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Orthoptera in the scat contents of the common palm civet (*Paradoxurus musangus*) on Pulau Ubin, Singapore

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Abstract. Predator–prey interaction can be crucial for studies in trophic-level ecology. Owing to their abundance and richness, many small arthropods, including the Orthoptera, are important prey in the ecosystem. Seventy scat samples from the common palm civet (*Paradoxurus musangus*) containing orthopteran parts (14.5%; n = 482) collected between May 2013 to May 2014 on Pulau Ubin, Singapore, were examined. From these scat samples, 12 orthopteran taxa were identified to genus or species level, representing about 21.1% of total species currently known on Pulau Ubin. Among these, most are ground dwellers and typically large. Six of the taxa found in the scat content were not recorded in Pulau Ubin previously. *Lebinthus luae* was the dominant orthopteran prey species (n = 39). This study demonstrates that sclerotised orthopteran parts in civet scats can be used to identify prey taxa in an attempt to better understand orthopteran diversity in the diet of the common palm civet, as well as their predator–prey interactions. It can also contribute information on the orthopteran diversity in the survey area.

Key words. insect, Orthoptera, carnivore, common palm civet, diet, scat content, predator–prey interaction

INTRODUCTION

Predator–prey interaction is an important area in animal ecology because predation leads to the inevitable removal of prey individuals from the ecosystem or habitat, and predators can regulate prey diversity (Paine, 1966; Crawly, 2009; Carpenter & Kitchell, 1996). Many small arthropods are important prey in the ecosystem (Wilson, 1987). These include the orthopterans, an order of insects that includes grasshoppers, crickets, and katydids. The Orthoptera are among the most diverse and common terrestrial macro-invertebrates, with more than 27,000 species worldwide and about 2,000 recorded species in biodiverse Southeast Asia (Cigliano et al., 2017; Tan et al., 2017a). Owing to their abundance and diversity, orthopterans fall prey to many insectivorous birds, mammals, and herpetofauna. Carbone et al. (1999) reported that 74% of the 158 species of small- to medium-sized carnivorans feed on invertebrates (including orthopterans) to some extent. As such, diversity of orthopterans may be potentially influential for other charismatic and keystone species (Joern, 1986; Heller, 1995).

Even though the diversity of orthopterans in Singapore is well documented with about 250 species recorded (M. K. Tan, unpublished data) and as many as 56 species have been documented on Pulau Ubin (Tan, 2010; Tan, 2013), studies on orthopterans as prey to high trophic-level species are limited, particularly in the Southeast Asia. It was previously reported that orthopterans are eaten by monkeys, bats, and even cats (Walker, 1964; Heller, 1995; Nickle & Heymann, 1996) in other parts of the world. In Singapore, orthopterans were also identified as prey in recent studies on scat content of leopard cats, *Prionailurus bengalensis* (29.2%; n = 65) (Chua et al., 2016) and spotted wood owls, *Strix seloputo* (T. M. Leong, pers comm.). These studies, however rarely identified the orthopterans to lower taxonomic ranks.

Another predator of orthopterans is the common palm civet, *Paradoxurus musangus* (Su & Sale, 2007; Aroon et al., 2009; Fung & Sivasothi, 2011; as *Paradoxurus hermaphroditus*), a small- to medium-sized, solitary, nocturnal, mostly arboreal mammal with a wide distribution range across Asia (Medway, 1983; Feldhamer et al., 2007). In Singapore, it was found to be widespread, and present on Pulau Ubin, an offshore island (Chua et al., 2012). While the common palm civet is known to be highly frugivorous (Bartels, 1964; Corlett, 1998; Grassman, 1998; Su & Sale, 2007; Nakashima et al., 2010; Fung & Sivasothi, 2011), it is an omnivore and has been documented to feed on small vertebrates and invertebrates (Su & Sale, 2007; Aroon, 2008; Xu & Sivasothi, 2010; Fung & Sivasothi, 2011). However, its prey diversity is little understood as the remains were often identified to order level or higher ranked groups, owing to difficulty in identifying partially digested animal parts. In Singapore, animal prey, in particular insects, was found in civet scats consistently throughout the year even when fruit sources were available, suggesting their potential importance in their diet (Fung et al., 2016).

