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FLOWER-VISITING BEES AND WASPS IN SINGAPORE PARKS (INSECTA: HYMENOPTERA)

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ABSTRACT. — In 2012 from February to June, a study was conducted by the National Biodiversity Centre, National Parks Board (NParks) to document the diversity and community of flower-visiting insects in seven parks. The insect orders recorded in the study are Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, and Orthoptera. Of these seven orders, Hymenopterans were the most abundant and diverse with 93 species from 13 families recorded, comprising 50 species of bees from four families, 24 species of wasps from seven families, and 19 species of ants (Formicidae). Among the 50 species of bees include six possible new records for Singapore. This paper presents the bees and wasps recorded from the study together with their respective species of flowers visited.

KEY WORDS. — Hymenoptera, bees, wasps, flower visiting insects, parks, Singapore

INTRODUCTION

Despite being highly developed, the city of Singapore is interspersed with numerous parks and gardens that add both greenery and recreational spaces to its urban landscape. A great variety of flowering plants are planted within many of these parks and gardens. These flowering plants not only provide visual appeal to park-goers, but they also attract and support communities of flower-visiting insects that feed on the floral resources.

Flower-visiting insects are diverse, spanning various orders including Hymenoptera (bees, wasps, and ants), Lepidoptera (butterflies and moths), Diptera (flies), and Coleoptera (beetles). These insects are abundant and play key roles in ecosystems, such as the pollination of flowering plants. Yet, the majority of flower-visiting insect fauna in Singapore receives little scientific attention and is largely unstudied.

Flower-visiting insects are important to the ecosystem because many of them are pollinators. Studies have shown that a lack of insect pollinators can lead to reduced seed set (Rathcke & Jules, 1993; Murcia, 1996; Kearns & Inouye, 1997; Cunningham, 2000) and further result in the loss of flowering plant species (Biesmeijer et al., 2006). Flower-visiting insects are also crucial for ensuring the reproductive fitness and conservation of plant populations (Pavlik et al., 1993; Bond, 1995; White & Boshier, 2000; Jabis et al., 2011). This is particularly significant in Singapore, where the majority of native flowering plant species are currently endangered or vulnerable (Turner et al., 1994; Chong et al., 2009).

In addition, flower-visiting insects are an integral part of the food webs and in maintaining the biodiversity in our ecosystems. The pollination of fruiting shrubs, trees, and palms by flower-visiting insects provide a supply of food that support populations of native frugivores such as bats and birds (Black et al., 2009). Many flower-visiting insects, in their larval and adult stages, also form the natural prey of native insectivorous species. Moreover, flower-visiting insects such as wasps and hoverflies, naturally control the populations of other insects, including pests (Waterhouse, 1998; Smith et al., 2008).

Research on the status of flower-visiting insects has produced evidence of a worldwide decline in many species such as butterflies (Van Dyck et al., 2009; Potts et al., 2010; Van Swaay et al., 2011) and bees (Cane & Tepedino, 2001; Kremen et al., 2002; Goulson et al., 2008). This decline has been attributed to anthropogenic activities that resulted in the loss of their natural habitats (Czech et al., 2000), food sources (flowering plants), viable nesting sites (Winfree et al., 2009), and the increased use of pesticides in agriculture (Henry et al., 2012; Whitehorn et al., 2012).

Conservation of flower-visiting insects has thus become a widespread concern (Kearns et al., 1998; Cunningham, 2000; Donaldson et al., 2002; Committee on the Status of Pollinators in North America, 2007). As urbanisation continues to progress in cities around the world, the need to understand the factors that affect flower-visiting insect communities in anthropogenic environments have also become increasingly evident (Hernandez, 2009). Studies in urban cities such as Vancouver, New York, and Berlin, have shown that even disturbed and fragmented pockets of green spaces with flowering plants can support diverse flower-visiting insect assemblages and be important for their conservation (Saure

1996; Tommasi et al., 2004; McFrederick & LeBuhn, 2006; Matteson et al., 2008; Matteson & Langellotto, 2010). Likewise, the green spaces within the urban city of Singapore also potentially harbor a rich diversity of flower-visiting insects that warrants a study.

However, with the exception of butterflies (Koh & Sodhi, 2004; Khew, 2010), flower-visiting insects in Singapore have been largely unstudied and data on their diversity and abundance is poor. Furthermore, ecological information on flower-visiting insects, such as which flowering plant species they forage or interact with, is limited to only a few studies and observations (Khew & Neo, 1997; Liow et al., 2001; Chong, 2010). Community level research involving all orders of flower-visiting insects and their associated-flora is also yet to be carried out in Singapore despite being recommended by various researchers as a means of elucidating the diverse web of interactions between flower-visiting insects and flowering plants (Jordano, 1987; Ellis & Ellis-Adam, 1993; Memmot, 1999; Yamazaki & Kato, 2003).

As an important start to addressing and highlighting these gaps in knowledge, this study aims to investigate the abundance composition, species richness, and floral-associations in Singapore's parks. It is with hope that the accumulated data will allow park managers to better understand the biodiversity within their parks and form the basis of future flower-visiting insect research and conservation in Singapore.

Owing to the enormous amount of data collected, we have chosen to present our results in separate parts. This paper focuses on the most abundant and diverse order Hymenoptera, in particular the bees and wasps, which are poorly studied locally even though they form the majority of flower-visiting insects. Also from this study, a checklist of flower-visiting butterfly species has been made available on the NParks website (NParks, 2013).

MATERIAL AND METHODS

Study sites. — As the study aims to gather baseline data on the diversity of flower-visiting insects in the parks of Singapore within a limited time period of five months from Feb.– Jun.2012, the study sites were selected based on visual assessment of having a high number of species of flowering plants (at least 10 species) growing closely together in abundance. Sites were also chosen based on differing features and surroundings to represent the variety of parks in Singapore.

From pre-survey reconnaissance visits to 22 different parks, it was observed that all the parks have different features and surroundings. Several parks have flowering plants, but the abundance, variety, and the manner in which they are grown vary widely. Certain parks are also in close proximity to features such as natural forest fragments, while others are located within urban matrixes and isolated from other green areas. Such surroundings provide different habitats for flower-visiting insects, which in turn affect their diversity and abundance found in the parks.

One distinct similarity observed was that the vast majority of flowering plants grown in all the parks were either horticultural varieties or non-native species (status of plants from Chong et al., 2009). This has implications on the floral resources available to different species of flower-visiting insects and it is a significant factor in shaping flower-visiting insect communities in parks and gardens (Comba et al., 1999a, 1999b; Burghardt, 2009).

Eventually, seven parks were selected (Figs. 1, 2):

1. **Bedok Town Park**: A small, highly urbanised community park composed largely of man-made elements. The park is surrounded by housing estates and a major expressway. No natural forest fragments nearby.
2. **Dairy Farm Nature Park**: A large nature park composed of secondary forest. A patch of primary forest in the Bukit Timah Nature Reserve is nearby.
3. **HortPark**: A small, highly urbanised park composed largely of man-made elements. The park is in close proximity to the secondary forest fragments of Telok Blangah Hill Park and Kent Ridge Park.
4. **MacRitchie Reservoir Park**: A park around a reservoir composed of a mixture of man-made and natural elements. The park contains a large patch of secondary forest.
5. **Pasir Ris Park**: A large coastal park composed largely of natural elements. The park contains a large patch of primary mangrove forest.
6. **Singapore Botanical Gardens**: A large urbanised park composed of man-made elements. The park contains patches of secondary forest and a patch of primary rainforest.
7. **Tampines Eco Green**: A large nature park composed of mostly natural elements. The park contains small patches of secondary forest. The park is surrounded by urban housing estate.

