NATURE IN SINGAPORE 2015 **8**: 37–51
Date of Publication: 18 June 2015

DIVERSITY OF ENTOMOFAUNA (ORTHOPTERA, REDUVIIDAE AND ACULEATA) IN THE MANDAI LAKE ROAD AREA, SINGAPORE

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ABSTRACT. — Vegetation in the Mandai Lake Road area of Singapore may give way to development despite the close proximity to the Central Catchment Nature Reserve. However, little is known about the biodiversity there, particularly the entomofauna. The order Orthoptera, family Reduviidae (from the order Hemiptera), and monophyletic lineage Aculeata (from the order Hymenoptera) were surveyed in 2014. For the Orthoptera, 84 species from 10 families were recorded (including 73 species from nine families from the 2014 sampling). Fourteen species were recorded in the adjacent nature reserves for the first time. Three new species were discovered and subsequently described. Three more are potentially new to science. For the Reduviidae, 23 species from seven subfamilies were recorded from sampling in 2013, 2014, and museum records, representing one fifth of the total number of species in Singapore (95). For the Aculeate Hymenoptera, at least 67 species were recorded.

KEY WORDS. — Orthoptera, Reduviidae, Aculeata, checklist, Mandai, Singapore

INTRODUCTION

The Mandai Lake Road area lies at the northern edge of the Central Catchment Nature Reserve (CCNR) of Singapore and leads to three tourist attractions of the Wildlife Reserves Singapore (Singapore Zoo, Night Safari, and River Safari). Vegetation along Mandai Lake Road consists of a matrix of different types, ranging from old secondary forest, abandoned plantations to scrub, and is therefore potentially rich in biodiversity. As with many forest patches in a rapidly developing Singapore, those along Mandai Lake Road are also subjected to natural and anthropogenic disturbances. In 2011, about 40 ha of secondary forest along the adjacent Mandai Road was damaged by storms which felled as many as 20,000 trees and saplings (Chua, 2011). Even though it is close to the nature reserves, part of the forest in the Mandai Lake Road area may also give way to development according to the Master Plan of the Urban Redevelopment Agency (2014) and Nature Society (Singapore) (2008).

Despite the impending plans for development, little is known about the biodiversity in the Mandai Lake Road area, particularly the entomofauna. While the insect collection from Mandai amassed by D. H. Murphy during the 1980s (and deposited at the Zoological Reference Collection, Lee Kong Chian Natural History Museum, National University of Singapore) may provide some clues to the insect diversity in the area, this may be incomplete or outdated. As such, providing an up-to-date checklist of insects in Mandai Lake Road area would be helpful in understanding its entomofaunal diversity. In the current study, three taxa were surveyed: order Orthoptera, family Reduviidae (from the order Hemiptera), and monophyletic lineage Aculeata (from the order Hymenoptera).

The order Orthoptera, which includes grasshoppers (suborder Caelifera), crickets, and katydids (suborder Ensifera), is an important component of terrestrial habitats as both primary consumer and as prey to terrestrial predators (Quinn et al., 1993; Lockwood, 1996; Samways, 1997; Armstrong & van Hensberen, 1999). Checklists of the Orthoptera in the Bukit Timah Nature Reserve (BTNR) and CCNR have been published (Tan, 2012a, 2012b). These covered the vegetation along Mandai Lake Road, as well as Mandai Track 15. However, they provide only baseline information for the entire nature reserves, and not a representative inventory for the Mandai Lake Road area.

The Reduviidae (Hemiptera: Heteroptera), commonly known as the assassin bugs, is a family consisting of more than 6,800 species. These mainly predatory insects are widely diverse in their morphology, diet specialisation, and microhabitat preference (Froeschner & Kormilev, 1989; Maldonado-Capriles, 1990; Schuh & Slater, 1995; Weirauch & Schuh, 2011). For example, members of the subfamily Ectrichodiinae are known to be obligate feeders of millipedes and are usually found in leaf litter (Schuh & Slater, 1995), while members of the subfamily Harpactorinae are generalists that are found on foliage and have been observed feeding on a wide variety of other insects that include orthopterans, dipterans and coleopterans (Readio, 1927; Louis, 1974; Maldonado-Capriles, 1990). While assassin bugs are cryptic and infrequently sighted, they are nevertheless an important link in the ecosystem being both predators of insects and prey to other animals. Their presence offers potential insights into the types of prey and microhabitat present

in an environment, much like bio-indicators (Moir & Brennan, 2007). Mandai Track 15 was previously surveyed for assassin bugs from Jun.2013 to Feb.2014, but information on the diversity of Reduviidae in the Mandai Lake Road area is not exhaustive. To supplement the checklist, museum records of Reduviidae from the area were also included.

The order Hymenoptera includes bees, wasps, ants, and sawflies. Within this, the Aculeata is a monophyletic group in the suborder Apocrita, and consists of bees, stinging wasps, and ants. The main defining feature of this group is that the females have their ovipositors modified into a stinger connected to a venom gland. The sting is used in self-defence and, in the case of wasps, to subdue and paralyse prey. To the best of our knowledge, no survey of Aculeate Hymenoptera has been carried out in this area. Therefore, this survey should provide a basic insight into this insect group in the Mandai Lake Road area and similar habitats elsewhere. As activity of some Hymenoptera species fluctuates through seasonal cycles or according to the availability of resources such as the flowering of certain plants, a longer survey period would be necessary to establish a comprehensive understanding on the diversity for the area.

Given the closeness of the Mandai Lake Road area to the CCNR, it serves as an important buffer zone but is also subject to future development. Data on biodiversity there is therefore a crucial part of the baseline information needed for effective conservation management and risk assessment so that the impact on the nature reserve is minimal. Between May and Aug.2014, the Orthoptera, Reduviidae and Aculeate Hymenoptera (excluding the ants) were sampled in the various vegetation types of the Mandai Lake Road area with the objectives to understand its entomofaunal diversity and provide baseline data for informed management of the vegetation there.

