *Vl. koreensis koreensis* (Busan); H: *Vl. koreensis koreensis* (Daegu); I: *P. snelleni* (Busan); J: *P. snelleni* (Daegu); K: *Pa. indica* (Busan); L: *Pa. indica* (Daegu)

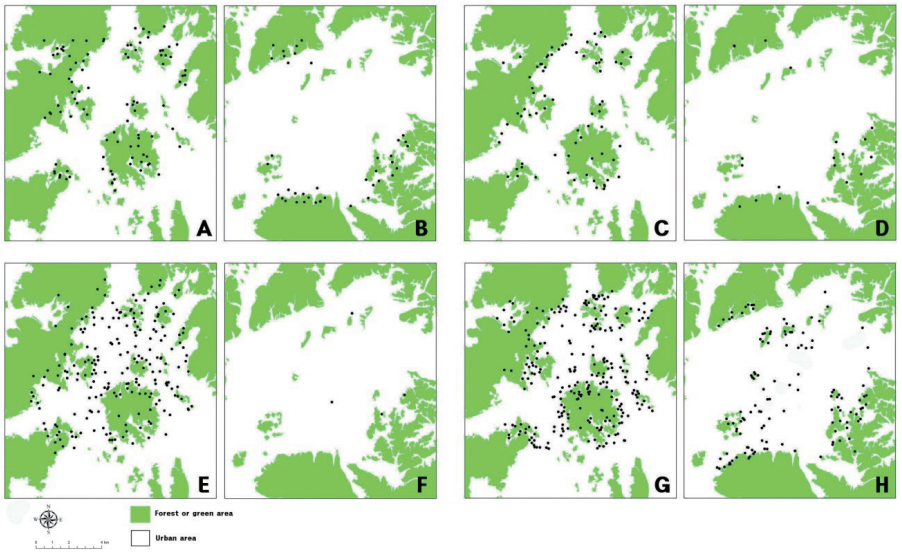

Fig. 3. Distribution of four urban & facultative dwellers in Busan and Daegu
A: *V. analis parallela* (Busan);
B: V. *analis parallela* (Daegu);
C: *V. simillima simillima* (Busan);
D: *V. simillima simillima* (Daegu);
E: *V. velutina nigrithorax* (Busan);
F: *V. velutina nigrithorax* (Daegu);
G: P. *rothneyi koreanus* (Busan);
H: *P. rothneyi koreanus* (Daegu)

within 500 m from an urban forest. Given its distribution up to 1,500 m, it is safe to assume that they are spread out in all parts of the city (Figs. 3E, 4A). According to Choi *et al*. (2012b), this species is very often found in urban forest as well as downtown throughout the whole city of Busan. It has an absolute predominance in urban areas as its presence in downtown has exceeded 90% whereas the presence of *V. simillima simillima* and *V. analis parallela* has decreased to below 5%.

It was believed that *V. velutina nigrithorax* was introduced to France for the first time in 2004 (Haxaire *et al*., 2006; Villemeant *et al*., 2011a; 2011b). A recent survey in France has shown that almost half (49%) of its population are found in urban areas (Villemant *et al*., 2011b). This is because its nests can be easily found in densely populated urban areas compared to rural areas (Rome *et al*., 2009). In Korea, however, it seems that factors affecting urban nests also include growth of green space, stability of nesting place, urban heat, and lack of natural predators and parasitoids as suggested by Choi *et al*. (2012a). The spread and predominance of new hornets in the city may cause a serious problem in terms of public health. Indeed, reports to remove nests of *V. velutina nigrithorax* in Busan in 2010 reached 41%, almost double that of *P. rothneyi koreanus* (22%) distributed in the past (Choi *et al*., 2012b).

Increased venomous *Vespa* species compared to existing *Polistes* with less venom in the city may cause very serious harm to urban areas. Particularly, *V. velutina nigrithorax* is the most aggressive wasp towards humans with the largest number among hornets (Martin, 1995; Matsuura, 1973). Therefore, perfect administration to prevent its harmful effects on humans is urgently needed from the prospective of public health in the future (Choi *et al*., 2012b). Meanwhile, only four specimens were found in Daegu, suggesting the initial stage of invasion of *V. velutina nigrithorax*. Each specimen was collected within 100 m, 300 m, and 2,500 m of the urban forest. The spread of this species and its victims may become more widespread in urban area of Daegu in the future (Figs. 3F and 4B).