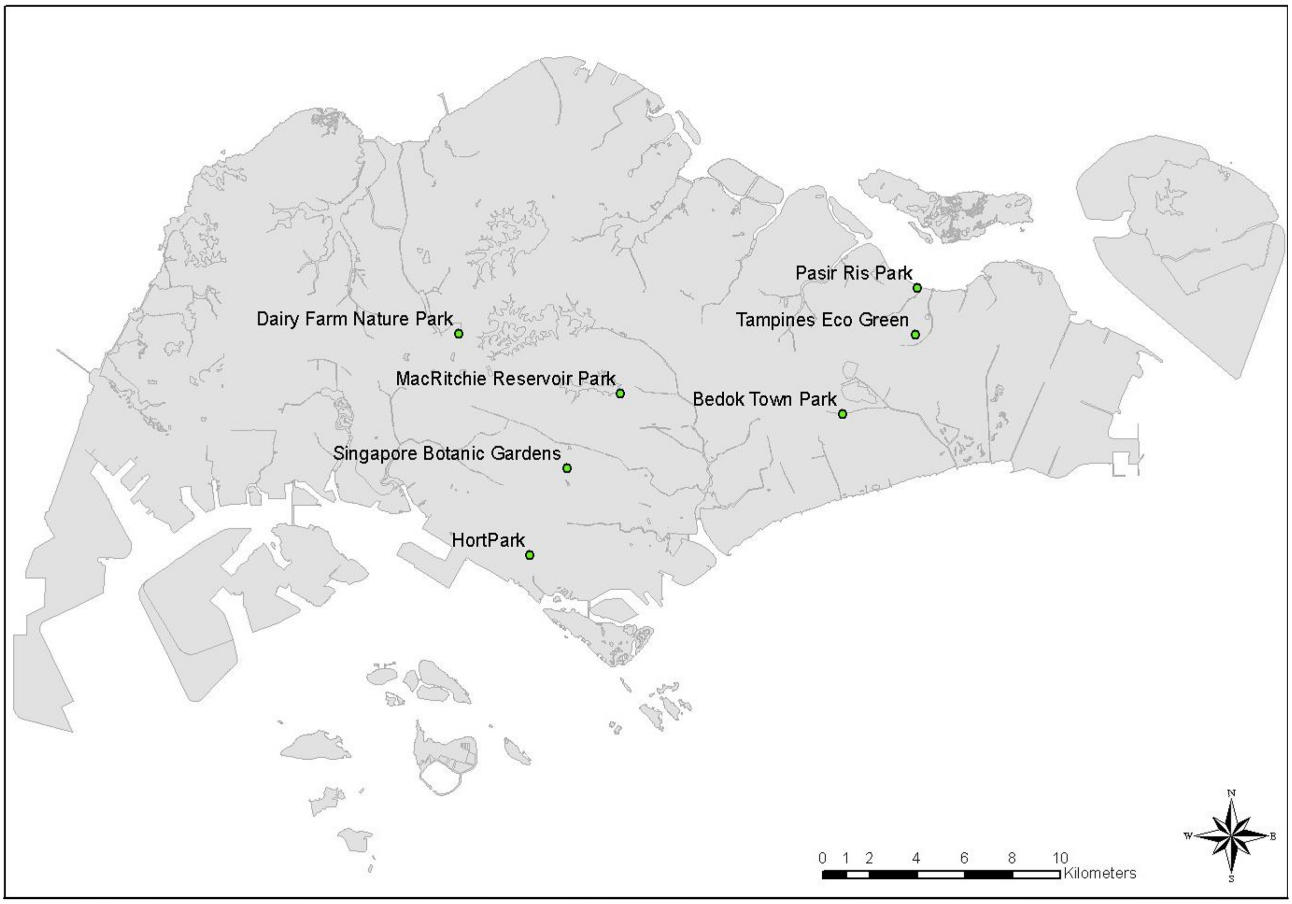

Fig. 1. The locations of the seven parks surveyed in the study are represented by the green dots on the map.

To ensure an even sampling effort among the parks, an estimated transect of 100 m was marked out in each of the study sites where flowers are most abundant. Transects were not necessarily linear as they followed the contours of the trails within the study sites. All surveys were conducted by walking along the transects.

Floral surveys. — A floristic survey was conducted in all study sites before the insect surveys to identify the species of flowering plants growing along the transect. The survey consisted of photographing all flowering plant species below 3 m in height and found growing within 1.5 m of either side of the transect. When photographs were insufficient for identification, plant samples were collected. The photographs and samples were then identified with the use of guidebooks (Foo, 1985; Boo et al., 2006) and the assistance of plant-experts from the National Biodiversity Centre.

Insect surveys. — Two different survey methodologies were conducted to record the insects and the flowering plants they visit along the transects: quantitative collection surveys and qualitative photographic surveys. Owing to logistical constraints, it was ineffective to conduct both kinds of sampling methods simultaneously within a single survey. Thus, only one sampling method was used per survey. The methods and purposes of the two surveys are described in detail below.

From Feb.2012 to Jun.2012, three quantitative collection surveys and three qualitative photographic surveys were conducted at each of the seven study sites. Each survey consists of a 2-h sampling period in the morning (0830–1030 hours) and another 2-h sampling period in the afternoon (1430–1630 hours). This was done to record insects that visit flowers during both time frames. Fieldwork was conducted only on calm, sunny, and partly cloudy days, as rain and high wind speeds have been shown to negatively affect flower-visiting insect activity (Roubik, 1989). In the event of rain, the survey was postponed and conducted at a later date.

Quantitative insect collection surveys. — Quantitative collection surveys consist of capturing insects that are visiting flowers. This allows us to quantify the number of individual flower-visiting insects present at the site during each survey and prevents the possibility of double-counting the same flower-visiting insect individual. This method further allows us to record the flowering plant species visited by each insect species, which is crucial for the investigation of plant-insect associations. Collection of specimens from the survey also enables close examination of taxonomic characters for identification and provide research material for future studies on flower-visiting insects.

Fig. 2. Study sites of the seven parks: A, Bedok Town Park; B, Dairy Farm Nature Park; C, HortPark; D, Pasir Ris Park; E, Healing Garden in Singapore Botanic Gardens; F, Macritchie Reservoir Park; G, Tampines Eco Green. (Photographs by: Zestin Soh).

Starting from a randomly selected point at 0830 hours, one to two surveyors walked systematically along the 100-m transect over the 2-h duration and captured all insects that were observed visiting flowers within 1.5 m of either side of the transect using a standard entomological net. Effort was made to avoid directly sweeping at the flowers when capturing the insects so as to reduce damage to the flora. Insects visiting flowers of plants more than 3 m above the ground were not collected. Specimens collected were recorded and labelled according to date, site, and flower species visited. Captured butterflies that could be unambiguously identified in the field were transferred into a holding container and subsequently released after the survey. This step was done to prevent double counting of individual butterflies during the 2-h survey. Weather conditions during the survey were also recorded. The process was repeated for the afternoon survey from 1430–1630 hours.

The flower-visiting insects collected were then identified as accurately as possible with the use of guidebooks (Khew, 2010), the assistance of experts, namely Alain Pauly (Royal Belgian Institute of Natural Sciences, Department of Entomology), John Ascher (American Natural History Museum, Division of Invertebrate Zoology), Nur-Zati Mustafa (Forest Research Institute Malaysia), Stephan Risch (Leverkusen, Germany), and John X. Q. Lee, and by comparing them with existing specimens in the Zoological Reference Collection (ZRC) of the Raffles Museum of Biodiversity Research. Unique specimens were pinned, while the rest were stored in vials containing 95% alcohol. Pinned specimens were deposited at the ZRC of the Raffles Museum of Biodiversity Research, National University of Singapore, while the specimens in alcohol are kept with the first author.

Qualitative insect photographic surveys. — Qualitative photographic surveys consist of photographing insects in the act of visiting flowers. These surveys were purely qualitative, and no abundance data was recorded during the surveys. However, the photographic surveys complemented the data in recording the diversity of insect-plant relationships as well as the species richness of each site, as uncollected species of insects that were photographed could also be added to the total list of species recorded there.

This method of photographic documentation can provide insight into how each insect species visit the flowers and whether the insect makes contact with a flower's reproductive organs during the visit. These records can assist in the elucidation of the specific type of plant-insect association. For instance, insects that are documented chewing through the flower receptacle to gain access to nectar can be identified as floral larcenists that possibly do not provide pollination services for the flowering plant. Furthermore, photographs taken during the surveys may be used in education or in promoting the diversity and importance of flower-visiting insects in Singapore's parks. They can also assist both the members of public as well as park managers in identifying species of flower-visiting insects.

Starting from a randomly selected point at 0830 hours, one to two surveyors walked systematically along the 100-m transect over a 2-h duration and photographed all the insects that were observed visiting flowers within 1.5 m of either side of the transect using a DSLR camera equipped with a macro lens. Insects visiting flowers of trees more than 3 m above the ground were not photographed. Weather conditions during the survey were also recorded. The process was repeated for the afternoon survey from 1430–1630 hours. Photographs of the insects were then sorted according to the site, date, and species of plant visited. The photographed flower-visiting insects and plants visited were then identified as accurately as possible with the assistance of keys, guidebooks, and experts.

RESULTS AND DISCUSSION

Abundance. — The abundance of flower-visiting insect fauna was obtained only from the results of the quantitative surveys. A total of 1,765 individual insects representing 168 species in six orders were recorded visiting the flowers of 88 plant species from 40 families over the 21 quantitative collection surveys. Overall, flower-visiting Hymenoptera were the most abundant and dominant of the insect orders (67.9%) across all the park study sites, followed by Lepidoptera (23.5%), Diptera (6.4%), Coleoptera (2.1%), and lastly Blattodea (0.1%) (Fig. 3).

