NATURE IN SINGAPORE 2011 **4**: 31–42
Date of Publication: 10 March 2011

THE COPIPHORINI (ORTHOPTERA: TETTIGONIIDAE: CONOCEPHALINAE) IN SINGAPORE

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INTRODUCTION

This paper attempts to document the taxonomy and biology of the tribe Copiphorini (Karny, 1912) in Singapore. The Copiphorini is a member of the subfamily Conocephalinae (Orthoptera: Tettigoniidae). From this preliminary survey, seven species from three genera were observed. The taxonomic treatment of the Copiphorini has, in some ways, been confusing and incomplete (Bailey, 1979; Rentz, 2010). This rather backward condition of the taxonomy of the tribe is mainly attributed to the lack of distinct diagnostic characters (Bailey, 1979). Moreover, little is also known about the biology of the Copiphorini owing to their marginal impact on economic crops (Willemse, 2001; Kim Tae-Woo, pers. comm.). Inadequate information about the life cycle, ecology, and behaviour of this tribe also makes progress in taxonomy difficult (Willemse, 2001). Reports on the Copiphorini in Singapore were published by Hebard (1922), and Murphy (1973) but only as parts of the orthopteran inventory. Thus far, there is no publication on the comprehensive study for the Copiphorini in Singapore. In this paper, diagnostic characteristics are re-examined and a provisional key to species of the Singaporean Copiphorini was composed. Additionally, notes on the biology of the Copiphorini in general are presented.

MATERIAL AND METHODS

Seven wasteland sites around Singapore were surveyed from Feb.−Nov.2010 (Table 1). Collections and field observations were carried out at night, during which the Copiphorini are most active. In-situ field photographs were taken to illustrate the biology of the Copiphorini, whenever possible. Adult males were located acoustically, collected and euthanized for morphological examination. Representative photographs of each species and their diagnostic characteristics were noted. A 0.05 mm vernier caliper was used for measurements. Liu Xianwei of the Shanghai Entomological Museum, Chinese Academy of Science, Shanghai, kindly identified the Copiphorini specimens. Specimens examined were deposited as voucher specimens at the Zoological Reference Collection (ZRC) of the Raffles Museum of Biodiversity Research (RMBR), National University of Singapore (NUS). Nymphs and adults were collected and reared in captivity for more intensive study of the biology of the Copiphorini. After the study, the surviving Copiphorini were released into the sites of their collections. Calling songs were recorded in-situ using a digital sound recorder (Cenix VR-W240J) at a maximum distance of 10 cm from the males. Analysis of calling songs was done using SoundRuler software.

In the species accounts, the following abbreviations are used: LT = length of left tegmen; TS = number of teeth on the male stridulatory file; LF = dorsal length of fastigium (from the vertex of fastigium to the foremost margin of the eye); LHF = ventral length of right (whenever possible) hind femur.

SPECIES RECORDS

Seven species of the Copiphorini from three genera were recorded in the seven vacant sites around Singapore, of which five were *Euconocephalus* species, and one species each of *Pseudorhynchus* and *Xestophrys* (Table 1). In contrast, only three species of the Copiphorini were previously recorded from Singapore by Hebard (1922). However, *Euconocephalus indicus* (Redtenbacher, 1891) was not encountered during the recent investigation, although it was recorded in Singapore by Hebard (1922). It is unclear if this is an artefact of poor sampling or genuine local extinction.

The following Copiphorini species were collected and examined.

***Euconocephalus pallidus* (Redtenbacher, 1891)** Figs. 1 (p. 35), 8a (p. 37), 9a (p. 38), 10a (p. 39), 12 (p. 40), 16 (p. 41)
Material examined. — 7 males (all green): ZRC.ORT.64, Upper Aljunied Road, 18 Mar.2010; ZRC.ORT.62, Bedok South Avenue 3, 25 Mar.2010; ZRC.ORT.03, Upper Aljunied Road, 28 Mar.2010; ZRC.ORT.63, Upper Aljunied Road,

Table 1. Summary of the occurrence of species of the Copiphorini at the seven vacant sites surveyed in Singapore.

Sites \ Species	1	2	3	4	5	6	7
Bedok South Avenue 3	+					+	
Tampines Avenue 1	+				+	+	
Upper Aljunied Road (ex-Bidadari Cemetery)	+		+	+			
West Commonwealth Avenue		+			+		
Holland woods		+	+		+		
Chestnut Avenue			+	+	+		
Neo Tiew Lane 2						+	+

1 = *Euconocephalus pallidus*; 2 = *Euconocephalus nasutus*; 3 = *Euconocephalus varius*; 4 = *Euconocephalus mucro*; 5 = *Euconocephalus picteti*; 6 = *Xestophrys horvathi*; 7 = *Pseudorhynchus minor*.