MATERIAL AND METHODS

Study site. — Herein known as the Mandai Lake Road area, the study site (Fig. 1) is located at the north-western margin of the CCNR. It includes vegetation on both sides of Mandai Lake Road, and is bordered by Mandai Road in the north, Mandai Track 15 in the west, Upper Seletar Reservoir in the east, and the boundary of Wildlife Reserves Singapore in the south. The area consists of old and disturbed secondary forest, secondary swamp forest, bamboo patch, grassy and shrubby plots. It serves as a buffer area for the northern part of the CCNR.

Data collection. — The study duration was between May and Aug.2014. Ten night surveys were conducted for the Orthoptera and Reduviidae as these two taxa are more diverse and common at night. During each survey, opportunistic sampling of adult and nymph orthopterans and reduviids were conducted, involving actively searching vegetation, sweeping the vegetation, breaking off branches and examining their interior, and locating calls. The number of individuals sighted was recorded for each species. Specimens that could not be identified in the field were collected for

Fig. 1. Satellite map indicating the study site. The red line demarcates the boundaries of the area sampled. Red dot on the inserted map of Singapore indicates the location of study site within Singapore. Maps by Google (2014).

further examination. Light trapping was also conducted once using a mercury vapour lamp. Eight surveys for the Aculeate Hymenoptera (excluding the ants) were conducted in the day, which involved visual observations and recording species that could be identified based on their appearance, as well as collecting with a handheld net.

Collected specimens were euthanised by freezing. Taxa were identified by the authors (Orthoptera by MKT, Reduviidae by HY, and Aculeata by JXQL) with the aid of taxonomic keys and descriptions and comparison with museum specimens. All specimens collected will be deposited in the Zoological Reference Collection (ZRC), Lee Kong Chian Natural History Museum (LKCNHM), National University of Singapore.

OBSERVATIONS AND RESULTS

***Orthoptera*.** — From sampling and known literature, 84 species of Orthoptera from 10 families were recorded. This is a fair representation of the total number of species (150) and families (11) recorded in the BTNR and CCNR (Tan, 2012a, b). The three most speciose families are Gryllidae, Tettigoniidae, and Acrididae, represented by 30, 20, and 13 species respectively. Such a distribution of diversity has also been observed for the entire BTNR and CCNR (Tan, 2012a, b).

In this study, 73 species from nine families were recorded: 18 species of grasshoppers, 37 of crickets, and 18 of katydids. This is over two times more species previously recorded from Mandai by Tan (2012a, b), in which only 30 species from seven families were recorded (Fig. 2). From the present survey, 14 species (two grasshoppers, eight crickets and four katydids) were recorded in the BTNR and CCNR for the first time. All species of the Orthoptera recorded from the Mandai Lake Road area are listed in Appendix 1.

***Reduviidae*.** — Twenty-three species from seven subfamilies were recorded from the Mandai Lake Road area (Fig. 3). In contrast with the total number of species in Singapore (95) (Yeo, 2015), which includes past records from the ZRC, the present record represents merely a quarter of the total. However, in comparison to the total number of species collected from recent field sampling in Singapore (33) (HY, pers. obs.), it remains a substantial proportion of the species richness found recently and could be an indication of shifting baselines due to possible extinctions. From the present sampling, the subfamily Harpactorinae is the most speciose in the Mandai Lake Road area, followed by Emesinae and Reduviinae. Members of the subfamilies Emesinae and Salyavatinae were observed to be more abundant as they were sighted during every survey, although no proper method and statistical analysis were carried out. All species of Reduviidae recorded from the Mandai Lake Road area are listed in Appendix 2.

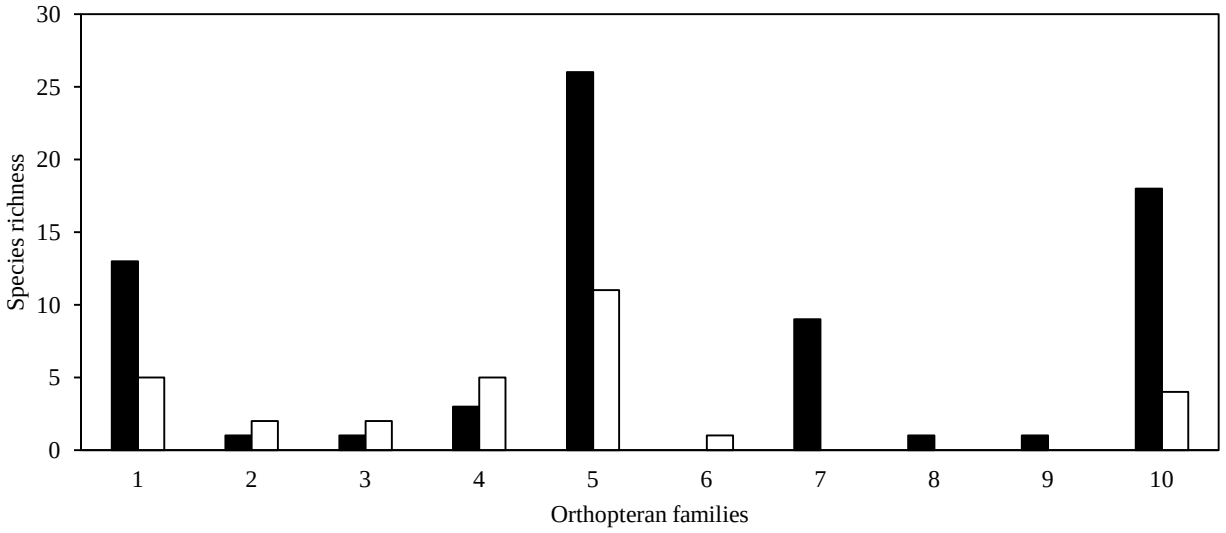

Fig. 2. Comparison of species richness in different families of the Orthoptera recorded from the Mandai Lake Road area, from the present sampling and in Tan (2012a, b). Seventy-three species from nine families were recorded from the sampling and 30 species from seven families were recorded by Tan (2012a, b). The black bar represents the present sampling and the white bar represents Tan (2012a, b). Orthopteran families: 1 = Acrididae, 2 = Chorotypidae, 3 = Pyrgomorphidae, 4 = Tetrigidae, 5 = Gryllidae, 6 = Gryllotalpidae; 7 = Mogoplistidae, 8 = Rhaphidophoridae, 9 = Gryllacrididae, 10 = Tettigoniidae.