Focusing on Hymenoptera, a total of 1,199 individuals of flower-visiting Hymenoptera from 82 species in 11 known families were recorded. The most abundant family was Apidae (57.8% of Hymenopterans recorded), followed by Halictidae (14.3%), Formicidae (8.8%), Megachilidae (6.8%), Vespidae (4.7%), Scoliidae (3.8%), Colletidae (2.2%), Crabronidae (0.5%), Sphecidae (0.5%), and Chrysididae (0.2%). 0.4% of the recorded Hymenopterans belonged to unknown families. The dominance of Apidae amongst the flower-visiting Hymenopteran families is largely due to the high absolute abundance of honeybees (Apidae: Apini) and stingless bees (Apidae: Meliponini). These two groups of bees are eusocial by nature, and in total they account for 67.7% of the Apidae bees recorded.

Apis cerana Fabricius, a species of honeybee (Fig. 4A), was the most abundant flower-visiting insect species overall, with 221 individuals recorded over all the surveys. Among all the flower-visiting insect species recorded in this study, *Apis cerana* was recorded foraging from the highest diversity of flowering plant species (29 species of flowering plants; ref. Table 1 in Appendix). This ability of *Apis cerana* to utilise a wide variety of floral resources, especially in parks

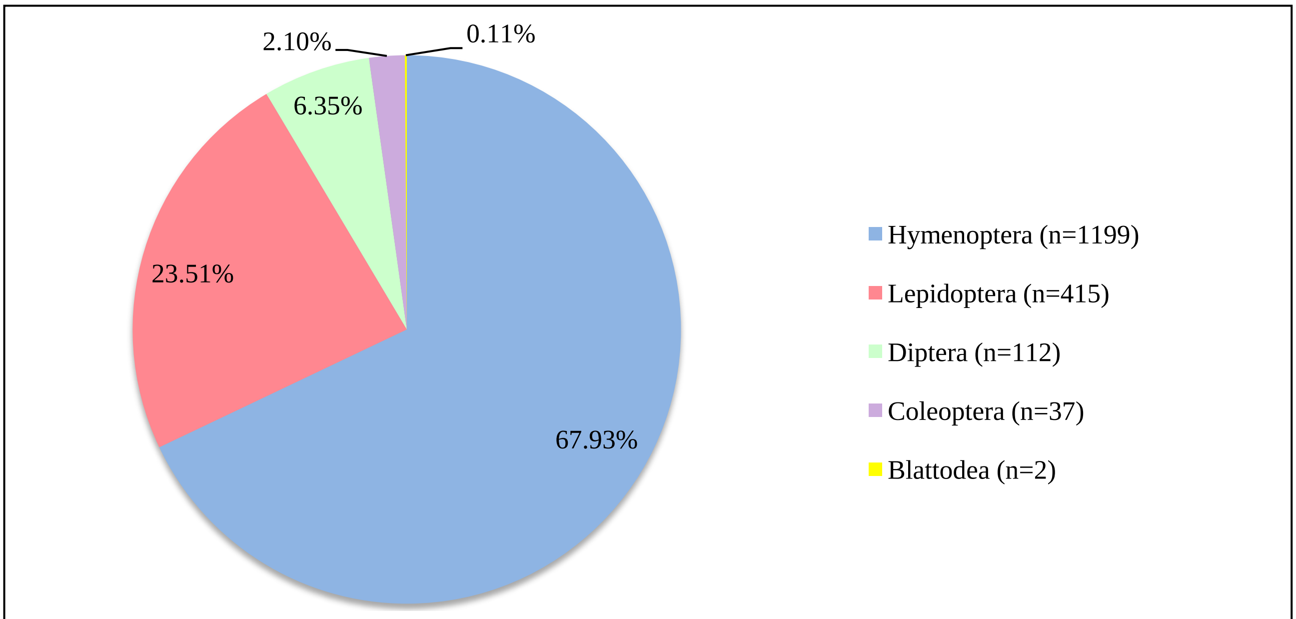

Fig. 3. Relative abundance of insect orders across all the parks over 21 quantitative surveys.

where the flowering plants species are mostly exotic, possibly explains dominance of this species in the flower-visiting insect community. *Apis cerana* was also recorded from all study sites except for the study site at MacRitchie Reservoir Park.

However, other non-eusocial species of Apidae such as *Braunsapis* sp1 (Apidae: Allodapini), *Ceratina* (*Ceratinidia*) sp1, and *Ceratina* (*Ceratinidia*) sp2 (both Apidae: Ceratinini) were also recorded in high overall absolute abundance. Similar to *Apis cerana*, these species were also recorded foraging for resources from a large variety of flowering plants in the parks. *Braunsapis* sp1 (Fig. 4B), the second most abundant flower-visiting insect species overall with 86 individuals recorded, visited 28 species of flowering plants (ref. Table 1 in Appendix). A reason for the high abundance of *Braunsapis* species and *Ceratina* species in parks may be because they nest in the stems of plants (Michener, 2007). The study sites were observed to contain a variety of plants with pithy stems that naturally provide these bee species with suitable nesting sites.

Halictidae is the second most abundant Hymenopteran family recorded. Half of the Halictid individuals recorded are represented by a single bee species, *Nomia strigata* Fabricius (Fig. 4C). *Nomia strigata*, a ground-nesting bee, was also the third most abundant flower-visiting insect species, with 79 individuals recorded overall (ref. Table 1 in Appendix). The absolute abundance of *Nomia strigata* is in part due to their dominance in MacRitchie Reservoir Park, where there is an abundance of suitable nesting sites and floral resources to forage from. With the exception of Bedok Town Park, *Nomia strigata* was also recorded visiting flowers at all the other parks.

Of all species of wasps, *Campsomeris* sp1 (Scoliidae) and *Eumenes* sp1 (Vespidae: Eumeninae) were the most abundant, with 26 and 20 individuals respectively (ref. Table 1 in Appendix). *Campsomeris* sp1 is a ground-nesting solitary wasp that was only recorded at HortPark among all the sites. Many individuals of this species were frequently recorded visiting *Antigonon leptopus* and *Bidens pilosa* in the study site. *Eumenes* sp1 was recorded in the study sites of Dairy Farm Nature Park, HortPark, and the Singapore Botanical Gardens visiting five different species of flowering plants.

Species richness. **—** Species richness of the insect fauna was obtained by combining the results from both qualitative and quantitative surveys. In total, 203 species of insects in seven orders were recorded visiting the flowers of 98 plant species over the 21 qualitative photographic surveys and 21 quantitative collection surveys conducted over all the sites.

Flower-visiting Hymenoptera was the most diverse order overall (Fig. 5), with 93 species from 13 families recorded visiting the flowers of 80 plants species. This comprised of 50 species of bees from four families, 24 species of wasps from seven known families, and 19 species of ants (Formicidae).

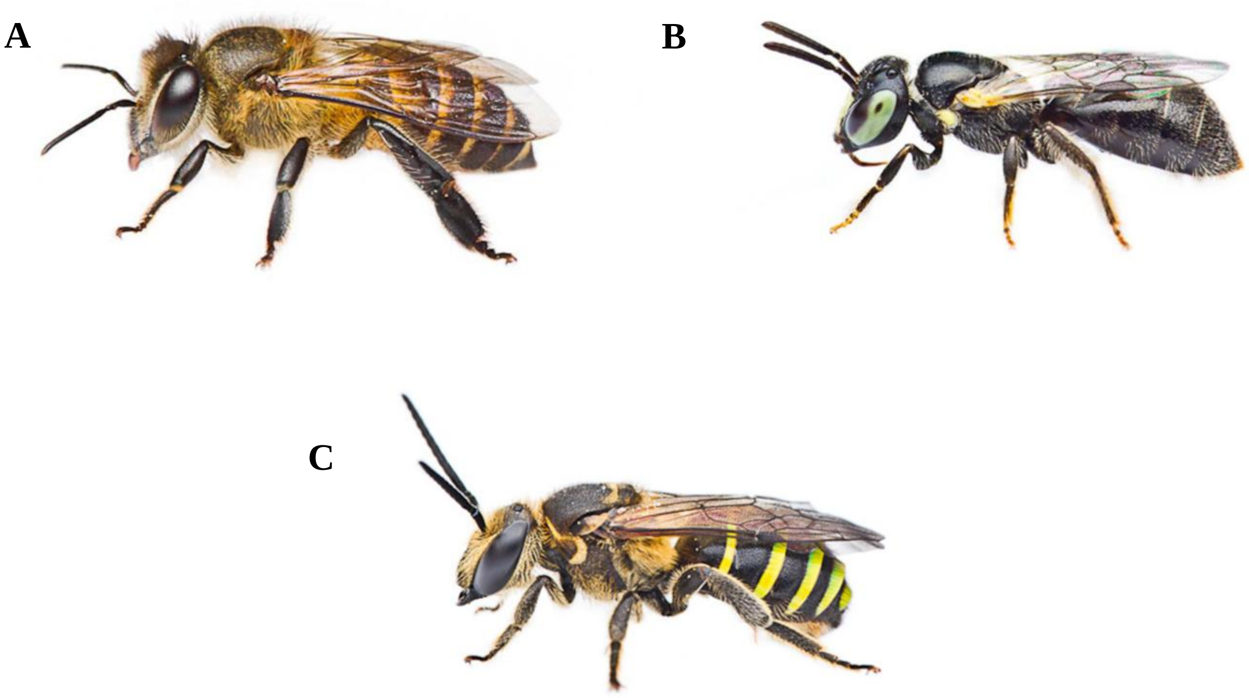

Fig. 4. The three most abundant flower-visiting insect species recorded. A, *Apis cerana* (~15 mm TL); B, *Braunsapis* sp1 (~7 mm TL); C, *Nomia strigata* (~13 mm TL).