A study to examine the diet, home range, and ecological role of the common palm civet on Pulau Ubin in Singapore, combined with the availability of expertise on orthopteran taxonomy presented an opportunity to study the orthopteran prey diversity in the diet of the common palm civet. From the scats of the common palm civet, orthopteran parts were retrieved and identified whenever possible. This article aims to answer the following questions: (1) Can sclerotised features be used for identifying orthopterans in the scat content? (2) What is the diversity, inferred habitat association, and size of orthopterans eaten by the common palm civet on Pulau Ubin?

MATERIALS & METHODS

Study area. Pulau Ubin (Pulau [=Island]) is a 1,131.4 ha rural island off the north-eastern coast of Singapore Island (01°24′N, 103°59′E). The main vegetation types on the island are secondary forest that developed after rubber plantations and farms were abandoned (Sha, 2002). Other vegetation types include mangrove forest, coastal forest, and grassland. The island provides a valuable site to study the diet of the common palm civet based on consistent sightings of this animal and its scats (Chua et al., 2009; Fung & Sivasothi, 2011).

Collection of civet scats. Visual surveys for common palm civet scats were conducted systematically on a weekly basis on designated transects from May 2013 to May 2014. Scats of the common palm civet were identified from the shape and size, and the presence of civet hair which was ingested accidentally during grooming (Fung & Sivasothi, 2011). The geographic coordinates of the defecation sites were recorded with a handheld GPS receiver (GPSMAP 60 CSx, Garmin, Olathe, KS). A total of 482 intact scats were collected.

Scat analysis and identification. Collected scat samples were preserved with 70% ethanol to kill potential parasites and prevent the growth of fungi. Each sample was rinsed with tap water and filtered through a sieve with mesh size of 0.25 mm. This mesh size was selected to ensure diet items would be retained after the wash (Fung & Sivasothi, 2011). The contents of the scat were sorted according to morphological similarity. The sorted items were then examined under a stereozoom microscope to identify the plant and animal matter to the lowest reliable taxonomic rank. Insect specimens were then further sorted for orthopterans, and identified using features including those of the tegmen, hindwings, head, legs, and sclerotised parts of genitalia, some of which contain diagnostic characters.

Data analyses. Frequency of occurrence (FO%) of Orthoptera and diversity of orthopteran species in the civet scats were determined. The FO% in scats was calculated as the percentage of the number of scats containing orthopteran remains to total number of scats. The habitats and size of orthopteran prey were also analysed and separated into the following broad categories—ground or foliage dweller, understorey, and/or open grassland species. The approximate body length as a proxy for the size of the orthopteran according to Tan (2012a, b) was ranked. For standardisation, male body length was used for ranking and comparison. Adult measurements were used as most of the identified orthopterans were adults, containing the sclerotised diagnostic features. Photographic images were made using the Visionary Digital (VD) BK PLUS Lab System with compact-macro lens EF 100mm 1:2.8 USM for habitus images, and with 5×, 10×, and 20× LD objective, and processed using Adobe Photoshop. Scales are given with the images.

RESULTS

Orthopteran prey diversity. Seventy scat samples (14.5%; n = 482) were found to contain orthopteran parts (Fig. 1). This taxon was also found to have the highest absolute frequency of occurrence in the scats compared to other insect taxa (34.7%; n = 202), as well as all prey taxa (21.3%; n = 328). In total, the orthopteran parts were identified into 17 different taxa (Fig. 2). Twelve taxa were identified to either species or genus level from the scat samples. These 12 taxa also represented about 21.1% of the total species currently known from Pulau Ubin (Table 1). The remaining taxa were identified to subfamily or family levels. Two taxa were only identified to order and suborder levels, and the former was labelled as ‘unidentified’. Among the 15 taxa identified to family level or below, two were grasshoppers, 12 were crickets and one was katydid (Table 1). Among the taxa found in the scat content, *Lebinthus luae* was dominant (n = 39). Six of the taxa found in the scat content were previously unrecorded in Pulau Ubin (Tan, 2010; Tan, 2013) (Table 1).