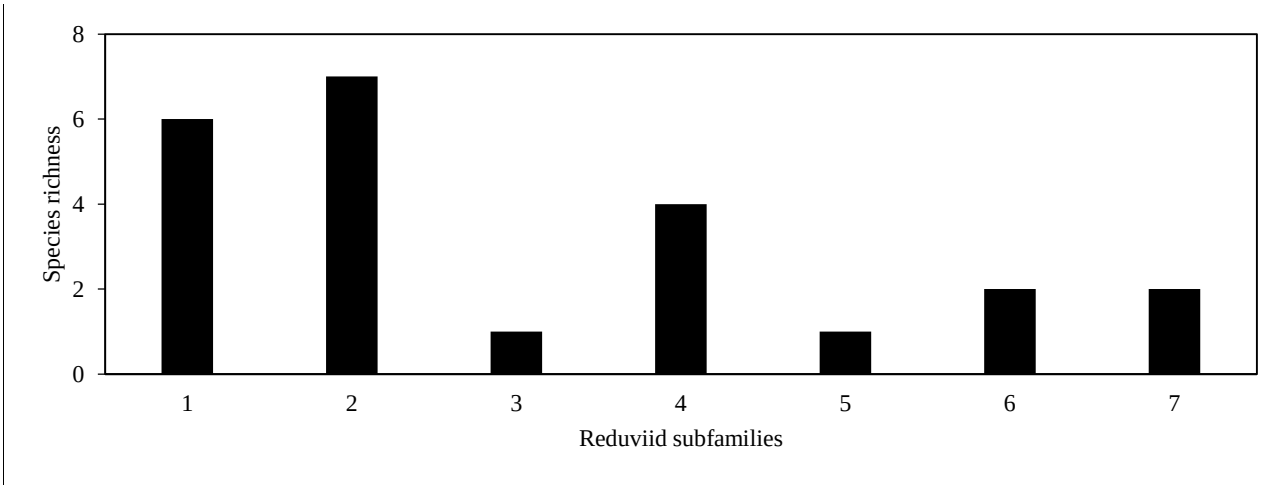

Fig. 3. Total species richness in different subfamilies of Reduviidae recorded from samplings at Mandai Lake Road area in 2013 and 2014. Twenty-three species from seven subfamilies were recorded. Legends: Reduviid subfamilies: 1 = Emesinae, 2 = Harpactorinae, 3 = Peraitinae, 4 = Reduviinae, 5 = Saicinae, 6 = Salyavatinae; 7 = Stenopodainae.

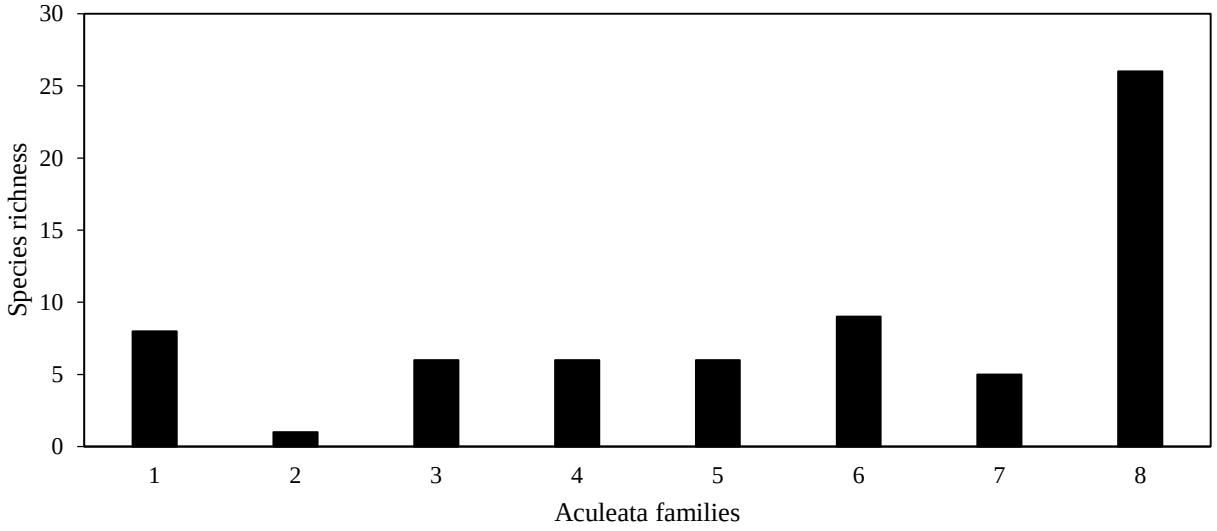

Fig. 4. Total species richness in different families of the Aculeata recorded from samplings at the Mandai Lake Road area in 2014. Sixty-seven species from eight families were recorded. Legends: Aculeata families: 1 = Apidae, 2 = Colletidae, 3 = Crabronidae, 4 = Halictidae, 5 = Megachilidae, 6 = Pompilidae, 7 = Sphecidae, 8 = Vespidae.

***Aculeata*.** — Sixty-seven species of Aculeate Hymenoptera from eight families were recorded, comprising 46 species of wasps from four families and 21 bees from four families (Fig. 4). Overall, the family with the highest number of species recorded within the survey area was the wasp family, Vespidae, which is a wide and diverse group comprising of both social and solitary species. Twenty-six species in this family were recorded, a far higher number than the family with the second highest number of species recorded, namely the Pompilidae (spider-hunting wasps), of which nine species were recorded. Fig. 4 shows the comparative species richness of the eight families of Aculeate Hymenoptera recorded in this survey, while all species recorded during the survey are listed in Appendix 3.