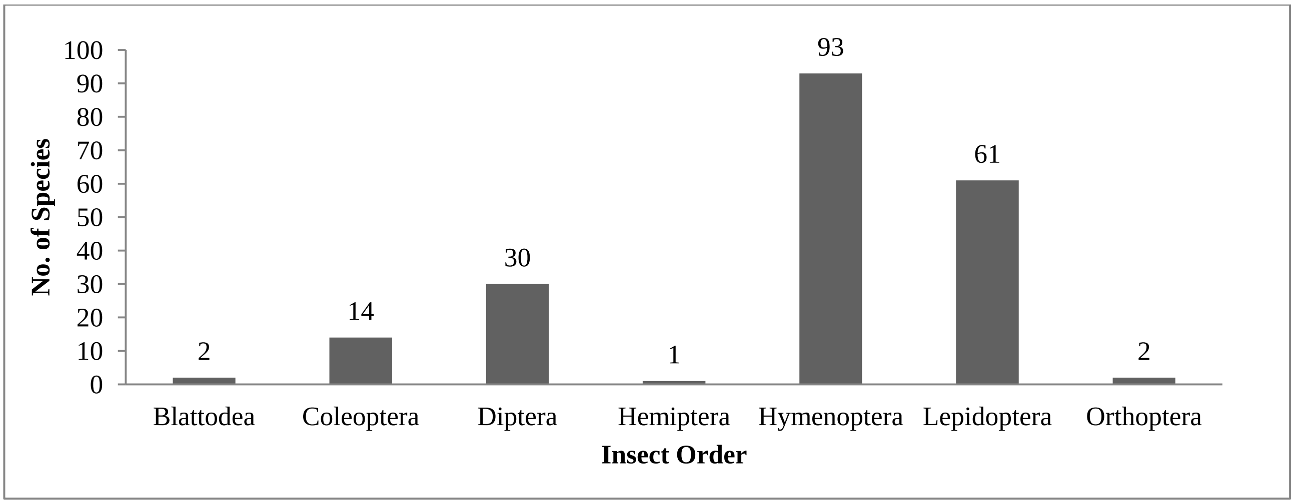

Fig. 5. Species richness of flower-visiting insect orders recorded across all the parks surveyed.

Of the four bee families recorded, Apidae was the most diverse (23 species), followed by Megachilidae (14 species), Halictidae (12 species), and lastly Colletidae (one species). The species richness of bees recorded in this study of parks is surprisingly high, as the most recent major study on bee diversity in Singapore by Liow et al. (2001) recorded only 29 species of bees from five forest sites in Singapore.

Furthermore, while the family Megachilidae was completely unrecorded by Liow et al. (2001) during a study of bees in the five forest sites in Singapore, this study recorded 14 species in the seven parks. This finding is significant because Megachilid bees can play an important role in pollination in tropical lowland forests (Bawa, 1990), and their relatively high species richness in parks gives evidence that managed green spaces in Singapore can potentially support a large diversity of Megachilid species. Megachilid bees are known to be cavity-nesters (Michener, 2007). As suggested by Matteson et al. (2010), the relatively high species richness of cavity-nesting bees in semi-urban areas, such as parks, may be because such environments contain a variety of man-made and natural structures that provide many different-sized cavities for opportunistic nesting.

Moreover, the record of 14 species of Megachilidae increases our knowledge of this bee family in Singapore, as previously only two species were mentioned as having been recorded in Singapore in Ng et al. (2011). Based on the Discover Life bee species guide and world checklist (Ascher & Pickering, 2012), six species of Megachilid recorded represent new records for Singapore. These species are *Megachile* cf. *griseopicta* (Fig. 6A), *Chalicodoma* sp1 (Fig. 6B), *Chalicodoma disjuncta* (Fig. 6C), *Chalicodoma umbripennis* Smith (Fig. 6D), *Megachile* sp. (species-group of *Megachile fulviventris* Friese) (Fig 6E) and *Heriades* (*Michenerella*) sp1 (Fig. 6F). There were also no specimens of these species present in the ZRC of the Raffles Museum of Biodiversity and Research prior to this publication (pers. obs). However, as many of these species have been recorded in nearby regions such as India and Malaysia (Ascher & Pickering, 2012), it is not surprising that they have been found in Singapore. Of the Megachilids encountered during this study, *Megachile* sp. (species-group of *Megachile fulviventris* Friese), *Megachile* cf. *griseopicta*, and *Megachile ramera* were noted to be exceptionally uncommon, with fewer than three individual specimens of each species recorded.

One noteworthy species of small carpenter bee (Apidae: Xylocopinae: Ceratinini) collected is *Ceratina* (*Catoceratina*) *perforatrix* (Fig. 7). Although this species had previously been recorded from Singapore, it was noted by Vecht (1952) to be rare and probably restricted to primary forests. However in this study, *Ceratina* (*Catoceratina*) *perforatrix* was recorded visiting exotic flowers in urbanised and nature parks such as Bedok Town Park, HortPark, Tampines Eco Green, and Dairy Farm. It is thus surprising to find that this species is able to survive in the parks of Singapore. Little is known about this species' biology (Natapot Warrit, pers. comm.), and it may be an interesting subject for further investigation.

Of the seven known families of flower-visiting wasps recorded, Vespidae was the most diverse (12 species). Five species of Vespids are of the subfamily Eumeninae (commonly known as potter wasps), one is from Polistinae (paper wasps), three are from the subfamily Stenogastrinae (hover wasps), and three are of the subfamily Vespinae, genus Vespa (true hornets). The other wasp families were Scoliidae and Sphecidae (three species each), Chalcididae (two species), and Chrysididae and Crabronidae (one species each). Two species of wasps recorded were from unidentified families.

Species representatives of bees and wasps families are shown in Fig. 8 and Fig. 9.