Inferred habitat association and size of orthopteran prey. Six out of 15 taxa identified to familial level or below were ground dwellers, occurring 67 times in the 70 scat samples that contained orthopteran parts (Fig. 2). Nine taxa were foliage dwellers, but these occurred only 18 times in scat samples (Fig. 2). Nine of the 12 taxa identified to generic level or below were understorey species, but only one species was considered an open grassland species and another co-occurring in both habitats (Table 1). Eight of the 12 taxa were above the 75% quartile (> 22 mm in body length) and nine taxa were above the median size (> 18 mm in body length) (Fig. 3). Only *Velarifictorus aspersus* and *Lebinthus luae* are smaller than the median size (Fig. 3).

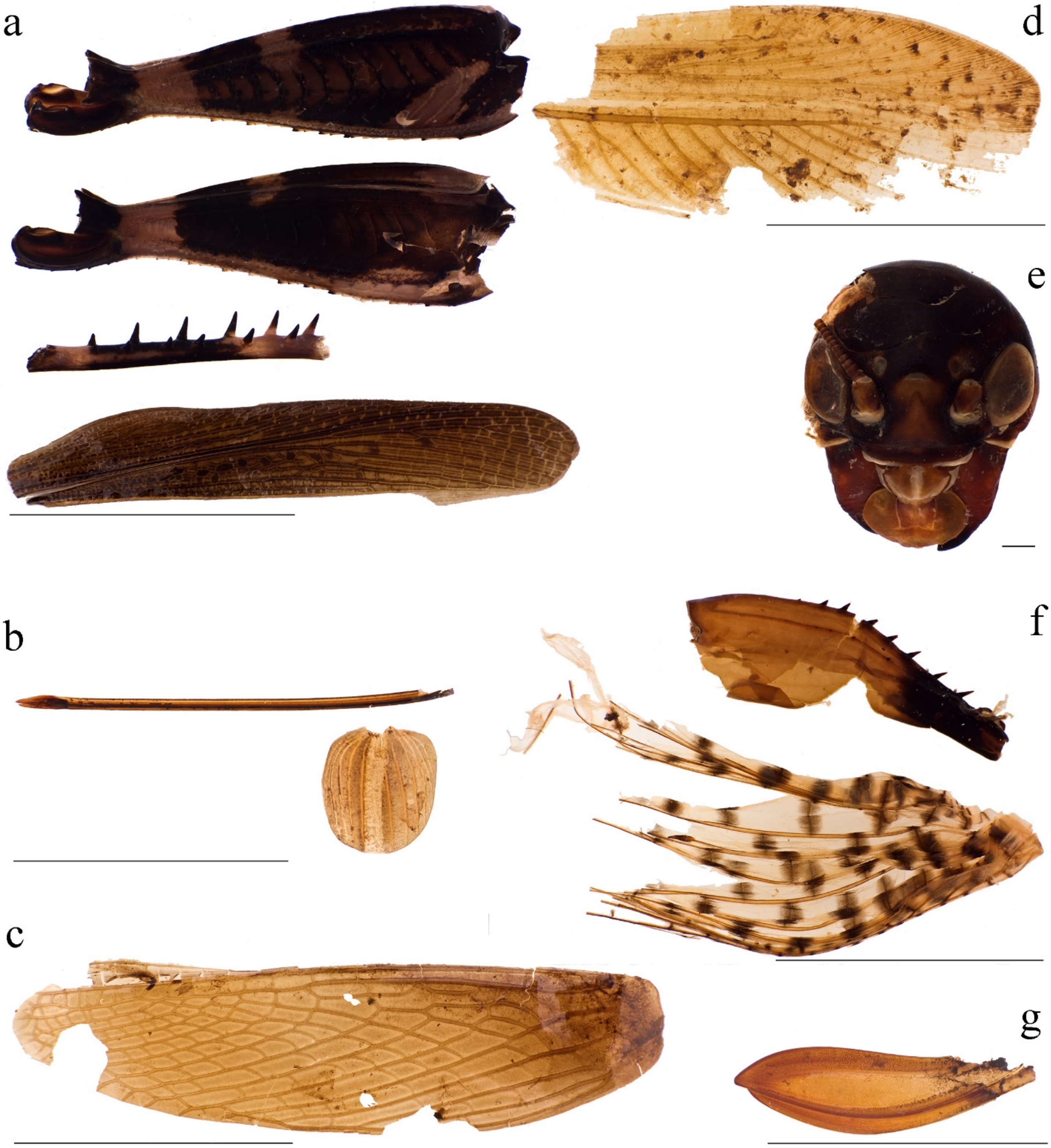

Fig. 1. A sample of orthopteran parts found in the scat samples. *Traulia azureipennis* hind leg and tegmen (a); *Lebinthus luae* ovipositor and female tegmen (b); *Gymnogryllus sylvestris* female tegmen (c); Gryllinae female tegmen (d); Gryllinae head (e); *Caustogryllacris* hind leg (part) and hind wings (f); *Oxylakis singaporensis* ovipositor (g). Scale bars = 1 mm (e), 10 mm (all except e).

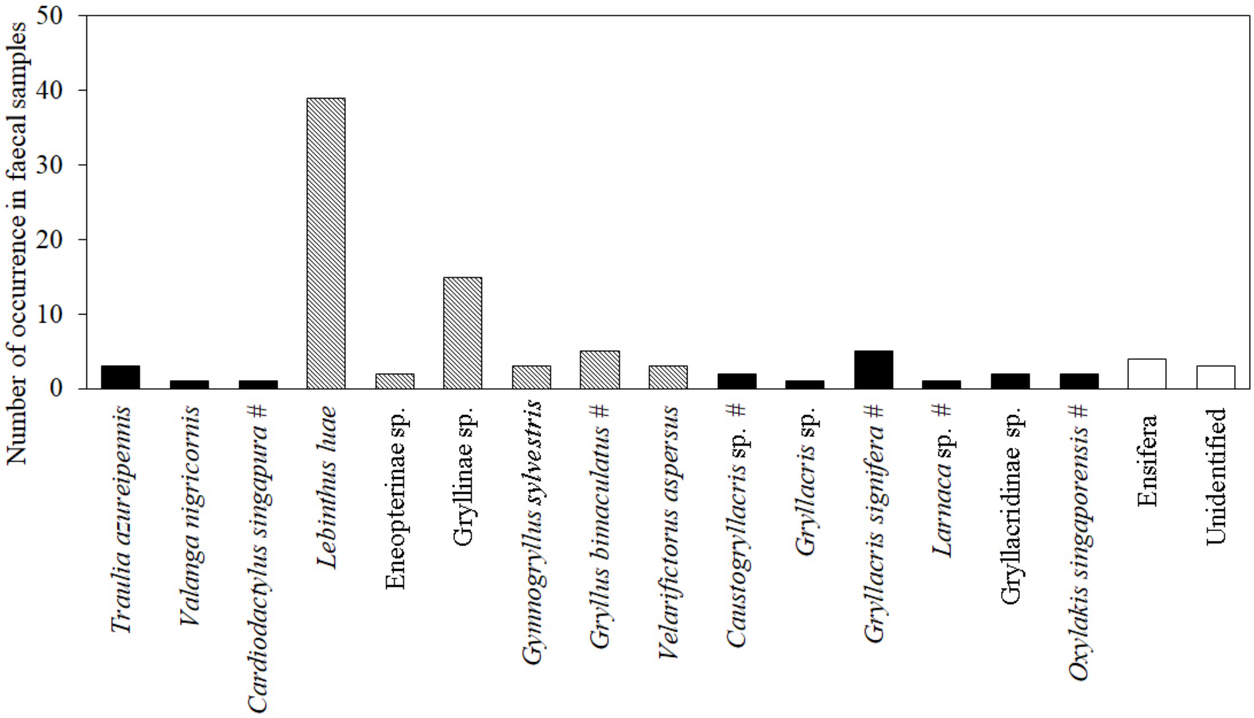

Fig. 2. Bar graph showing the occurrence of 17 Orthoptera taxa from scat samples (n = 70). Black bars = foliage dwellers; checked bars = ground dwellers; white bars = unknown. Remark: # represents taxa from the scat sample previously unrecorded in Pulau Ubin.