DISCUSSION

***Orthoptera*.** — Tan (2012a, 2012b) recorded about 150 species of Orthoptera from various parts in and around the BTNR and CCNR, and this included 30 species from Mandai Track 15. From the survey in 2014, as many as 73 species were recorded from the Mandai Lake Road area. This showed that while Tan (2012a, 2012b) provided baseline information for the BTNR and CCNR diversity, site specific information within and around the nature reserves remained incomplete. Moreover, 13 species were recorded from the BTNR and CCNR for the first time, even though none of these species were new to Singapore. These included the grasshopper, *Acrida willemsei* previously known in small grassy plots around Singapore (Pulau Ubin, Bidadari Cemetery, and East Coast Park) (Tan, 2010; Tan et al., 2012) (Fig. 5A), *Amusurgus* species 5 (Fig. 5E), and the cone-headed katydids *Conocephalus longipennis* (Fig. 5G) and

Xestophrys horvathi (Fig. 5H). Both species of cone-headed katydids occur in different parts of Singapore but they have been recorded in and around the BTNR and CCNR for the first time (Tan, 2011; Tan et al., 2012). These findings also suggest that with more sampling, more species may be revealed in the Mandai Lake Road area, as well as in the BTNR and CCNR.

Additionally, three species new to science were described from the Mandai Lake Road area: *Microrнebius distinctus*, *Microrнebius eclipsus* (Fig. 5F), and *Microrнebius mandai* (see Tan, 2014). Three other species are potentially new: *Duolandrevus* (*Surdolandrevus*) species 1, *Sclerogryllus* species 1 and 2 (Fig. 5D). Further examination to verify the identity of these orthopterans are currently being carried out. The secondary forest there is also taxonomically significant as a type locality for recent new species discovery, which is a mole cricket *Gryllotalpa nymphicus* currently known only from Singapore (Tan, 2012c). As such, this study indicates that the true species richness of the Mandai Lake Road area and Singapore remains elusive with more species awaiting discoveries.

There are also some species with interesting ecology found in the vegetation in the Mandai Lake Road area. For example, the silent slime cricket *Beybienkoana trapeza* (Fig. 5C), although recorded in other sites in Singapore and described from China, appears to be associated with bamboo (Liu & Shi, 2012; Tan, 2012b; Tan & Wang 2012). In Singapore, this species was found so far only in bamboo but not among other vegetation types. Further testing on the habitat preferences of this species can possibly help shed light on the importance of bamboo for Singapore orthopterans. Other interesting observations include forest-restricted species of grasshoppers. Unlike many species of grasshoppers in Singapore, there are a few which are restricted to the forest, one of which is *Meltripata picta* (Fig. 5B). Nevertheless, little remains known about these cryptic species, including the taxonomic status and much of their life history. These habitat-specific species highlight the importance of the matrix of vegetation types in the Mandai Lake Road area in supporting the diversity of Orthoptera in Singapore.

***Reduviidae*.** — Members of the subfamily Harpactorinae are known to be largely generalists and are often found on foliage (Readio, 1927; Louis, 1974; Maldonado-Capriles, 1990). One of them, *Agyrius* cf. *podagicus* was observed to reside frequently on banana plants, suggesting that association between reduviids and plant species may exist (HY, pers obs.) (Fig. 6C). The Mandai Track 15 site harbours a number of banana plant (*Musa* spp.) stands which were presumably abandoned (Chua, 2012) and were observed to be strongly associated with the assassin bug *Agyrius* cf. *podagricus*. All 17 individuals of *Agyrius* cf. *podagricus* sighted were on banana plants and can be found among the folds of dead leaves hanging from the stem or on rotting banana fruits. It may be suggested that their prey, such as several species of lepidopterans, are associated with banana plants (Ostmark, 1974), and in turn the *Agyrius* reduviid. Persistent sightings of assassin bugs on the same plant are unusual as reduviids do not usually aggregate, with the exception of their nymphs. Hence, the Mandai Track 15 patch offers potential sites to study the plant–herbivore–predator interactions.

The Emesinae (Figs. 6A, B) is a large cosmopolitan subfamily which was observed in the Mandai Lake Road area to be found on leaf litter and foliage (Wygodzinsky, 1958; Redei, 2007; Tartanic, 2012; HY, pers. obs.) while species of the Reduviinae (Fig. 6G) are more often associated with tree trunks and dead wood (Hwang & Weirauch, 2012; HY, pers. obs.). The presence of species from three subfamilies with very different life histories indicates that there is a wide array of microhabitats in the Mandai Lake Road area necessary to support the diversity of species (Gilpin & Diamond, 1980). Currently the diet of the Emesinae is not well known, although there are sightings of them with small prey items such as moths and spiders (HY, pers. obs.). Field observations indicated that Salyavatines from the Mandai Lake Road area feed on termites as suggested by previous research (Miller, 1953; McMahan, 1982; Maldonado-Capriles, 1990), with three out of 25 *Lisarda* spp. individuals found near termite trails and were observed to actively approach the termites. Reduviids are therefore important as predators in the ecosystem (Paine, 1980).

***Aculeata*.** — Despite the short-term sampling, the Mandai Lake Road area appears to have a fairly wide diversity of bees and wasps. No previous surveys had been done in this area, and few attempts to comprehensively record the Aculeate Hymenoptera of Singapore have been made. One of the most comprehensive surveys was by Soh & Ngiam (2013), in which 70 species of Aculeate Hymenoptera from 11 families, comprising 50 species of bees from four families and 24 species of wasps from seven families were recorded from seven urban parks in Singapore. It is interesting to note that the results of this survey were contrary to results by Soh & Ngiam (2013) in that the species richness of wasps was distinctly higher than that of bees, although this is probably due to the fact that Soh & Ngiam (2013) exclusively surveyed flowers which generally attract a greater number of bees because flowers are an important source of food (nectar and pollen) for both adult bees and their brood. The present survey placed equal emphasis on other microhabitats besides flowers, such as other vegetation (grass, shrubs, and non-flowering leafy plants), sources of water or mud (used by many solitary species as a nesting material), and on the ground.