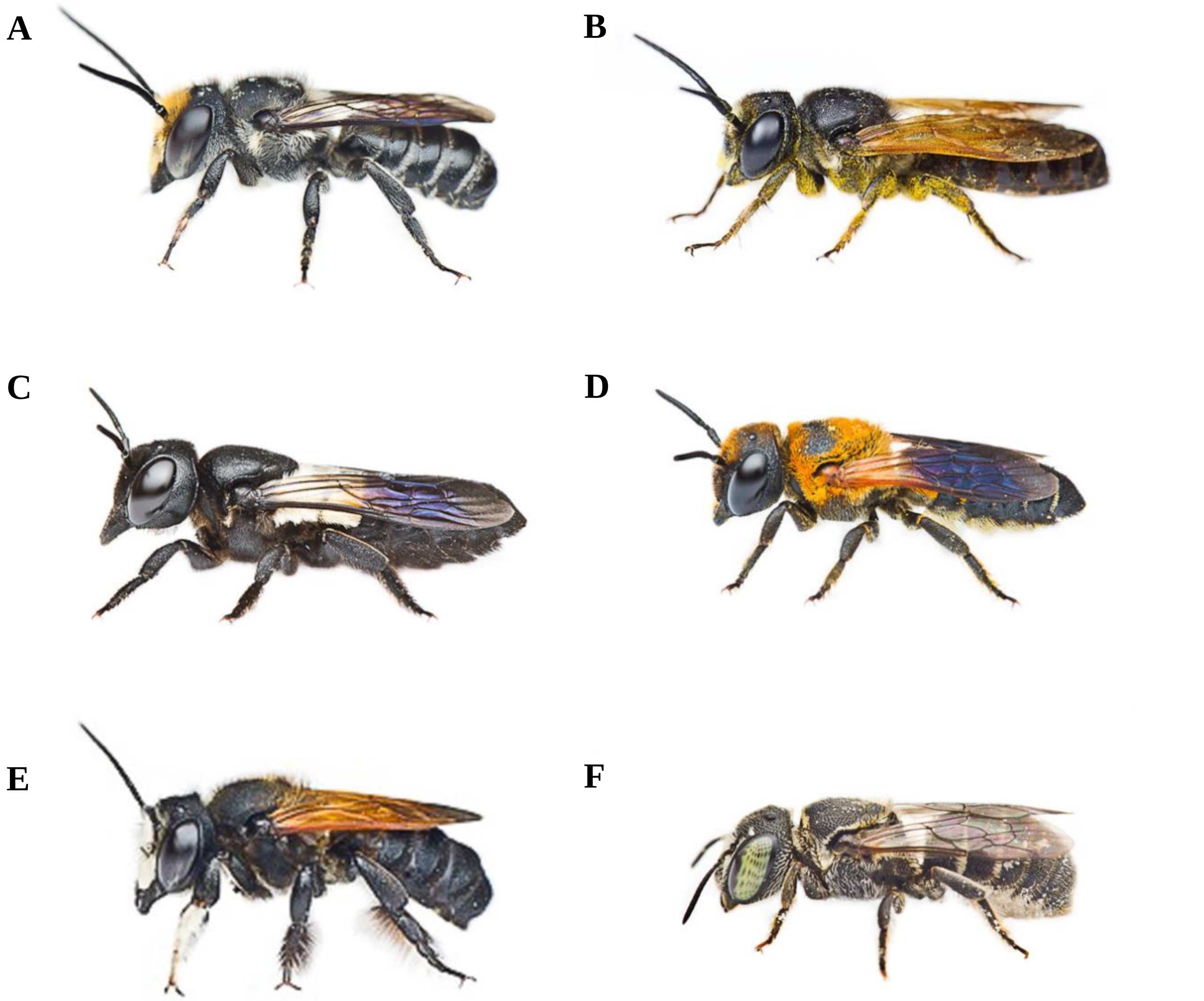

Fig. 6. Possible new records for Singapore include: A, *Megachile* cf. *griseopicta* (~18 mm TL); B, *Chalicodoma* sp1 (~17 mm TL); C, *Chalicodoma disjuncta* (~19 mm TL); D, *Chalicodoma umbripennis* (~16 mm TL); E, *Megachile* sp. (species-group of *Megachile fulviventris* Friese) (~17 mm TL); F, *Heriades* (*Michenerella*) sp1 (~7 mm TL). (Photographs by: Zestin Soh).

Fig. 7. *Ceratina (Catoceratina) perforatrix* (~ 13 mm TL), a noteworthy species. It was thought to be rare and restricted to primary forests, but in Singapore it was frequently recorded from urbanised parks. (Photographs by: Zestin Soh).

Comparison between parks. — In terms of relative abundance of flower-visiting Hymenoptera from the seven parks, HortPark had the highest abundance followed by Singapore Botanic Gardens, Pasir Ris Park, Bedok Town Park, Tampines Eco Green, Dairy Farm Nature Park, and lastly, MacRitchie Reservoir Park (Fig. 10).

With regards to species richness, Pasir Ris Park and Dairy Farm Nature Park were most diverse followed by Singapore Botanic Gardens, HortPark, and Tampines Eco Green. Bedok Town Park and MacRitchie Reservoir Park had the lowest species richness of flower-visiting Hymenoptera (Fig. 11).

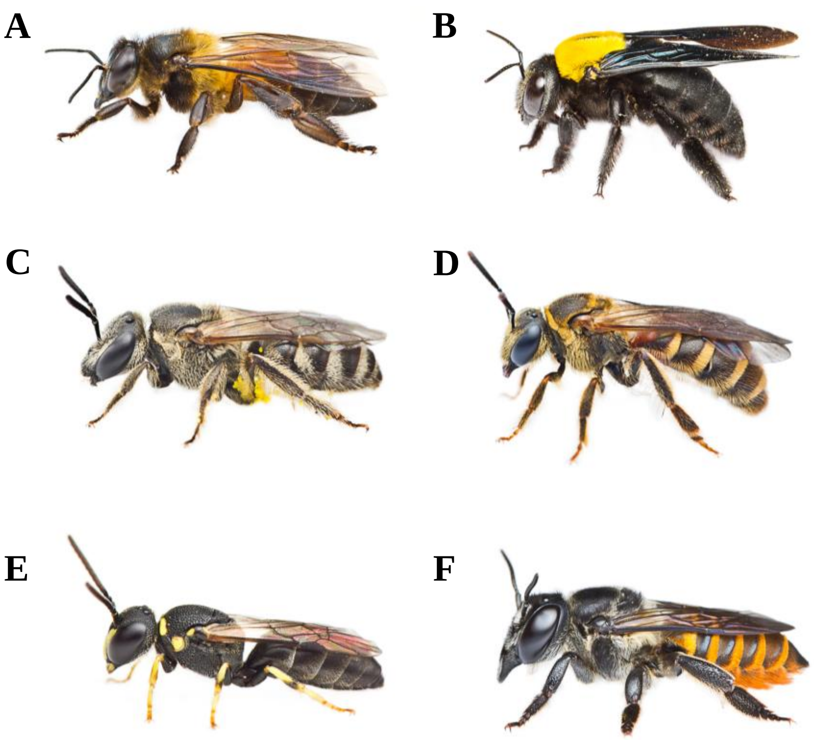

Fig. 8. Species representatives of bee families recorded. A, Apidae, Apinae *Apis dorsata* (~25 mm TL); B, Apidae, Xylocopinae *Xylocopa aestuans* (~26 mm TL); C, Halictidae, Halictinae *Lasioglossum* sp1 (~11 mm TL); D, Halictidae, Nomiinae *Lipotriches ceratina* (~10 mm TL); E, Colletidae, Hylaeinae *Hylaeus* sp1 (~10 mm TL); F, Megachilidae, Megachilinae *Megachile ramera* (~21 mm TL). (Photographs by: Zestin Soh).

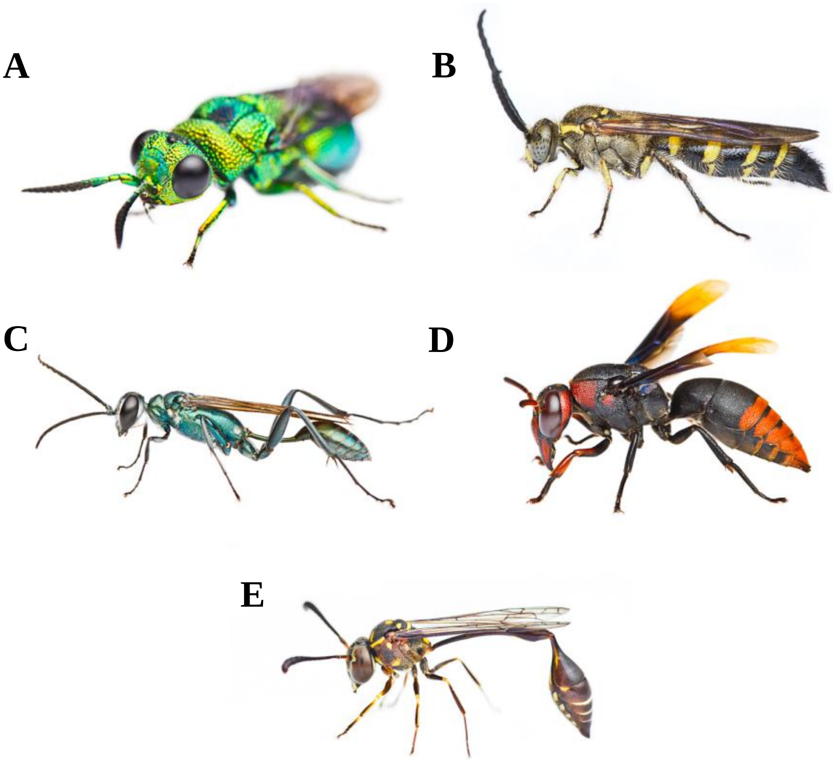

Fig. 9. Some species representatives of wasp families recorded. A, Chrysididae, Chrysidinae wasp sp1 (~12 mm TL); B, Scoliidae, Campsomerinae *Campsomeris* sp2 (~20 mm TL); C, Sphecidae, Sceliphrinae *Chalybion* sp1 (~20 mm TL); D, Vespidae, Eumeninae *Rhynchium haemorrhoidale* (~21 mm TL); E, Vespidae, Stenogastrinae wasp sp1 (~16 mm TL). (Photographs by: Zestin Soh).

