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Insect visitors to flowers of cultivated *Ardisia elliptica* Thunb. (Myrsinaceae) and *Memecylon caeruleum* Jack (Melastomataceae) in Singapore

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Abstract. This study documents the composition and behaviour of insect visitors to flowers of cultivated plants of *Ardisia elliptica* Thunb. and *Memecylon caeruleum* Jack at the National University of Singapore Kent Ridge Campus, Singapore. During a synchronous flowering of these plants from January to February 2016, six and 13 insect species were observed to visit flowers of *Ardisia elliptica* and *Memecylon caeruleum*, respectively. A comparison of floral visitors for both species showed an overlap of the principal visitor, *Amegilla* (*Zonamegilla*) *andrewsi* (Cockerell) for flowers of both *Ardisia elliptica* and *Memecylon caeruleum*, but the exclusive visitation of three *Megachile* species to *Memecylon caeruleum* flowers suggests the presence of two distinct guilds that frequent the flowers of *Ardisia elliptica* and *Memecylon caeruleum*. These observations, coupled with other Singapore observations, provide a baseline for understanding native pollinators for both species.

Key words. bees, insect pollinators, plant-pollinator networks, Singapore

INTRODUCTION

Ardisia (Myrsinaceae) and *Memecylon* (Melastomaceae) are plant genera native to the Indian subcontinent and Southeast Asia (Giesen et al., 2007; Maxwell, 1980), and in the case of *Ardisia*, also found in the exotic plant trade (Sellers et al., 2007). Published observations of insect pollinators are scarce for *Ardisia* and non-existent for *Memecylon*. The only study to have examined pollinator visitation to *Ardisia* was conducted in subtropical hardwood forests in Dade County, Florida, USA on non-native *Ardisia escallonioides* (Pascarella, 1997a). Aside from Soh & Ngiam (2013), pollination studies have yet to be conducted on *Ardisia elliptica* Thunb. and *Memecylon caeruleum* Jack in their native ranges.

Ardisia elliptica Thunb. is listed as among the world's most ecologically impactful globally invasive species (Lowe et al., 2000). However, within its native range, it is a nationally Endangered plant in Singapore (Tan et al., 2008) noted to occur naturally in coastal scrubland (Giesen et al., 2007). It is also planted in coastal parks in Singapore Island (Tan, 2008) and locally elsewhere, for example, as an ornamental plant in the National University Singapore (NUS) Kent Ridge Campus. It has pink- or white-petalled, pentamerous flowers, pendulous in axillary inflorescences of five to seven flowers. It has five connivent stamens with introse, longitudinal, anther dehiscence, and a slightly longer style with a small punctiform stigma (Pascarella, 1997b). The study of breeding systems of *Ardisia* in Florida identified bees as the main group of pollinators for *Ardisia elliptica* (Pascarella, 1997b).

Memecylon caeruleum Jack is a native species that is nationally Critically Endangered in Singapore (Tan et al., 2008). Various members of its family are known to be visited by pollen-collecting bees (Renner, 1989; Clausing & Renner, 2001). A study on the floral biology of *Memecylon caeruleum* (Stein & Tobe, 1989) noted the presence of poricidal anthers and the absence of nectaries, which suggests a buzz-pollination syndrome by pollen-collecting bees (Harter et al., 2002).

The synchronous flowering from January to February 2016 of adjacent clumps of *Ardisia elliptica* and *Memecylon caeruleum* at the National University of Singapore (NUS) Kent Ridge Campus afforded an opportunity to observe visitations of potential pollinators on these plants within their native range. It also allowed us to compare the two plants' visitor communities and plant–pollinator interactions. Although both plant species are native to Singapore, their presence within the campus was the result of a research project to landscape part of the campus with plant species native to Singapore (H. T. W. Tan, pers. comm.). Opportunistic records of insect visitations to the two plant species at other restoration plantings across Singapore were also included as supplementary data.

With a burgeoning exotic plant trade leading to continued trans-continental introductions it is imperative to acquire baseline information about pollinator interactions within the native distribution of these plants and to compare native and non-native pollinator guilds. Such data may enable the elucidation of mechanisms by which invasive plants integrate within local plant-pollinator networks and the downstream effects of such integration.