While the overall species richness of bees and wasps recorded in this survey appeared to be relatively high and most of the species expected to be found in such habitats were present, some generally common species were not observed. For instance, the large carpenter bees of the genus *Xylocopa* are generally common in similar habitats, and at least four

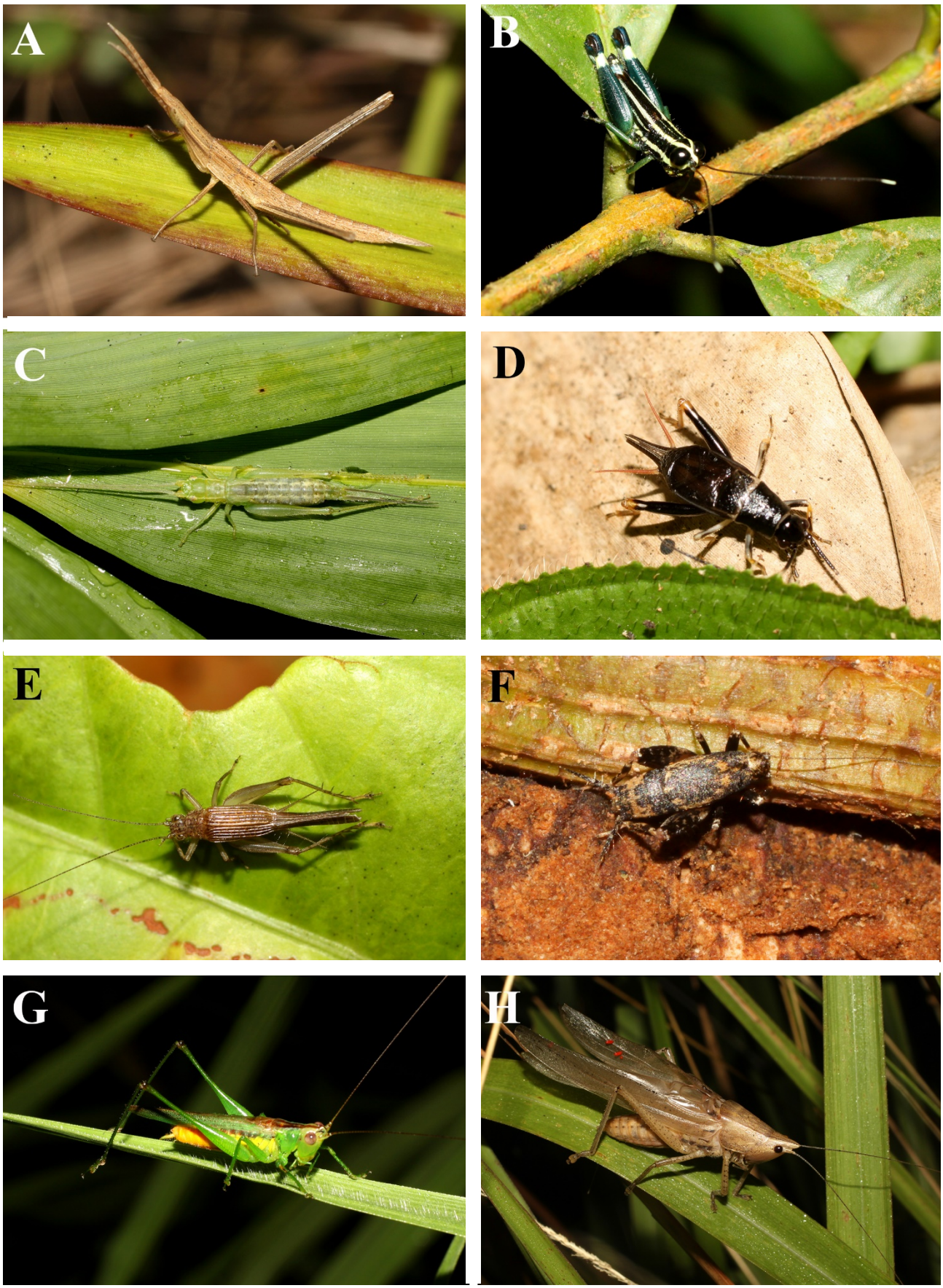

Fig. 5. Noteworthy species of Orthoptera from the Mandai Lake Road area: *Acrida willemsei* (A), *Meltripata picta* (B), *Beybienkoana trapeza* (C), *Sclerogryllus* species 2 (D), *Amusurgus* species 5 (E), *Micrornebius eclipsus* (F), *Conocephalus longipennis* (G), *Xestophrys horvathi* (H). (Photographs by: Tan Ming Kai).