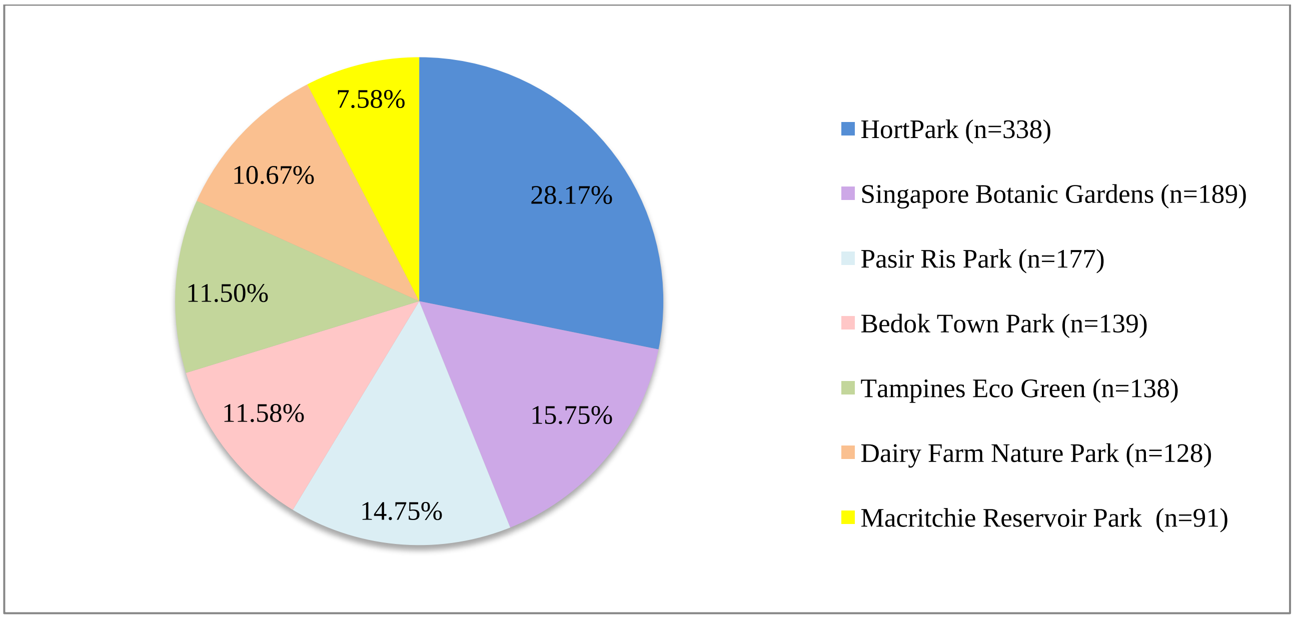

Fig. 10. Relative abundance of all flower-visiting Hymenoptera recorded from the seven parks.

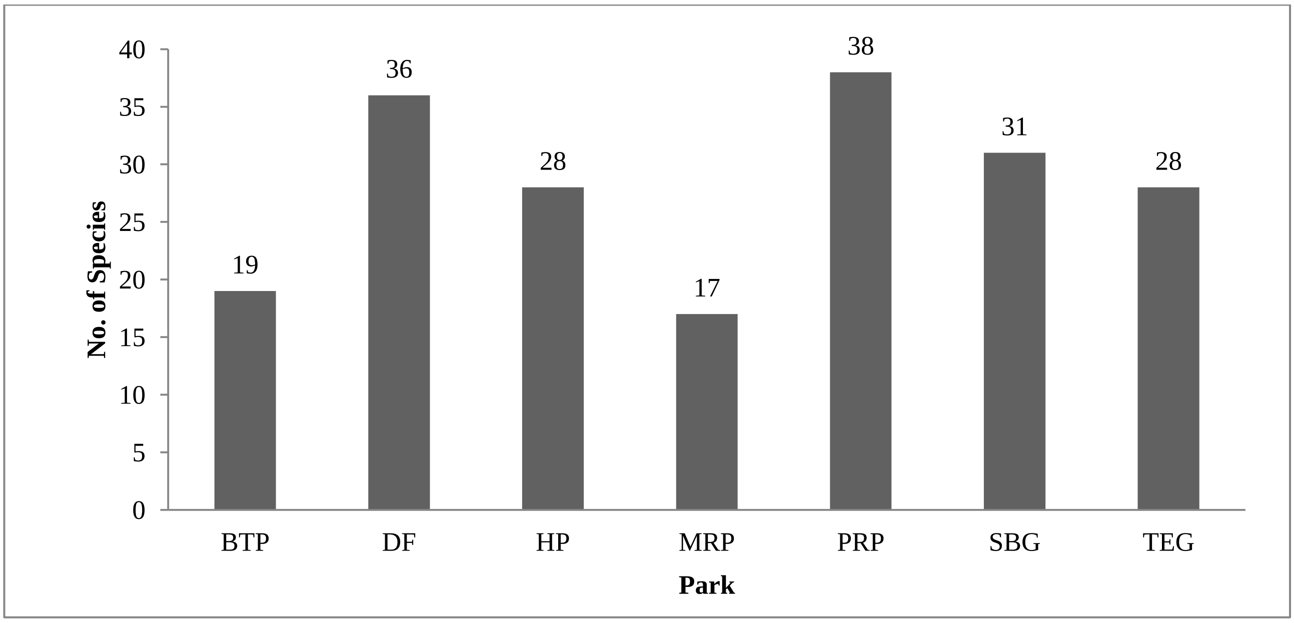

Fig. 11. Species richness of flower-visiting Hymenoptera from the seven parks. BTP: Bedok Town Park; DF: Dairy Farm Nature Park; HP: Hort Park; MRP: Macritchie Reservoir Park; PRP: Pasir Ris Park; SBG: Singapore Botanic Gardens; TEG:Tampines Eco Green.

From the results of this study, the site at Dairy Farm Nature Park potentially has the highest flower-visiting insect diversity of the seven parks at the time of surveying. When the species richness of the various insect orders were compared among the park sites, Dairy Farm Nature Park was recorded to be among the highest of the parks in terms of overall flower-visiting insect fauna, flower-visiting Hymenoptera and flower-visiting Lepidoptera. More significantly, many unusual and uncommon species of insects were recorded only at this site, including *Megachile ramera* Cockerell and *Austronomia takauensis* Friese, both of which have Singapore as their type localities. Furthermore, many new species of flower-visiting insects and floral associations were constantly recorded with each subsequent survey conducted at the study site of Dairy Farm Nature Park (relative to the surveys conducted at the other sites). These findings suggest that Dairy Farm might be an important site for flower-visiting insect conservation, and further studies should be conducted over a longer period of time to estimate the true species richness of flower-visiting insects in the park.

The high diversity of flower-visiting insects in Dairy Farm might firstly be attributed to the surrounding features of the study site. The study site in Dairy Farm Nature Park is located at the edge of secondary forest, and is also in close-proximity to the secondary and primary forest patches of Bukit Timah Nature Reserve. These surroundings might provide habitats suitable for forest-dwelling species of flower-visiting insects that visit the study site for floral resources. Another notable feature of the Dairy Farm study site is the relatively wide variety of cultivated exotics, naturalised exotics, and native flowering plants growing there. This might have also contributed to the overall diversity of flower-visiting insects as the different species were recorded visiting these three kinds of flowering plants for resources.

Flowering plants. — A significant finding from this study was that certain species of naturalised flowering plants, such as *Asystasia gangetica*, *Bidens pilosa*, and *Stachytarpheta indica* were visited by exceptionally high diversity of flower-visiting hymenoptera. These plants are exotic and have established reproductive populations in various environments in Singapore (Chong et al., 2009). In Dairy Farm Nature Park, *Asystasia gangetica* received by far the most species of hymenopteran visitors (20 species) among all the flowering plants in the study site. In addition, a number of rare and unusual flower-visiting insect species in Dairy Farm Nature Park such as *Megachile ramera*, *Megachile* sp. (species-group of *Megachile. fulviventris* Friese), and *Megachile* cf. *griseopicta* were also only recorded visiting *Asystasia gangetica*. In HortPark, *Bidens pilosa* received the most species (12 species) of flower-visiting hymenoptera of all the flowering plants surveyed. In Bedok Town Park, *Stachytarpheta indica* received the most species of hymenopteran visitors (six species in total) among all the other plants surveyed in the park. The high number of species visiting these exotic plants could be because their flowers provide a nutritious and easily accessible food resource, although this requires further investigation. Nonetheless, these survey results strongly suggest that certain species of naturalised flowering plants have a significant role in maintaining flower-visiting insect diversity in the park setting of Singapore.

From the plant perspective, the exceptionally high diversity of insect visitors might possibly be linked with an increase in the opportunities for their pollination, thus enabling these exotics to successfully establish themselves within Singapore’s parks. However, some native species of insects are not morphologically adapted to visit exotic flowers, and thus might resort to floral larceny in the form of stealing or robbing nectar from flowers without providing them with pollination (Inouye, 1980; Irwin et al., 2001). In Dairy Farm Nature Park, one particular unidentified species of potter wasp, *Eumenine* sp1 (Vespidae: Eumeninae) was frequently recorded robbing nectar by chewing through the sepals of the *Asystasia gangetica* flower to gain access to the nectar. Thus, insect species that visit flowering plants do not necessarily provide them with pollination.

While a diverse community of flower-visiting insects may benefit from the resources provided by naturalised exotics, it is crucial to note that these insect-plant associations may potentially have negative effects on the ecosystem in the long run. For one, naturalised flowering plants may possibly become invasive in the future due to increased opportunities for pollination by insects. Secondly, non-native wildflowers may also draw away insects from visiting native plants in the forest, thus reducing their chance of receiving pollination. This outcome would defeat the initial purpose of conserving pollinator populations for the preservation of endangered native plant species.