11 May.2010; ZRC.ORT.06, Bedok South Avenue 3, 29 Jul.2010; ZRC.ORT.61, Bedok South Avenue 3, 29 Jul.2010; ZRC.ORT.75, Tampines Avenue 1, 18 Sep.2010.
Morphological data. — LT: 35.80 – 44.00 mm; TS (left): 68 – 72; TS (right): 48 – 54; LF: 2.10 – 2.60 mm; LHF: 18.45 – 23.20 mm.

***Euconocephalus nasutus* (Thunberg, 1815)** Figs. 2 (p. 35), 8b (p. 37), 9b (p. 38)
Material examined. — 3 males (all green): ZRC.ORT.09, Holland woods, 24 Jul.2010; ZRC.ORT.58, Holland woods, 4 Aug.2010; ZRC.ORT.70, West Commonwealth Avenue, 27 Aug.2010.
Morphological data. — LT: 30.15 – 34.95 mm; TS (left): 79 – 91; TS (right): 54 – 62; LF: 2.25 – 2.60 mm; LHF: 19.55 – 21.45 mm.

***Euconocephalus varius* (Walker, 1869)** Figs. 3 (p. 35), 8c (p. 37), 9c (p. 38)
Material examined. — 5 males (3 green, 2 brown): ZRC.ORT.59, Upper Aljunied Road, 27 Feb.2010; ZRC.ORT.02, Upper Aljunied Road, 5 Mar.2010; ZRC.ORT.60, Upper Aljunied Road, 5 Mar.2010; ZRC.ORT.08, Chestnut Avenue, 5 Aug.2010; ZRC.ORT.05, Holland woods, 8 Aug.2010.
Morphological data. — LT: 33.30 – 36.00 mm; TS (left): 63 – 68; TS (right): 45 – 48; LF: 3.10 – 3.50 mm; LHF: 18.20 – 20.55 mm.

***Euconocephalus mucro* (de Haan, 1842)** Figs. 4 (p. 35), 8d (p. 37), 9d (p. 38), 10b (p. 39), 17a (p. 42)
Material examined. — 6 males (3 green, 3 brown): ZRC.ORT.01, Upper Aljunied Road, 27 Feb.2010; ZRC.ORT.55, Upper Aljunied Road, 27 Feb.2010; ZRC.ORT.56, Upper Aljunied Road, 1 Apr.2010; ZRC.ORT.57, Upper Aljunied Road, 8 Apr.2010; ZRC.ORT.07, Upper Aljunied Road, 11 May.2010; ZRC.ORT.04, Chestnut Avenue, 9 Jul.2010.
Morphological data. — LT: 37.80 – 44.80 mm; TS (left): 86 – 96; TS (right): 48 – 61; LF: 3.70 – 4.50 mm; LHF: 19.40 – 23.85 mm.

***Euconocephalus picteti* (Redtenbacher, 1891)** Figs. 5a (p. 36), b (p. 36), 8e (p. 37), 9e (p. 38)
Material examined. — 6 males (all brown): ZRC.ORT.66, Chestnut Avenue, 10 Jul.2010; ZRC.ORT.11, Chestnut Avenue, 20 Jul.2010; ZRC.ORT.65, West Commonwealth Avenue, 23 Jul.2010; ZRC.ORT.10, Holland woods, 24 Jul.2010; ZRC.ORT.67, Chestnut Avenue, 5 Aug.2010; ZRC.ORT.74, Tampines Avenue 1, 18 Sep.2010.
Morphological data. — LT: 31.95 – 35.65 mm; TS (left): 75 – 86; TS (right): 54 – 62; LF: 2.20 – 2.75 mm; LHF: 19.60 – 21.80 mm.
Remarks. — An adult female specimen, collected along Chestnut Avenue on 8 Sep.2010 for the study of reproductive behaviour, was deposited at the ZRC (ZRC.ORT.72).

***Xestophrys horvathi* (Bolivar, 1905)** Figs. 6 (p. 36), 8f (p. 37), 9f (p. 38), 11 (p. 39), 15 (p. 41)
Material examined. — 6 males (all brown): ZRC.ORT.12, Tampines Avenue 1, 30 Apr.2010; ZRC.ORT.68a, Tampines Avenue 1, 11 Jul.2010; ZRC.ORT.68b, Tampines Avenue 1, 11 Jul.2010; ZRC.ORT.13, Neo Tiew Lane 2, 3 Aug.2010; ZRC.ORT.69, Neo Tiew Lane 2, 3 Aug.2010; ZRC.ORT.73, Bedok South Avenue 3, 17 Sep.2010.
Morphological data. — LT: 38.05 – 41.25 mm; TS (left): 43 – 48; TS (right): 25 – 32; LF: 2.30 – 3.70 mm; LHF: 16.75 – 18.45 mm.