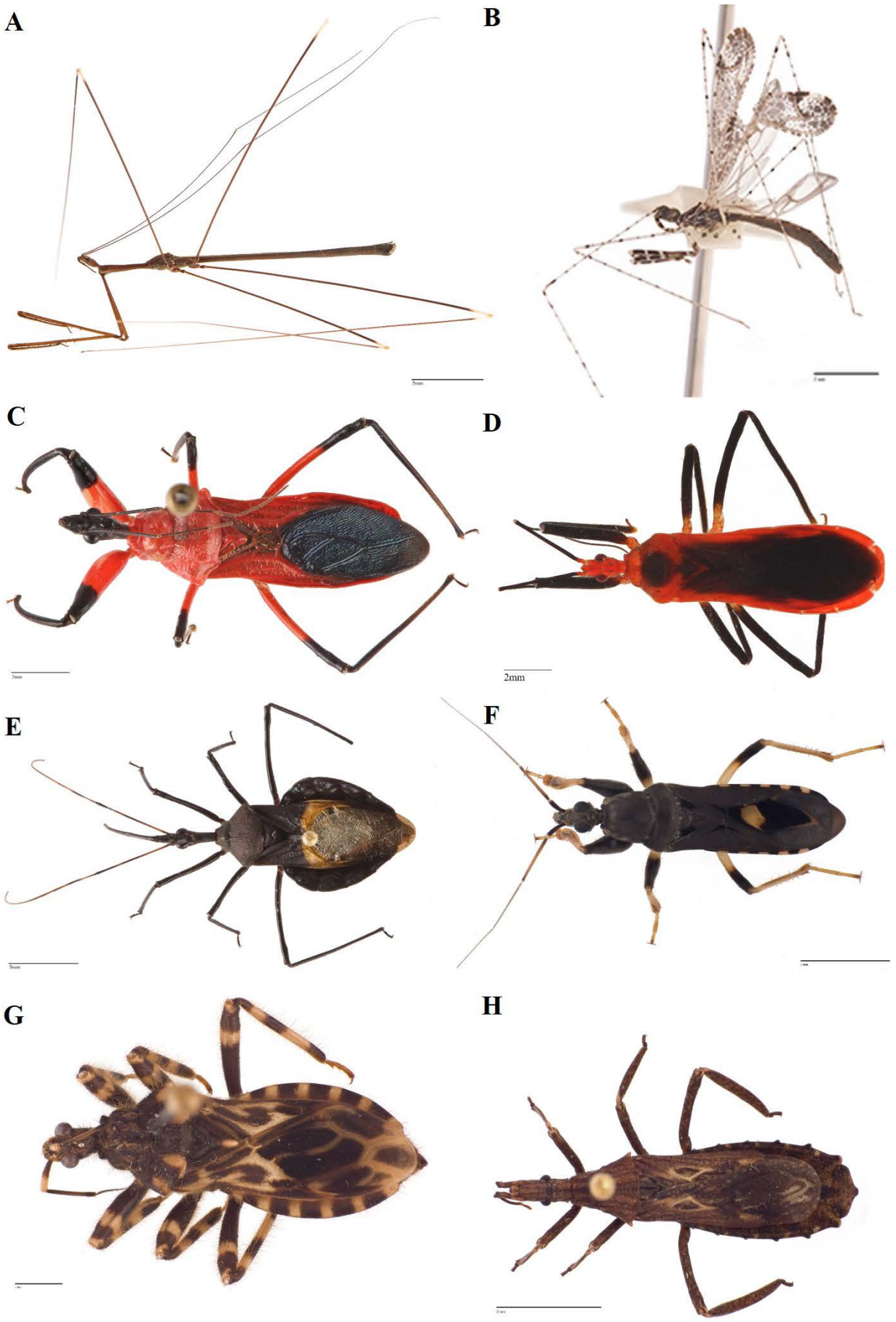

Fig. 6. Some species of Reduviidae from the Mandai Lake Road area: A, Emesinae; *Gardena melinarthrum*; B, *Empicoris* species; C, Harpactorinae: *Agyrius* cf. *podagricus*; D, *Graptoclopius* nr. species; E, *Sycanus* species 2; F, Peiratinae: *Ectomocoris atrox*; G, Reduviinae: *Acanthaspis inermis*; H, Stenopodainae: *Aulacogenia patalungae*. Scale bar: 2mm (B,C,D,G), 5 mm (A,E,F,H). (Photographs by: Yeo Huiqing).

Fig. 7. Some species of Aculeate Hymenoptera found in the Mandai Lake Road area: A, *Apis cerana*; B, *Ceratina unimaculata*; C, *Nomia (Acunomia) strigata*; D, *Trypoxylon* species; E, Pompilidae undetermined species 1; F, *Ropalidia marginata*; G, *Metischnogaster* species (Photographs by: John X. Q. Lee).

species can be expected to be found in the survey area. However, a distinct absence of such bees was noted, with only one species, the large *Xylocopa latipes*, seen on only two occasions. Only one species of stingless bee, *Tetragonula* cf. *laeviceps*, was observed, although at least three other species are commonly present in similar habitats (JXQL, pers. obs). The common honeybee *Apis cerana* was found throughout the study site, but the other two commonly observed honeybee species, *Apis andreniformis* and *Apis dorsata*, were completely absent. Two of the most common social wasps, *Vespa affinis* and *Polistes sagittarius*, were not recorded within the study site, although both species were recorded at the nearby Singapore Zoo. Finally, no members of the family Scoliidae, a family with many local representatives from the families *Campsomeris*, *Scolia* and *Megascolia* were recorded, even though they are frequently found in similar habitats. Their total absence was both noticeable and remarkable. As these wasps prey on larvae of scarab beetles (Coleoptera: Scarabaeidae), their presence may be an indicator of the abundance of such beetles in a given area. Two noteworthy species were the paper wasp, *Ropalidia marginata* and the hover wasp, *Metischnogaster* species. No specimens collected in Singapore are present in the ZRC, and JXQL has not encountered them elsewhere in Singapore for more than a decade of active surveying. On the whole, the Mandai Lake Road area appears to provide a fairly diverse range of microhabitats for Aculeate Hymenoptera, and a long-term survey of the area would be useful to establish baseline data of species found in the area.

CONCLUSIONS

The number of Orthopterans found at the Mandai Lake Road area is comparable to those for the BTNR and CCNR. Three species of Orthoptera were found to be new to science, with three more possibly new too—indicating that the Orthopterans in the area are poorly studied. While the Reduviid species found here were considerably fewer than the total number recorded in Singapore, they are still a comprehensive representation of the group found here. A reasonably wide diversity of Aculeate Hymenoptera was also observed, showing that the area is a suitable habitat for many species. Being situated along the edge of the Central Catchment Nature Reserve, the Mandai Lake Road area acts as a buffer zone with a variety of habitats. Any poorly planned development of this area could have consequences for the already fragile forests and its entomofauna in Singapore. Therefore, this paper hopes to emphasise the need for baseline scientific data for more effective conservation management and planning for the future of the biodiversity in the Mandai Lake Road area.

ACKNOWLEDGEMENTS

The permission to conduct this study was granted by the National Parks Board, Singapore (Research permits NP/RP10-073-3, NP/RP13-087 and NP/RP13-048).

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Appendix 1. Checklist of the Orthoptera recorded in Tan (2012a, b) and from the survey of the Mandai Lake Road area in 2014. The classification utilised was that of the Orthoptera Species File Online Version 5.0/5.0 (Eades et al., 2014). The families, subfamilies, and genera are arranged alphabetically for ease of reference. Identification of some species is doubtful without comparison with type specimens and museum collections and are thus denoted as 'species'.