It is therefore extremely important for Singapore to carefully and consciously manage its flower-visiting insects. However in order to do so, it is first necessary to understand the insects and their diverse and complex web of relationships with their associated plants. Yet knowledge of flower-visiting Hymenoptera, the most dominant of the insect orders in species richness and abundance, is very lacking. These are compelling reasons for more in-depth studies to be conducted in this field of research in Singapore.

RECOMMENDATIONS ON FLOWERING PLANT SPECIES

Among the flowering plants surveyed in this study are a few noteworthy species that received a high diversity of insect visitors.

The first plant is the native *Melastoma malabathricum*, which received the highest diversity of visitors of all the native plants surveyed in this study. As this plant is native and is visited by a wide variety of flower-visiting insect species, it may be beneficial to grow more of this species in other parks to support the flower-visiting insect communities there. In addition, this plant may support bird populations, as species of flower-peckers and bulbuls have been observed to feed on the fruits of *Melastoma malabathricum* (pers. obs.).

The next species is *Vitex trifolia*, an exotic plant that received the most species of insect visitors among the plants surveyed in the Pasir Ris Park study site. *Vitex trifolia* is especially noteworthy among the plants as it received several species of uncommon megachilid bees. However, instead of planting the exotic *Vitex trifolia* in parks, park managers could possibly look into planting other species of *Vitex* that are native to Singapore, such as *Vitex gamosepala*, *Vitex negundo*, *Vitex pinnata*, and *Vitex vestita*. Planting these native plants will minimise the potential threat of an invasion of exotic plants in the ecosystem. Moreover, as these plants are closely related to *Vitex trifolia*, there is a possibility that they support a similar diversity of flower-visiting insects. More research should be done in the future to confirm this.

The final plant species is *Leea rubra*. This plant received the most species of visitors of the plants surveyed at Tampines Eco Green, and also the second highest number of insect visitor species of all the plants surveyed in this study. However, *Leea rubra* is presumed to be a nationally extinct species, and thus the individuals of *Leea rubra* surveyed in this study are introduced and not considered part of the native population (Lok et al., 2011). Park managers should therefore consider trying to grow other species of *Leea* that are native to Singapore in parks, such as *Leea angulata* and *Leea indica*. These flowering plant species might possibly be able to support a similar diversity of flower-visiting insects.

Some recommendations for future research include:

More surveys over more areas of the parks. — Parks with large land size (such as Dairy Farm Nature Park and the Singapore Botanic Gardens) require a greater number of surveys to be conducted over more areas of the parks in order to fully represent the diversity of flower-visiting insects that the entire park contains.

Long-term surveys. — As certain flowering plant species bloom at different times of the year and populations of flower-visiting insects may fluctuate over a long period of time, future surveys should be conducted over a longer duration (a few years at least) in order to capture the entire spectrum of flower-visitors and floral associations. Moreover, a long-term research study would provide an important baseline that would allow for the monitoring of flower-visiting insect populations in Singapore.

Surveys focusing on native flowering plants. — This would provide information on the diversity of insects species that are supported by native plants. Native plants that support a wide diversity of flower-visiting insects can be planted in higher abundance around parks. If the native plants are endangered, data on their flower-visitors would also provide baseline information on their possible pollinators. This data can be tested further and eventually be used for the conservation of endangered native plants.

A prominent finding from this short-term study is that in spite of the urban developments in Singapore, flower-visiting insect communities within its parks are still very diverse. Unique and unusual species of insects as well as interesting floral associations can be also observed within each park, which highlights their individual importance in flower-visiting insect conservation. Therefore, we strongly believe that new and exciting flower visiting insect species will be discovered as more research is conducted in other parks of Singapore.

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The first author honours this work to his late father Soh Jit Sheng, with whom many hours were spent nurturing a passion for nature.

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APPENDIX

Table 1. Summary of Hymenoptera species visiting respective flower species.

Hymenoptera Species	Flowering Plants (see Table 2 for species codes)	Total No. of Flowering Plant Species
Apidae		
Apinae		
Anthophorini		
Amegilla sp1 (small)	TU1, VE1, VE6	3
Amegilla sp2 (large)	AC1, AC2, FA1, FA6, FA9, LA5, NY1, RU2,VE1, VE3, VE4, ME2, MY1	13
Apini		
Apis andreniformis	AR1, PY1	2
Apis cerana	AC2, AL1, AP1, AR1, AS2, AS7, C03, CU2, EU2, FA5, FA6, FA7, LA5, LY1, MV1, MV2, NY1, OX1, PU1, PY1, RU1, RU3, SO1, TU1, VE1, VE4, VE5, VE6, VI1	29
Apis dorsata	AC2, FA6	2
Melectini		
Thyreus sp1	AS2, AS7, LA4, LA5, VE1, VE4, VE5	7
Thyreus sp2 (different thoracic markings from sp1)	AC2	1
Meliponini		
Trigona (*Tetragonula*) *fuscobalteata*	AL1, AY1, AS5, EU2, IR1, LA2, LI1, MV1, RT2, OR1	10
Trigona (*Heterotrigona*) *itama*	AS5, AS7, EU2, FA10, LA2, MV1, SA1	7
Trigona (*Tetragonula*) *reepeni*	LA2, MV1,	2
Trigona sp1	AP1, CU1, PU1, PY1, SO1,	5
Trigona sp2	LA2	1
Xylocopinae		
Allodapini		
Braunsapis sp1	AC2, AC4, AL1, AM1, AR1, AS3, AS5, AS6, AS7, AS8, BL1, CL1, CU1, LA1, LA2, LA5, LY1, MV2, OX1, PY1, PR1, RU1, RU3, TU1, VE1, VE2, VE4, VI1	28
Ceratinini		
Ceratina (*Neoceratina*) *dentipes*	LI1, LY1	2
Ceratina (*Pithitis*) *smaragdula*	FA2, LA5, ME2	3
Ceratina (*Pithitis*) *unimaculata*	AC2, ME2	2
Ceratina (*Ceratinidia*) sp1(parapsidal lines, smooth concave face markings)	AC2, AC4, AL1, AS5, AS8, CL1, CU2, LA5, LI1, ME1, PY1, VE2, ME2, VI1	14
Ceratina (*Ceratinidia*) sp2 (parapsidal lines, jagged markings)	AC2, AS8, CL1, CU1, LA5, VE2, ME2, VI1	8
Ceratina (*Catoceratina*) *perforatrix*	AC2, AC3, AC4, CU1, LA5, ME1, ME2, TU1	8
Xylocopini		
Xylocopa caerulea	ME2	1
Xylocopa aestuans	CU1, FA3, FA8, FA9, FA10, LA5, MV2, PL1, TU1, VE1, VE6, GO1, ME2, MT1	14
Xylocopa flavonigrescens	LA5	1
Xylocopa latipes	CU1, FA1, FA3, MV1, MV2, VE6, CO2, ME2	8
Chalcididae		
Brachymeria sp1(black with yellow hindlegs)	AM1	1
Chalcid wasp sp2 (tiny)	AL1	1
Chrysididae		
Chrysidinae		
Chrysid wasp sp1	AC2, FA10	2
Colletidae		

Hymenoptera Species	Flowering Plants (see Table 2 for species codes)	Total No. of Flowering Plant Species
Hylaeinae		
Hylaeus sp1	MT1	1
Crabronidae		
Tachytes sp1	VI1	1
Formicidae		
Dolichoderinae		
Iridomyrmex sp1	AL1, AS4,	2
Tapinoma melanocephalem	AC4, CU1	2
Formicinae		
Anoplolepis gracilipes	AS4, ME2	2
Camponotus sp1	AS4, ME2	2
Camponotus sp2	AP1	1
Camponotus sp3	ME2	1
Camponotus sp4	AC2, AL1, AM1, AY1, AP1, AS4, MV2, ME1, SO1, ME2, VI1	11
Camponotus sp5 (brown)	AL1	1
Camponotus sp6	EU1	1
Polyrhachis sp1 (black, 2 petiolar spines)	AS4, ME2	2
Polyrhachis sp2 (golden)	ME2	1
Myrmicinae		
Crematogaster sp1	AT1, CU1	2
Meranoplus cf. *bicolor*	AT1, AI1	2
Monomorium pharaonis	CU1, AI1	2
Pheidole sp1	AT1	1
Pheidole sp2	PY1	1
Pheidologeton sp1	AS8, CO1, CU1	3
Tetramorium sp1	ME2	1
Tetramorium sp2	AP1	1
Halictidae		
Austronomia takauensis	AC2, FA4, ME1, RU4	4
Homalictus cf. *adonidiae*	AR1	1
Hoplonomia sp1	AC4, PY1	2
Lasioglossum sp1 (grey, rounded pronotum)	AC2, AC4, AM1, AS2, AS3, AS4, CL1, CU1, CU2, FA6, FA7, LA1, I1, MV2, PY1, PR1, TU1, VI1	18
Lasioglossum sp2 (large, apical bands on 2nd and 3rd tergite)	CU1	1
Lasioglossum sp3 (more abdominal bands, extra markings on thorax)	TU1	1
Lipotriches ceratina	AS9, PO1, PO3, PY1, PO2, VI1	6
Nomia strigata	AC2, AC3, AC4, AM1, AS2, FA1, LA2, LA4, LA5, LI1, MV1, PY1, VE1, ME2, MY1	15
Nomia (*Maculonomia*) *terminata*	ME2, MY1	2
Nomia sp1 (black abdomen, thin abdominal lines)	AM1	1
Pachyhalictus sp1	AC2, CU1, ME2	3
Pseudapis siamensis	AM1, AS2, PY1	3
Megachilidae		
Chalicodoma disjuncta	LA5, VE4, VE6	3
Chalicodoma sp1 (black body, orange wings, slender)	MV2	1
Chalicodoma umbripennis	LA5, LY1, MV2, VE6	4
Coelioxys sp1	AC2, AS2, AS7, MV2	4