***Pseudorhynchus minor* (Redtenbacher, 1891)** Figs. 7 (p. 36), 8g (p. 37), 9g (p. 38)
Material examined. — 2 males (all green): ZRC.ORT.14, Neo Tiew Lane 2, 3 Aug.2010; ZRC.ORT.71, Neo Tiew Lane 2, 28 Aug.2010.
Morphological data. — LT: 43.90 – 45.30 mm; TS (left): 41 – 46; TS (right): 27 – 28; LF: 3.90 – 4.30 mm; LHF: 18.70 – 19.45 mm.

PROVISIONAL KEYS TO SPECIES OF THE COPIPHORINI IN SINGAPORE

In devising this key, references and modifications were made to keys by Murphy (1973), Bailey (1979), and Kim and Kim (2002), whenever appropriate.

1. Body relatively long and slender. Hind femur surpassing well beyond the end of the abdomen when straightened. (*Euconocephalus*)..... **2**
1. Body relatively short and stout. Hind femur barely surpassing the end of the abdomen when straightened. (*Xestophrys* or *Pseudorhynchus*)..... **6**

2. Apex of tegmen obliquely truncated (Figs. 8b, c, e).. ..... **3**
2. Apex of tegmen narrowly rounded (Figs. 8a, d).. ..... **5**

3. Fastigium with black pigmentation on the ventral surface..... ***Euconocephalus picteti***
3. Fastigium without black pigmentation on the ventral surface..... **4**

4. Fastigium long and fairly pointed, LF >3.00 mm. TS (left) <70..... ***Euconocephalus varius***
4. Fastigium short and blunt, LF <3.00 mm. TS (left) >70. ..... ***Euconocephalus nasutus***

5. Fastigium short, LF <3.00 mm. Left stridulatory file sinuous and relatively slender (Fig. 9a). TS (left) <80. Calling song resonant buzz (loud, clear and continues for a long time) (Fig. 10a)..... ***Euconocephalus pallidus***
5. Fastigium long and fairly pointed, LF >3.50 mm. Left stridulatory file crescent-shaped and relatively broad (Fig. 9d). TS (left) >80. Calling song a continuous series of chirps of fairly similar length (Fig.10b).... ***Euconocephalus mucro***

6. Left stridulatory file crescent-shaped (Fig. 9f). Distinct ventral tubercle and distinct ventral notch of fastigium absent. Fastigium blunt apically. Always brown. ..... ***Xestophrys horvathi***
6. Left stridulatory file bulbous (Fig. 9g). Distinct ventral tubercle and distinct ventral notch of fastigium present. Fastigium distinctly pointed apically. ..... ***Pseudorhynchus minor***

OBSERVATIONS AND DISCUSSION

Food selection and feeding. − The Copiphorini are omnivorous and were found to feed mostly at night. Natural diets of adults and nymphs are mainly stems (Fig. 11), seeds (Figs. 12, 13), and leaf blades of a range of sedges (Cyperaceae) and grasses (Gramineae and Poaceae). Observations suggest that the natural diet does not vary significantly between Copiphorini species. The feeding process sometimes involves the ingestion of the detached seed 'held' between the fore tarsi (Fig. 13b). This may later prompt the Copiphorini individual to preen its tarsi before proceeding with the detachment of another seed. Carnivory of other animals was not encountered in nature as well as in captivity. Nevertheless, cannibalistic feeding among individuals of the tribe was observed in captivity. Moulting nymphs were eaten by similarly sized nymphs. A dead adult was also devoured by another adult. Cannibalism was not observed in nature. This may be explained by fewer contacts and more escape opportunities in nature.

Reproduction. − Males were observed in all sites to stridulate on most nights of visits. Adults and nymphs of different instars were also found to coexist temporally. These observations indicate that the Copiphorini in the aseasonal, humid tropical climate of Singapore reproduce and develop throughout the year or nearly so. Studies of the reproductive behaviours of the Copiphorini in captivity suggest that the female selects the male. The male was found to initiate mating by stridulating when the female approaches. Stridulation stopped after the female moved away without mating. At other times, the male was observed to approach the female anti-parallelly and to extend the posterior towards that of female. The female, however, moved away without mating. Oviposition observed in captivity involved the female creating a minute slit with its ovipositor and inserting more than half of its ovipositor parallelly into the grass stem. This is typical of katydids with "elongate ovipositors of uniform dimensions" (Rentz, 2010). Upon dissection of the stem, two pale yellow, elongated eggs were found. Each egg was about 7 mm long and tough on the exterior. It can be inferred that the female spreads the risk by depositing its eggs in numerous stems (Leong Tzi Ming, pers. comm.). Observations in captivity reveal that the tip of the ovipositor is used to inspect suitable sites and to incise stems for oviposition.