	Tan (2012a, 2012b)	**2014 Survey**	**New Record for the BTNR and CCNR**
FAMILY ACRIDIDAE			
Subfamily Acridinae			
Acrida willemsei Dirsh, 1954 (Fig. 5A)		+	+
Phlaeoba antennata Brunner von Wattenwyl, 1893	+	+	
Phlaeoba infumata Brunner von Wattenwyl, 1893		+	
Subfamily Catantopinae			
Apalacris varicornis Walker, 1870		+	
Meltripata picta Bolívar, 1923 (Fig. 5B)		+	
Stenocatantops splendens (Thunberg, 1815)	+	+	
Traulia azureipennis (Serville, 1838)		+	
Xenocatantops humilis (Serville, 1838)	+	+	
Subfamily Cyrtacanthacridinae			
Valanga nigricornis (Burmeister, 1838)	+	+	
Subfamily Oedipodinae			
Trilophidia annulata (Thunberg,1815)		+	
Subfamily Oxyinae			
Oxya japonica japonica (Thunberg, 1815)		+	
Pseudoxya diminuta (Walker, 1871)	+	+	
Subfamily Spathosterninae			
Spathosternum prasiniferum (Walker, 1871)		+	+
FAMILY CHOROTYPIDAE			
Subfamily Erianthinae			
Erianthus species	+	+	
Subfamily Mnesicleinae			
Mnesicles species	+		
FAMILY PYRGOMORPHIDAE			
Subfamily Pyrgomorphinae			
Atractomorpha psittacina psittacina (de Haan, 1842)	+	+	
Tagasta marginella (Thunberg, 1815)	+		
FAMILY TETRIGIDAE			
Subfamily Scelimeninae			
Criotettix cf. *robustus* (Hancock, 1907)	+		
Subfamily Tetriginae			
Coptotettix spp.	+	+	
Euparatettix variabilis (Bolívar, 1887)	+		
Euparatettix species	+	+	
Phaesticus cf. *insularis* (Hancock, 1907)	+	+	
FAMILY GRYLLIDAE			
Subfamily Eneopterinae			
Cardiodactylus singapura Robillard, 2011		+	
Nisitrus vittatus (de Haan, 1842)		+	
Subfamily Euscyrtinae			
Beybienkoana trapeza Liu & Shi, 2012 (Fig. 5C)	+	+	
Euscyrtus concinnus (de Haan, 1842)	+	+	
Euscyrtus cf. *hemelytrus* (de Haan, 1842)	+	+	
Patiscus malayanus Chopard, 1969		+	
Subfamily Gryllinae			
Gymnogryllus species (red, species 2 in Tan, 2012b)		+	
Teleogryllus species		+	
Velarifictorus aspersus (Walker, 1869)		+	
Subfamily Landrevinae			
Duolandrevus (*Eulandrevus*) species	+		
Duolandrevus (*Surdolandrevus*) species		+	+
Landrevinae nymph		+	
Subfamily Nemobiinae			
Pteronemobius species 1 (species 1 in Tan, 2012b)	+	+	
Pteronemobius species 2 (species 4 in Tan, 2012b)		+	

	Tan (2012a, 2012b)	2014 Survey	New Record for the BTNR and CCNR
Subfamily Oecanthinae			
Oecanthus species	+		
Subfamily Podoscirtinae			
Aphonoides species (species 4 in Tan, 2012b)	+		
Sonotrella (*Megatrella*) *typica* Gorochov, 2002		+	
Subfamily Sclerogryllinae			
Sclerogryllus species 1	+	+	
Sclerogryllus species 2 (Fig. 5D)		+	+
Subfamily Trigonidiinae			
Amusurgus species 1 (species 2 in Tan, 2012b)		+	
Amusurgus species 2 (species 3 in Tan, 2012b)		+	
Amusurgus species 3 (species 4 in Tan, 2012b)		+	
Amusurgus species 4 (species 5 in Tan, 2012b)	+		
Amusurgus species 5 (Fig. 5E)		+	+
Anaxipha species (species 6 in Tan, 2012b)	+	+	
Homoeoxipha lycoides (Walker, 1869)	+	+	
Metioche pallipes (Stål, 1861)		+	+
Natula longipennis (Serville, 1838)		+	
Svistella species		+	
Trigonidiinae species		+	+
FAMILY GRYLLOTALPIDAE			
Subfamily Gryllotalpinae			
Gryllotalpa nymphicus Tan, 2012	+		
FAMILY MOGOPLISTIDAE			
Subfamily Mogoplistinae			
Apterornebius species		+	
Cycloptiloides cf. *timah* Ingrisch, 2006		+	
Ectatoderus angusticollis Chopard, 1969		+	
Micrornebius distinctus Tan, 2014		+	+
Micrornebius eclipsus Tan, 2014 (Fig. 5F)		+	+
Micrornebius mandai Tan, 2014		+	+
Ornebius albipalpus Ingrisch, 2006		+	
Ornebius cf. *pullus* Ingrisch, 2006		+	
Ornebius species		+	
FAMILY RHAPHIDOPHORIDAE			
Subfamily Rhaphidophorinae			
Rhaphidophora species		+	
FAMILY GRYLLACRIDIDAE			
Subfamily Gryllacridinae			
Gryllacris species		+	
FAMILY TETTIGONIIDAE			
Subfamily Conocephalinae			
Conocephalus longipennis (de Haan, 1842) (Fig. 5G)		+	+
Conocephalus maculatus (Le Guillou, 1841)		+	
Conocephalus melaenus (de Haan, 1842)	+	+	
Conocephalus species		+	
Euconocephalus mucro (de Haan, 1842)		+	+
Euconocephalus nasutus (Thunberg, 1815)		+	
Euconocephalus pallidus (Redtenbacher, 1891)		+	+
Peracca macritchiensis Tan & Ingrisch, 2014		+	
Xestophrys horvathi Bolívar, 1905 (Fig. 5H)		+	+
Nahlaksia bidadari Ingrisch & Tan, 2012	+		
Oxylakis species	+		
Subfamily Hexacentrinae			
Hexacentrus unicolor Serville, 1831		+	
Subfamily Lipotactinae			
Lipotactes maculatus Hebard, 1922		+	
Subfamily Listroscelidinae			
Carliphisis species		+	
Subfamily Meconematinae			
Alloteratura species (species 2 in Tan, 2012b)		+	

	Tan (2012a, 2012b)	2014 Survey	New Record for the BTNR and CCNR
Subfamily Mecopodinae			
Mecopoda elongata (Linnaeus, 1758)	+	+	
Subfamily Phaneropterinae			
Ducetia japonica (Thunberg, 1815)		+	
Elimaea (*Elimaea*) species		+	
Phaneroptera brevis (Serville, 1838)		+	
Subfamily Pseudophyllinae			
Chondroderella borneensis (Brunner von Wattenwyl, 1895)		+	

Appendix 2. Checklist of the Reduviidae recorded in the 2013 and 2014 surveys in the Mandai Lake Road area, and from the Zoological Reference Collection, Lee Kong Chian Natural History Museum records. The families, subfamilies, and genera are arranged alphabetically for ease of reference. Identification of some species is doubtful without comparison with type specimens and museum collections and are denoted as 'species'.