MATERIAL & METHODS

Observations of the floral visitors to *Ardisia elliptica* and *Memecylon caeruleum* took place at two sites along Science Drive 4, situated within the Faculty of Science at the National University of Singapore Kent Ridge Campus, Singapore. The synchronous flowering of adjacent clumps of plants of the two species allowed for the observation of floral visitor choice between these. Observations took place three times daily: early morning (0900–1030 hours), late morning (1030–1200 hours) and early afternoon (1230–1400 hours). Species identity, number of visits and behaviour of floral visitors were recorded during each observation period. A total of nine separate days of observations were conducted between January and February 2016, amounting to 12 h and 32 min of observations in total.

From the NUS Insect Diversity Laboratory Database (Ascher et al., unpublished), last updated on 28 May 2019, we retrieved the total pool of bee species previously known from the Kent Ridge Campus study site (e.g., vouchers from Chan, 2016), as well as all the known associations between Hymenoptera and these two plant species in Singapore. Non-parametric multidimensional scaling (NMDS) was conducted on Hymenopteran species communities to visualise differences in Hymenopteran species composition across 19 different plant species known on the Kent Ridge Campus study site.

OBSERVATIONS & RESULTS

Observations. Six insect species were observed to visit flowers of *Ardisia elliptica* (Table 1) at the site, with Hymenoptera the most frequent of the visitors (93.5%, n = 108). One species of solitary bee, the relatively large and long-tongued *Amegilla* (*Zonamegilla*) *andrewsi* (Cockerell), was recorded as the principal visitor to *Ardisia elliptica* forming the bulk of floral visits (66.7%, n = 72). Flowers of *Memecylon caeruleum* were visited by 13 insect species (Table 1), with the bees *Amegilla andrewsi* (41.2%, n = 204), *Megachile* (*Aethomegachile*) *laticeps* Smith (16.2%, n = 80), and *Nomia iridescens* Smith (14.2%, n = 76), comprised the bulk of floral visits as principal visitors. A relatively large proportion of the visitors to *Memecylon caeruleum* were leaf-cutter and resin bees of the genus *Megachile* (Fig. 1), (32%, n = 158) of which none were recorded visiting *Ardisia elliptica*. *Megachile umbripennis* Smith, and *Megachile disjuncta* (Fabricius) are species that have been noted to be potentially exotic to Singapore based on lack of historic collections (Ascher et al., 2016).

Fig. 1. *Megachile laticeps*, a leaf-cutter bee, visiting *Memecylon caeruleum* in Singapore. (Photograph by: Zestin W. W. Soh).

Table 1. Floral visitors of *Ardisia elliptica* (Myrsinaceae) and *Memecylon caeruleum* (Melastomaceae) at Science Drive 4 of Kent Ridge Campus of the National University of Singapore campus from January to February 2016.

	Number of Visits	
Species	To *Ardisia elliptica*	To *Memecylon caeruleum*
Order Hymenoptera		
Family Apidae		
Subfamily Apinae		
Amegilla (*Zonamegilla*) *andrews*i	72	204
Apis (*Apis*) *cerana*	11	13
Apis (*Megapis*) *dorsata*	0	2
Tetragonula valdezi	6	0
Xylocopa (*Koptortosoma*) *flavonigrescens*	0	18
Xylocopa (*Koptortosoma*) *flavonigrescens* or *X. aestuans*	1	0
Xylocopa (*Platynopoda*) *latipes*	0	1
Family Halictidae		
Subfamily Nomiinae		
Nomia (*Acunomia*) *iridescens*	0	76
Nomia (*Acunomia*) *strigata*	11	19
Family Megachilidae		
Subfamily Megachilinae		
Megachile (*Callomegachile*) *disjuncta*	0	16
Megachile (*Aethomegachile*) *laticeps*	0	80
Megachile (*Callomegachile*) *umbripennis*	0	62
Family Vespidae		
Subfamily Vespinae		
Vespa affinis	0	1
Subfamily Eumeninae		
Delta sp.	0	1
Subfamily Polistinae		
Polistes sp.	0	1
Order Diptera		
Family Syrphidae		
Unidentified spp.	7	0
Unidentified		
Medium-sized wasp	0	1