Hymenoptera Species	Flowering Plants (see Table 2 for species codes)	Total No. of Flowering Plant Species
Coelioxys sp2 (pink marking on cheek)	AM1	1
Creightonella atrata	CU1, FA3, MA1	3
Heriades (*Michenerella*) sp1	AM1, AS2, LA1, LA5, LY1, RU3	6
Megachilid sp1 (greyish body, white pubescence and abdominal banding)	TU1	1
Megachile cf. *griseopicta*	AC2	1
Megachile cf. *tricincta*	AC4, AS1, AS2, AS7, LY1, MV2, PY1, TU1, MA1, MT1	10
Megachile sp. (species-group of *Megachile fulviventris* Friese)	AC2	1
Megachile laticeps	AC2, FA10, LA5, LY1, TU1	5
Megachile conjuncta	FA2, MT1	2
Megachile ramera	AC2	1
Scoliidae		
Campsomerinae		
Campsomeris sp1 (solid grey thorax)	AP1, AS2, PY1	3
Campsomeris sp2 (grey thorax with black and yellow markings)	AC2, AL1, AM1, AS2, BL1	5
Scoliinae		
Scolia sp1 (large, black body, orange fur on thorax)	CU1	1
Sphecidae		
Chalybion sp1	EU2	1
Sphecid wasp sp1	EU1	1
Sphecid wasp sp2 (tiny, black)	EU1	1
Vespidae		
Eumeninae		
Delta sp1 (large, red)	LA5, MT1, VI1	3
Eumenes sp1 (black body with thin yellow markings)	AL1, AM1, AS2, AS4, LA3, LA5,	6
Eumenine wasp sp1 (small, yellow body with black stripes)	AC2, AS2, LA3, LA5	4
Eumenine wasp sp2 (small, solid black body)	VE1	1
Rhynchium haemorrhoidale	AC2, AS4, EU2, LA3, LA5, VI1	6
Polistinae		
Ropalidia sumatrae	EU2	1
Stenogastrinae		
Eustenogaster sp1(large, yellow with blue and red markings)	AS4	1
Stenogastrine wasp sp1 (brown, yellow markings)	LA5	1
Stenogastrine wasp sp2 (black, metallic)	LA5	1
Vespinae		
Vespa affinis	VI1	1
Vespa analis	VI1	1
Vespa tropica	VI1	1
Unknown Hymenoptera		
Unknown wasp sp1 (red and black)	EU1	1
Unknown wasp sp2 (tiny, long ovipositor)	ME2	1

Table 2. Summary of codes assigned to plant species visited by insects, and total no. of species of visiting Hymenoptera. Note: Asterisk (*) behind plant species name denotes that the species is native according to Chong et al. (2009). Double Asterisk (**) behind plant species name denotes that the species is native but is now presumed to be nationally extinct, as per Chong et al. (2009).

Plants	Code	Total No. of Hymenopteran Species Visited
Acanthaceae	**AC**	
Andrographis paniculata	AC1	1
Asystasia gangetica	AC2	23
Ruellia malacosperma	AC3	2
Strobilanthes cusia	AC4	8
Alismataceae	**AT**	
Echinodorus palafolius	AT1	3
Alliaceae	**AL**	
Allium tuberosum	AL1	10
Amaranthaceae	**AM**	
Celosia argentea	AM1	11
Amaryllidaceae	**AY**	
Hymenocallis speciosa	AY1	2
Apiaceae	**AI**	
*Centella asiatica**	AI1	2
Apocynaceae	**AP**	
Asclepias curassavica	AP1	6
Arecaceae	**AR**	
Carpentaria acuminata	AR1	4
Asteraceae	**AS**	
Ageratum conyzoides	AS1	1
Bidens pilosa	AS2	12
Cosmos caudatus	AS3	2
Mikania micrantha	AS4	8
Sphagneticola trilobata	AS5	4
Stevia rebaudiana	AS6	1
Tagetes sp.	AS7	6
Tridax procumbens	AS8	4
Vernonia cinerea	AS9	1
Blechnaceae	**BL**	
Blechum pyramidatum	BL1	2
Cleomaceae	**CL**	
Cleome rutidosperma	CL1	4
Costaceae	**CO**	
Costus sp. Red Rose	CO1	1
*Costus speciosus**	CO2	1
Costus woodsonii	CO3	1
Cucurbitaceae	**CU**	
Luffa aegyptiaca	CU1	15
Luffa sp.	CU2	3
Euphorbiaceae	**EU**	
Euphorbia hirta	EU1	4
Jatropha podagrica	EU2	6
Fabaceae	**FA**	
Clitoria ternatea	FA1	3
Crotalaria pallida	FA2	2
Crotalaria retusa	FA3	3
Desmodium triflorum	FA4	1
Mimosa diplotricha	FA5	1
Mimosa pudica	FA6	4
Neptunia plena	FA7	2
Senna alata	FA8	1
Senna obtusifolia	FA9	2

Plants	**Code**	**Total No. of Hymenopteran Species Visited**
Senna polyphylla	FA10	4
Goodeniaceae	**GO**	
*Scaevola taccada**	GO1	1
Iridaceae	**IR**	
Neomarica longifolia	IR1	1
Lamiaceae	**LA**	
Calamintha nepeta	LA1	3
Callicarpa pedunculata	LA2	6
Hyptis brevipes	LA3	3
Leonurus japonicus	LA4	2
Vitex trifolia	LA5	21
Linderniaceae	**LI**	
Torenia polygonoides	LI1	5
Lythraceae	**LY**	
Cuphea hyssopifolia	LY1	7
Malpighiaceae	**MA**	
*Tristellateia australasiae**	MA1	2
Malvaceae	**MV**	
Hibiscus sp.	MV1	6
Muntingia calabura	MV2	10
Melastomataceae	**ME**	
Dissotis rotundifolias	ME1	4
*Melastoma malabathricum**	ME2	20
Myrsinaceae	**MY**	
Ardisia elliptica	MY1	3
Myrtaceae	**MT**	
*Syzygium zeylanicum**	MT1	5
Nyctaginaceae	**NY**	
Mirabilis jalapa	NY1	2
Orchidaceae	**OR**	
*Spathoglottis plicata**	OR1	1
Oxalidaceae	**OX**	
Oxalis barrelieri	OX1	2
Plantaginaceae	**PL**	
Otacanthus caeruleus	PL1	1
Plumbaginaceae	**PU**	
Plumbago auriculata	PU1	2
Poaceae	**PO**	
Imperata cylindrica	PO1	1
*Ischaemum muticum**	PO2	1
Paspalum conjugatum	PO3	1
Polygonaceae	**PY**	
Antigonon leptopus	PY1	13
Portulacaceae	**PR**	
Talinum fruticosum	PR1	2
Rubiaceae	**RU**	
Ixora sp.	RU1	2
Mussaenda philippica	RU2	1
Rondeletia leucophylla	RU3	3
Spermacoce latifolia	RU4	1
Rutaceae	**RT**	
Murraya paniculata	RT2	1
Sapindaceae	**SA**	
Cardiospermum halicacabum	SA1	1
Solanaceae	**SO**	
Capsicum sp.	SO1	3

Plants	Code	Total No. of Hymenopteran Species Visited
Turneraceae	**TU**	
Turnera subulata	TU1	10
Verbenaceae	**VE**	
Duranta erecta	VE1	8
Lantana cf. *montevidensis*	VE2	3
Lantana camara	VE3	1
Stachytarpheta cayennesis	VE4	5
Stachytarpheta Dwarf Red	VE5	2
Stachytarpheta indica	VE6	6
Vitaceae	**VI**	
*Leea rubra***	VI1	13