	2013 Survey	2014 Survey	Museum Record(s)
Subfamily Emesinae			
Ademula reticulata (McAtee & Malloch, 1926)		+	
Emesopsis species (Fig. 6B)		+	+
Empicoris species		+	
Gardena muscicapa (Bergroth, 1906)	+	+	
Gardena melinarthrum Dohrn, 1860 (Fig. 6A)	+		
Tridemula plurima(McAtee & Malloch, 1926)			
Subfamily Harpactorinae			
Agyrius cf. *podagricus* Stål, 1863 (Fig. 6C)	+	+	
Cosmolestes picticeps (Stål, 1859)	+		
Euagoras plagiatus (Burmeister, 1834)	+		
Graptoclopius nr. species (Fig. 6D)		+	
Sycanus species 1	+	+	
Sycanus species 2 (Fig. 6E)	+	+	
Velinus nigrigenu (Amyot & Serville, 1843)	+		
Subfamily Peiratinae			
Ectomocoris atrox (Stål, 1855) (Fig. 6F)	+	+	
Subfamily Reduviinae			
Acanthaspis inermis Stål, 1870 (Fig. 6G)	+		
Acanthaspis cf. *quadriannulata* Stål, 1870	+		
Acanthaspis signifera Stål, 1863	+		
Inara flavopicta Stål, 1859	+		
Subfamily Saicinae			
Species 1 nymph	-		
Subfamily Salyavatinae			
Lisarda annularis (Walker, 1873)		+	
Lisarda inornata (Walker, 1873)		+	+
Subfamily Stenopodainae			
Aulacogenia patalungae Miller, 1940 (Fig. 6H)		+	
Sastrapada species	+		

Appendix 3. Checklist of the Aculeate Hymenoptera recorded from the Mandai Lake Road area in 2014. The families, subfamilies, genera and tribes are arranged alphabetically for ease of reference. Many of the species found were not identified to species or even to genus at the time of publication. Identification of some species are doubtful without comparison with type specimens and museum collections and are denoted as 'species'.

FAMILY APIDAE
- Subfamily Apinae
  - *Amegilla* cf. *zonata* (Linnaeus, 1758)
  - *Apis cerana* Fabricius, 1793 (Fig. 7A)
  - *Tetragonula* cf. *laeviceps* (Smith, 1857)
- Subfamily Xylocopinae
  - *Ceratina unimaculata* Smith, 1879 (Fig. 7B)
  - *Ceratina nigrolateralis* Cockerell, 1916
  - *Ceratina* species 1
  - *Ceratina* species 2
  - *Xylocopa latipes* (Drury, 1773)

FAMILY COLLETIDAE
- Subfamily Hylaeinae
  - *Hylaeus* species 1

FAMILY CRABRONIDAE
- Subfamily Crabroninae
  - *Trypoxylon* species 1 (Fig. 7D)
  - *Trypoxylon* species 2
- Subfamily Larrinae
  - *Liris* species 1
  - *Liris* species 2
  - Undetermined species 1
  - Undetermined species 2

FAMILY HALICTIDAE
- Subfamily Halictinae
  - Undetermined species 1
  - Undetermined species 2

Subfamily Nomiinae
- *Lipotriches ceratina* (Smith, 1857)
- *Nomia (Acunomia) strigata* (Fabricius, 1793) (Fig. 7C)
- *Nomia (Maculonomia) apicalis* Smith, 1857
- *Nomia (Maculonomia) terminata* Smith, 1876

FAMILY MEGACHILIDAE
- Subfamily Megaphilinae
  - *Coelioxys* species 1
  - *Heriades* species 1
  - *Megachile disjuncta* (Fabricius, 1781)
  - *Megachile laticeps* Smith, 1853
  - *Megachile subrixator* Cockerell, 1915
  - *Megachile* species 1

FAMILY POMPILIDAE
- Subfamily Pompilinae
  - *Auplopus species* 1
  - *Tachypompilus analis* (Fabricius, 1781)
  - Undetermined species 1 (Fig. 7E)
  - Undetermined species 2
  - Undetermined species 3
  - Undetermined species 4
  - Undetermined species 5
  - Undetermined species 6
  - Undetermined species 7

FAMILY SPHECIDAE
- Subfamily Sceliphrinae
  - *Sceliphron javanum* (Lepeletier, 1845)
  - *Sceliphron madraspatanum* (Fabricius, 1781)
- Subfamily Sphecinae
  - *Isodontia* cf. *diodon* (Kohl, 1890)
  - *Isodontia* species 1
  - *Sphex sericeus* (Fabricius, 1804)

FAMILY VESPIDAE
- Subfamily Eumeninae
  - *Allorhynchium argentatum* (Fabricius, 1804)
  - *Delta pyriforme* (Fabricius, 1775)
  - *Phimenes* species 1
  - *Rhynchium haemorrhoidale* (Fabricius, 1775)
  - Undetermined species 1
  - Undetermined species 2
  - Undetermined species 3
  - Undetermined species 4
  - Undetermined species 5
  - Undetermined species 6
  - Undetermined species 7
- Subfamily Polistinae
  - *Polistes meadeanus* (Schulthess, 1913)
  - *Polistes stigma* (Fabricius, 1793)
  - *Ropalidia erythrospila* (Cameron, 1908)
  - *Ropalidia marginata* (Lepeletier, 1836) (Fig. 7F)
  - *Ropalidia* species 1
  - *Ropalidia* species 2
- Subfamily Stenogastrinae
  - *Eustenogaster* species 1
  - *Eustenogaster* species 2
  - *Liostenogaster nitidipennis* (Saussure, 1853)
  - *Metischnogaster* species 1 (Fig. 7G)
  - *Parischnogaster mellyi* (Saussure, 1852)
  - *Parischnogaster nigricans* (Cameron, 1902)
  - *Parischnogaster* species1
- Subfamily Vespinae
  - *Vespa analis* Fabricius 1775
  - *Vespa tropica* (Linnaeus, 1758)