Shared visitors for both flowers include the bees *Amegilla andrewsi*, *Apis cerana* Fabricius, and *Nomia strigata* (Fabricius). Several *Amegilla andrewsi* females were observed to consecutively visit flowers of both species within a single-afternoon observation period. Notably, *Nomia strigata* and *Amegilla andrewsi* exhibited different floral visitation behaviours when visiting flowers of the two species (Table 2). Both *Nomia strigata* (Fig. 2A) and *Amegilla andrewsi* were observed to sonicate flowers of *Ardisia elliptica*, wrapping their bodies around the stamen and stigma of the flower and vibrating vigorously with an audible sound (see Video 1). Pollen was observed to spew out from the anthers onto the bee following such behaviour. In contrast, we did not observe sonication at *Memecylon caeruleum*. *Nomia strigata* was observed to slowly glean and rub its body against the stamens of *Memecylon caeruleum* for up to 5 seconds per flower. *Amegilla andrewsi* was observed hovering above each individual flower, with its tongue extended, before diving into the flowers and landing on the stamens very briefly (1 second) before returning to a hovering position (see Video 2).

Megachile laticeps, *Megachile umbripennis*, and *Megachile disjuncta* were observed to damage and break *Memecylon caeruleum* flowers on occasion in the process of floral visitation. Individual females rubbed their abdominal scopae (pollen-transporting hairs) vigorously on the stamens and stigma of the flower, causing irreparable stamen breakage in some instances.

Database records. From the database, we found that the bee species observed at Science Drive 4 for both plant species formed 20% of the total bee species known from Kent Ridge Campus (12 out of 58 species) and 30% of the total pool of bee species recorded from around University Hall (12 out of 40 species), the building and its surroundings adjacent to Science Drive 4. Database records in Singapore showed additional species visiting *Ardisia elliptica* and *Memecylon caeruleum* (Table 3). Notably, we observed several species sonicating *Ardisia elliptica*. The NMDS ordination plot shows

Fig. 2. Flower visitations at Science Drive 4, NUS Kent Ridge Campus. a, *Nomia strigata* buzz pollinating *Ardisia elliptica* flowers; b, evidence of *Memecylon caeruleum* stamen breakage after visitation by *Megachile laticeps.*

Table 2. Differences in flower-visitation behaviour of *Amegilla andrewsi* and *Nomia strigata* at *Ardisia elliptica* and *Memecylon caeruleum.*

	Flower-visitation Behaviour	
Species	At *Ardisia elliptica*	At *Memecylon caeruleum*
Amegilla (*Zonamegilla*) *andrewsi*	Sonication	Pause very briefly at flowers
Nomia (*Acunomia*) *strigata*	Sonication	Slowly gleaning pollen from the flowers
Apis (*Apis*) *cerana*	Pause briefly at flowers	

Table 3. Prior records of hymenopteran visitors to *Ardisia elliptica* and *Memecylon caerulum* from various locations across Singapore from 2012–2019. Records were retrieved from the NUS Insect Diversity Laboratory Database and Soh & Ngiam (2013). Abbreviations: BH—Pulau Ubin Butterfly Hill; HP—HortPark; MRP—MacRitchie Reservoir Park; NUS— University Hall, NUS Kent Ridge Campus; PP—Pasir Ris Park; SBG—Singapore Botanic Gardens.