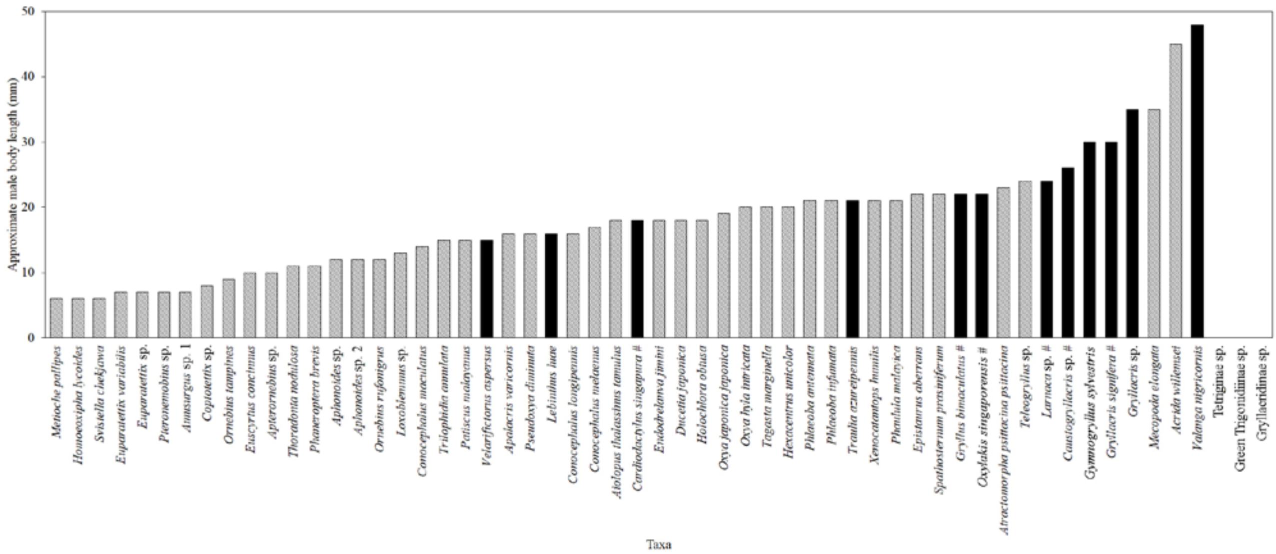

Fig. 3. Bar graph showing the approximate male body length of the orthopteran taxa from Pulau Ubin (n = 57). Black bars = found in the scat samples. Remark: # represents taxa from the scat samples but previously unrecorded in Pulau Ubin.

DISCUSSION

A novel attempt was made to identify and document the orthopteran prey to the lowest taxonomic level (generic or specific level) based on sclerotised diagnostic features of orthopteran body parts from the scat content of the common palm civet. Seventy samples contained orthopteran parts. The identifiable taxa represented about 21.1% of total species currently known to Pulau Ubin. This study showed that the sclerotised features on orthopteran body parts can be used for identifying orthopteran taxa in the scat content, with 12 out of 17 taxa identified to generic or specific level.

The relatively high frequency of occurrence of orthopterans in the scats compared to other insect taxa, as well as all prey taxa, suggests the potential importance of orthopterans in the diet of the common palm civet. Animal prey can provide important supplementary nutrients such as proteins, lipids, and calcium (Bell, 1990; Jothish, 2011). Studies also showed that orthopterans are high in protein and can make highly nutritious prey (e.g., Defoliart et al., 1982; Chakravorty et al., 2014; Ghosh et al., 2017). Other species of civets such as the Malay civet (*Viverra tangalunga*), masked palm civet

(*Paguma larvata*), and small Indian civet (*Viverra indica)* have also been documented to feed on orthopterans and other insects (Wan, 2009; Colon & Sugau, 2012), suggesting the importance of insects as prey for small- to medium-sized carnivorans (Carbone et al., 1999).