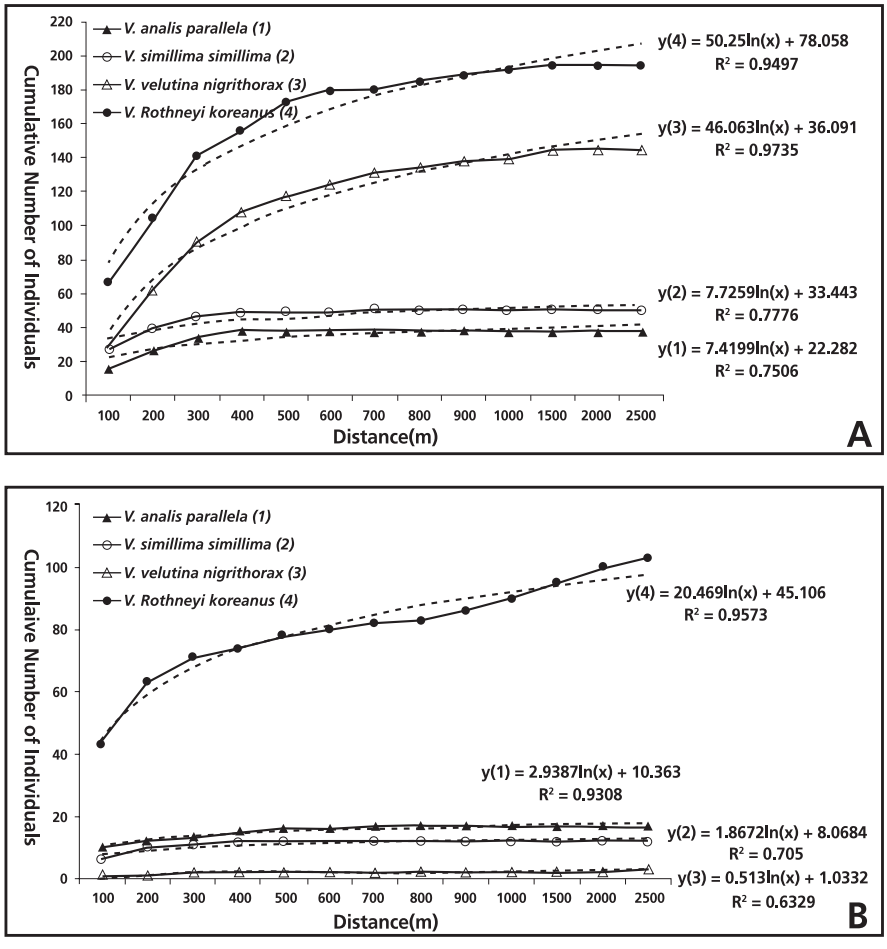

Fig. 4. Comparison of distribution tendencies depending on distance for urban forest of four urban and facultative dwellers in Busan (A) and Daegu (B). The solid and dotted lines indicate the cumulative number of individuals with distance from the edge of urban forest and its trend line, respectively. Each distance values are based on collecting sites (point) of Fig. 2, 3.

P. rothneyi koreanus is most commonly found in urban areas. It makes up the largest part of harmful species of urban social wasps (Choi & Moon, 2005; Choi *et al*., 2006; 2012b). With regard to its distribution, it nests near the innermost of urban areas and within 1,500 m and 2,500 m of forest in Busan and Daegu, respectively (Figs. 3G, 3H; 4A, 4B). Its nesting sites include a diverse range of artificial structures such as under weaves, window frames, and walls of buildings. Owing to its foraging distance being within 50 m (Hibino, 1981), it seems that it prefers to seek feeding sources in small forest within its foraging distance regardless of forest size. It is often seen to use flyer sheets and waste papers as nest materials, suggesting its adaptation to urban environments. This species is the largest and most aggressive paper wasp with a colony size of around 100-200 individuals. However, its harmful effects are far weaker than hornet (*Vespa*) and yellowjacket (*Vespula*). However, since it nests at urban areas where it might directly encounter people, it has been recognized as the most dangerous species to humans as classifying the species of Vespidae is not possible.

Comparison of the distribution of social wasps based on distribution of forests in Busan and Daegu

Outside Busan, there are five forests. In the interior, there are one UMF and four USFs of small and medium spread loosely in between (Fig. 1). In Busan, there are a number of USFs. These UMFs function as bridges, forming a green network with diverse interactions (Oh *et al*., 2010). Thus, social wasps are able to inhabit not only forests and edges of forests, but also areas close to forests and deep into urban areas depending on the distribution of forests, nesting, and foraging distance.

On the other hand, in Daegu, a typical inland basin city, there is one UMF at the outskirts of the city. Its interior is comprised of small urban forest parks such as Duryu Park (Fig. 1). A number of USFs are located far from the exterior UMF with a low green density. They are not sufficient to function as a bridge to connect Daegu's green network. Therefore, except for certain social wasps that are adapted to an urban environment, most social wasps tend to habitat in forests or nearby compared to those in Busan.

As shown in Fig. 4, we found that regression curves for *P. rothneyi koreanus* had much steeper slopes than those for other species. This meant that *P. rothneyi koreanus* was already well distributed in most urban areas. On the other hand, curves for *P. rothneyi koreanus* in Busan had a much steeper slope than those in Daegu. This could mean that Busan's architecture is more accommodating for wasps to inhabit them in an ecological network. According to Oh *et al*. (2010), the mean distance from UMF to USF in Busan is 1,289 m, which is smaller than that in Daegu at 2,281m. This could mean that *P. rothneyi koreanus* has efficiently spread out using urban forests as stepping stones within the urban ecological network.

Consequently, the distribution of social wasps known to cause harm to urban areas is directly affected by the distribution of urban forests, which might be a cause of the recent rapid increase of social wasps in urban areas. However, as local community is not in a position to decrease the number or size of urban forests due to social wasps, diverse countermeasures such as control of colonies of social wasps according to lifecycle and arrangement of substitute habitats are needed.

Conflict of Interest

The authors declare that they have no competing interests.

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