Plant Species	**Flower-visiting Species**	**Ability to Sonicate**	**Observed Sonicating**	**Localities in Singapore**
Ardisia elliptica	*Nomia* (*Acunomia*) *strigata*	Y	Y	MRP, SBG, PP, NUS
	Amegilla (*Zonamegilla*) *andrewsi*	Y	Y	MRP, NUS
	Nomia (*Maculonomia*) sp. aff. *apicalis*	Y	Y	SBG, BH
	Nomia (*Maculonomia*) *fuscipennis*	Y	Y	MRP
	Heterotrigona itama	N	N	SBG
	Apis (*Apis*) *cerana*	N	N	NUS
	Xylocopa (*Koptortosoma*) *aestuans*	Y	N	NUS
	Apis (*Micrapis*) *andreniformis*	N	N	NUS
	Braunsapis hewitti	N	N	NUS
	Tetragonula valdezi	N	N	NUS
	Patellapis (*Pachyhalictus*) *murbanus*	Y	N	NUS
Memecylon caerulum	*Megachile* (*Aethomegachile*) *laticeps*	N	N	HP, NUS
	Megachile (*Callomegachile*) *disjuncta*	N	N	NUS
	Amegilla (*Zonamegilla*) *andrewsi*	Y	N	NUS
	Tetragonula valdezi	N	N	SBG

that *Ardisia elliptica* and *Memecylon caeruleum* are located close together on the plot, indicating a high similarity in the species composition of Hymenoptera that visit the two plant species compared to other plant species (Fig. 3). This supports our observation of shared visitors between *Ardisia elliptica* and *Memecylon caeruleum*.

DISCUSSION

Our study is the first to focus on pollinating insects that visit *Ardisia elliptica* and *Memecylon caeruleum* within its native range. We confirmed that bees are the major floral visitors of *Ardisia elliptica* as speculated by Pascarella (1997b) and consistent with observations from other species in the genus namely *Ardisia escallonioides* (Pascarella, 1997a). As several bee visitors of *Ardisia elliptica* were observed to sonicate at the flowers, our study also suggests that *Ardisia elliptica* is buzz pollinated. Other bees without the ability to sonicate that visited *Ardisia elliptica* flowers may have been attracted to the nectar, but were unable to extract any pollen and are thus not legitimate pollinators. Floral visitors to *Memecylon caeruleum* were not consistent with studies of its nectaries (Stein & Tobe, 1989) which suggested that it is pollinated by buzz-pollinating bees. We did not observe any buzz pollination by its principal visitors (*Nomia iridescens* and *Amegilla andrewsi*) despite their ability to sonicate. Several of its visiting bee species (*Megachile laticeps, Megachile umbripennis, Megachile disjuncta, Apis cerana)* were also observed to be non-sonicating. The breakage of the anthers of