Most orthopteran species preyed on were found to be ground dwellers, indicating that the highly arboreal common palm civet utilises different strata of vegetation for foraging. Concurrent camera trapping showed that common palm civets move on ground where these insects were taken to supplement their largely frugivorous diet. Abundant species of orthopterans such as *Lebinthus luae* and *Velarifictorus aspersus* which occur in different habitats on Pulau Ubin, were frequently encountered in the scat content of the common palm civet. These species are likely to be encountered more frequently, and thus eaten in a higher proportion. *Lebinthus luae* is abundant in coastal forests while *Velarifictorus aspersus* is ubiquitous throughout Pulau Ubin. As these crickets tend to forage and mate at night, they are likely to fall prey to the common palm civet, which is also nocturnal. Calling male crickets (Robillard & Tan, 2013; Tan et al., 2017b) could be easier to detect, and thus be more likely to be eaten. It has been shown that civet species are dietary generalists and opportunistic feeders, and can change their diet in accordance to the availability of different food sources (Zhou et al., 2008). It is likely that orthopterans form part of the diet where they are commonly available. The high encounter rates of these crickets as well as high detectability render them as a food source with a high degree of predictability. From these crickets, the common palm civets can obtain considerable nutrition with relatively little net energy spent on foraging.

Orthopteran species found in civet scats are generally large species ranging between 18–50 mm, such as *Valanga nigricornis* and *Gymnogryllus sylvestris*. Larger species of orthopterans tend to be more conspicuous and are more likely to be preyed on by vertebrate predators (Whitman & Vincent, 2008). This is in accordance to the optimal foraging theory which suggests that handling of larger prey may be more profitable than smaller ones, at least for large-sized predators (Carbone et al., 1999; Costa, 2009). In addition, large orthopterans may be easier prey for common palm civets as their ability to escape from predators decreases with increasing body size (Whitman, 2008). However, it must be emphasised that, as with many diet studies using the visual method, there may be the possibility of false negatives (Nielsen et al., 2017). Small arthropods or less sclerotised specimens may be completely digested and cannot be detected. Orthopteran nymphs, in particular, may be overlooked as they are often soft-bodied and do not possess sclerotised identifying features that can be preserved in the scat and identified accurately (Nielsen et al., 2017).

Among these 12 taxa of orthopterans found in the scats, as many as six of them were not recorded in Pulau Ubin previously (Tan, 2010, 2013). This is likely an artefact of incomplete sampling on the island of Pulau Ubin. While Tan (2010) focused the sampling in the mixed vegetation along the Sensory Trail, Tan (2013) focused in the mangrove and coastal forest of Chek Jawa. As many orthopterans are likely to have specialised niches, they may not be found in the two sites that were previously surveyed. For example, *Larnaca* sp., *Oxylakis singaporensis*, and *Caustogryllacris* sp. are generally found in secondary and old secondary forests (Tan, 2012b), and thus may not be found in opened habitats along the Sensory Trail, and the mangrove and coastal forests in Chek Jawa. Nonetheless, this also indicates that more comprehensive surveys of orthopterans across the entire Pulau Ubin are needed to provide a more complete understanding of the orthopteran diversity there.

This appears to be the first study that documents the use of sclerotised identifying characters to identify orthopteran parts in civet scats to better understand orthopteran diversity in the diet of the common palm civet. Previous work on civet diet generally categorised prey in scat content into broad taxonomic groups such as orders (Su & Sale, 2007; Aroon, 2008; Fung & Sivasothi, 2011). Venation on the tegmen, male sclerotised genitalia, and ovipositors are important identifying characters used in Orthoptera taxonomy. Other characters such as those of the head, patterns on hind wings, and legs can also be helpful identifying features. All these appear to be relatively well preserved in the scat samples. Previous surveys of Orthoptera on Pulau Ubin (Tan, 2010, 2013) have allowed us to narrow our scope during species identification.

In conclusion, the present study is an attempt to better understand the prey diversity, in particular the orthopterans, in the diet of the common palm civet. We attempted to address the knowledge gap on the ecological roles of orthopterans in Singapore, and specifically on how they can be prey items for larger animals. Sclerotised remains found in the scats of the common palm civet allowed us to successfully identify as many as 12 taxa of orthopterans, most of which are relatively large species and ground dwellers. Using similar techniques, future work can be conducted on other small carnivoran diet to better understand the interactions between orthopterans and their predators in Singapore and Southeast Asia. In addition, such research can potentially uncover previously undocumented orthopterans, thus contributing to our knowledge on the diversity of Orthoptera.