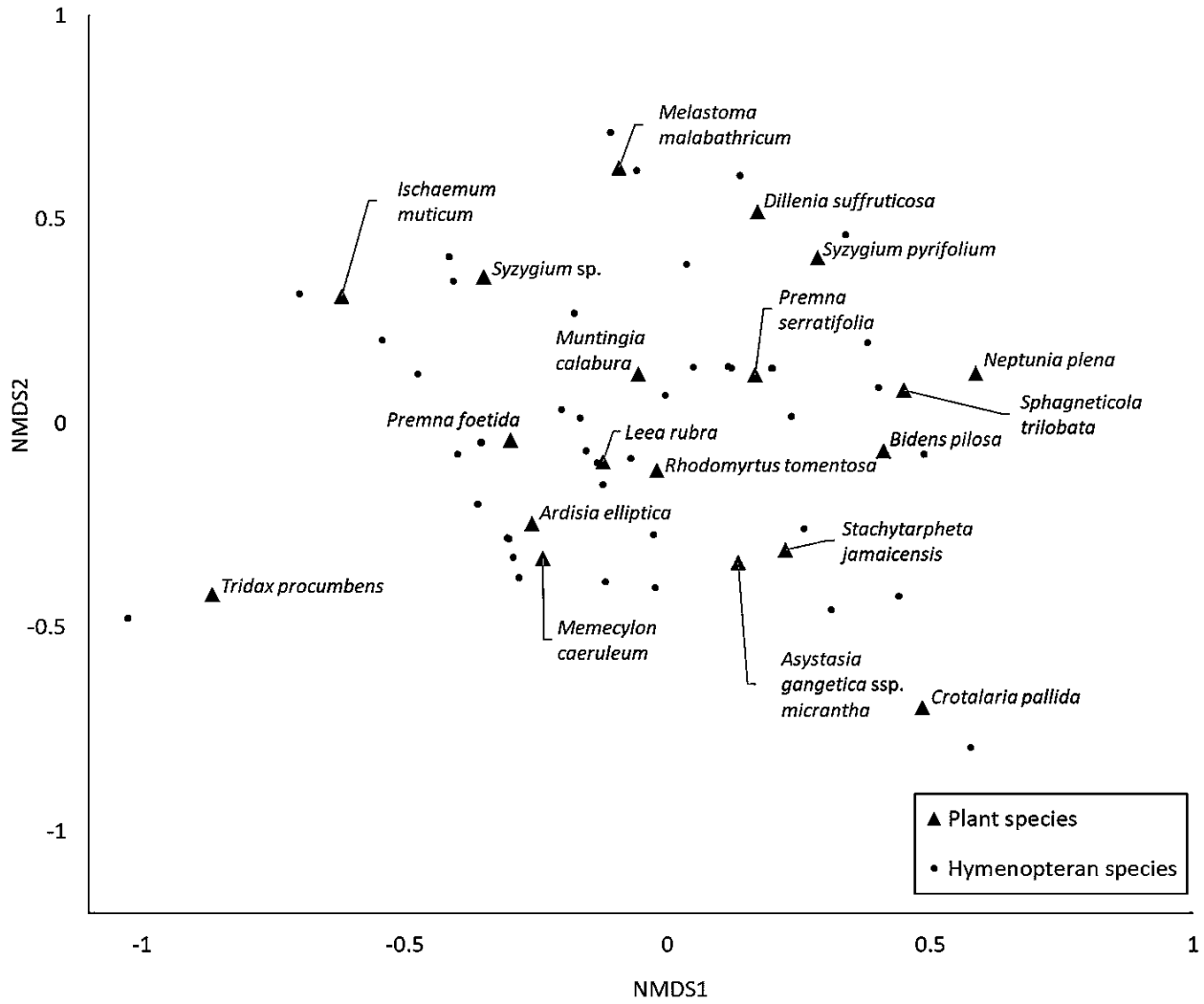

Fig. 3. NMDS ordination plot showing differences in Hymenopteran species composition between plant species on the NUS Kent Ridge Campus. Plant species located closer together on the plot have a higher similarity in Hymenopteran species composition.

Memecylon caeruleum by the potentially exotic *Megachile disjuncta* and *Megachile umbripennis* may however suggest that these species are not their natural pollinators.

A comparison of floral visitors for both species in the present study showed an overlap of the principal visitor *Amegilla andrewsi* for flowers of both *Ardisia elliptica* and *Memecylon caeruleum*, but the exclusive visitation of *Megachile laticeps, Megachile umbripennis* and *Megachile disjuncta* to *Memecylon caeruleum* flowers suggests the presence of two distinct guilds that frequent the flowers of *Ardisia elliptica* and *Memecylon caeruleum*. Only 20% of the total bee fauna known from Kent Ridge Campus visit the flowers of *Ardisia elliptica* and *Memecylon caeuleum*. This shows that not all Singapore bee species are able to serve as pollinators for native plant species and highlights the importance of identifying the specific pollinator guilds that may need to be conserved to ensure pollination persists for native plants.

CONCLUSIONS

The present study documents the composition and behaviour of principal floral visitors to *Ardisia elliptica* and *Memecylon caeruleum* cultivated together in adjacent clumps at Science Drive 4 in the NUS Kent Ridge Campus, Singapore. These observations coupled with other Singapore observations provide a baseline for understanding native pollinators for both species. A comparison of floral visitors of *Ardisia elliptica* and *Memecylon caeruleum* at Science Drive 4 suggests the presence of two distinct guilds that visits each flower with some overlap in bees such as *Amegilla andrewsi* and *Nomia strigata* that visit flowers of both species but interact with each differently.

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VIDEO LINKS

1. *Amegilla andrewsi* visiting *Memecylon caeruleum* at Singapore Botanic Gardens on 3 March 2017. https://www.youtube.com/watch?v=4F2EBopDuBA
2. *Nomia strigata* sonication of *Ardisia elliptica* at Singapore Botanic Gardens on 3 November 2016. https://www.youtube.com/watch?v=rj7fGwZvhxw