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SUPPLEMENTARY INFORMATION

Table 1. Species checklist of Orthoptera in Pulau Ubin. This is based on primarily on Tan (2010) and Tan (2013), whose species are those marked '+' under the Known List column. Species found in the scat samples were also added to this checklist. Fifty-seven species were recorded from Pulau Ubin. Remark: # represents taxa from the scat samples but previously unrecorded in Pulau Ubin. Under habitat preference, OG = open grassland, and US = understorey.

Family (Subfamily)	**Taxon**	**Known List**	**Scat Samples**	**Habitat Preference**	**Approximate Male Body Length (mm)**
Acrididae (Acridinae)	*Acrida willemsei*	+		OG	45
	Phlaeoba antennata	+		OG	21
	Phlaeoba infumata	+		OG	21
Acrididae (Catantopinae)	*Traulia azureipennis*	+	+	US	21
	Xenocatantops humilis	+		OG/US	21
	Apalacris varicornis	+		US	16
Acrididae (Coptacridinae)	*Epistaurus aberrans*	+		OG	22
Acrididae (Cyrtacanthacridinae)	*Valanga nigricornis*	+	+	OG	48
Acrididae (Oedipodinae)	*Aiolopus thalassinus tamulus*	+		OG	18
	Trilophidia annulata	+		OG	15
Acrididae (Oxyinae)	*Oxya japonica japonica*	+		OG	19
	Oxya hyla intricata	+		OG	20
	Pseudoxya diminuta	+		OG	16
Acrididae (Spathosterninae)	*Spathosternum prasiniferum*	+		OG	22
Pyrgomorphidae (Pyrgomorphinae)	*Atractomorpha psittacina psittacina*	+		OG	23
	Tagasta marginella	+		OG	20
Tetrigidae (Scelimeninae)	*Thoradonta nodulosa*	+		US	11
Tetrigidae (Tetriginae)	*Coptotettix* sp.	+		US	8
	Euparatettix variabilis	+		OG/US	7
	Euparatettix sp.	+		OG	7
	Tetriginae sp.	+		US	?
Gryllidae (Eneopterinae)	*Cardiodactylus singapura #*		+	US	18
	Lebinthus luae	+	+	US	16
Gryllidae (Euscyrtinae)	*Euscyrtus concinnus*	+		OG	10
	Patiscus malayanus	+		OG	15
Gryllidae (Gryllinae)	*Gymnogryllus sylvestris*	+	+	US	30
	Gryllus bimaculatus #		+	US	22
	Velarifictorus aspersus	+	+	OG/US	15
	Loxoblemmus sp.	+		OG	13
	Teleogryllus sp.	+		OG	24
Gryllidae (Landrevinae)	*Endodrelanva jimini*	+		US	18
Gryllidae (Nemobiinae)	*Pteronemobius* sp.	+		OG	7
Gryllidae (Podoscirtinae)	*Aphonoides* sp.	+		US	12
	Aphonoides sp. 2	+		US	12
Gryllidae (Trigonidiinae)	*Metioche pallipes*	+		OG	6
	Amusurgus sp. 1	+		US	7
	Homoeoxipha lycoides	+		OG	6
	Svistella chekjawa	+		US	6
	Green *Trigonidiinae* sp.	+		US	?
Gryllacrididae (Gryllacridinae)	*Caustogryllacris* sp. #		+	US	26
	Gryllacris sp.	+	+	US	35
	Gryllacris signifera #		+	US	30
	Gryllacridinae sp.	+		US	?
	Larnaca sp. #		+	US	24
Mogoplistidae (Mogoplistinae)	*Ornebius rufonigrus*	+		US	12
	Apterornebius sp.	+		US	10
	Ornebius tampines	+		US	9
Tettigoniidae (Conocephalinae)	*Conocephalus maculatus*	+		OG	14
	Conocephalus longipennis	+		OG	16
	Conocephalus melaenus	+		OG	17
	Oxylakis singaporensis #		+	US	22
Tettigoniidae (Hexacentrinae)	*Hexacentrus unicolor*	+		OG	20
Tettigoniidae (Phaneropterinae)	*Mecopoda elongata*	+		OG/ US	35
	Ducetia japonica	+		OG	18
	Phaulula malayica	+		US	21
	Holochlora obtusa	+		US	18
	Phaneroptera brevis	+		OG	11