Growth and development. − Hatching was not observed in nature nor in captivity. Successful and failed moulting encounters during the day and night were observed in captivity, and in the field (Fig. 14). Detailed monitoring of the number of instars and moults is difficult especially when nymphs were observed to consume their skin shortly after moulting.

Locomotion. − Local movements within the habitat by flight, walking, and jumping were observed in nature. All known species of the Copiphorini in Singapore have well-developed hind wings for flight. Local flights observed

include females scouting for stridulating males, males switching sites of stridulation, and adults escaping upon disturbance. From field observations, the distance for each local flight usually does not surpass 10 m and 2 m above ground.

Parasites and predators. − Red mites (superorder Acariformes), a type of ecto-parasite, are commonly found to infest species of the Copiphorini in Singapore (Fig. 15). The mites attach their mandibles onto the veins of wings, and stridulatory apparatus (Fig. 16). From field observations, irritation caused by the mites stimulates the males to rub their hind legs against the wings or to vibrate their tegmina such as to produce instantaneous stridulation. Nymphs were not found to be plagued by red mites, probably owing to the undeveloped wings. Spiders appear to be the primary predator of the Copiphorini with numerous encounters in the field (Figs. 17a, b). It is unlikely that the Copiphorini are actively hunted by spiders. Rather, it can be inferred that the Copiphorini become entangled in the spider's web upon accidental contact with the sticky silk during flight or while walking.

Defensive strategies. − Green and brown colouration, along with straw-colour strips along lateral keels and dark spots on tegmina and abdomen in some species, help the Copiphorini resemble leaves and stems of tall grasses and sedges in which the katydids are mostly found. When the threat is detected, nymphs were observed to remain motionless on a stem or leaf of the grass or sedge with the limbs outstretched. This behaviour (Fig. 18a), which is also adopted by adults (Fig. 18b), makes it difficult for predator to discern the outline of the nymph. Males cease stridulating and remain motionless when approached. Upon closer contact, adults were observed to run along stem or through grass clumps, leap and fly off. In an open field, the adults change direction of flight suddenly — vertically and horizontally — and frantically before dropping suddenly to the ground or vegetation to distract predators. When handled, large adults may deliver bites with their mandibles. Defensive stridulation was not recorded.

Conclusions. − The investigation of the local Copiphorini suggests that the knowledge in this tribe is still very limited. In-depth bioacoustics and phylogenetic analysis may provide greater insights into the taxonomy and behaviour of the Copiphorini (Strazanac, 1996). More importantly, the abundance and diversity of the Copiphorini at these study sites may indicate that rich biodiversity exists in these wasteland sites. It is therefore also the aim of this paper to encourage more detailed study of the local orthopterans and the biodiversity in the wasteland sites in Singapore.

ACKNOWLEDGMENTS

I thank Liu Xianwei for kindly identifying the Copiphorini specimens and Lua Hui Kheng for kindly identifying the red mites. I am also grateful to Ngiam Wen Jiang Robin for kindly providing important references. I am thankful of Leong Tzi Ming (in particular) and Kim Tae-Woo for their advice and editorial contribution to this article. I thank Lua Hui Kheng of the Raffles Museum of Biodiversity Research for granting access to examine the orthopteran specimens.

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Fig. 1. *Euconocephalus pallidus* male (ZRC.ORT.06, LT = 41.15 mm) collected along Bedok South Avenue 3 on 29 Jul.2010.

Fig. 2. *Euconocephalus nasutus* male (ZRC.ORT.58, LT = 32.10 mm) collected along Holland woods on 4 Aug.2010.

Fig. 3. *Euconocephalus varius* male (ZRC.ORT.08, LT = 36.00 mm) collected along Chestnut Avenue on 5 Aug.2010.

Fig. 4. *Euconocephalus mucro* male (ZRC.ORT.07, LT = 37.80 mm) collected along Upper Aljunied Road on 11 May.2010.

Fig. 5. *Euconocephalus picteti*. a. Male (ZRC.ORT.11, LT = 33.70 mm) collected along Chestnut Avenue on 20 Jul.2010. b. Male (ZRC.ORT.10, LT = 34.95 mm) collected along Holland woods on 24 Jul.2010.

Fig. 6. *Xestophrys horvathi* male (ZRC.ORT.69, LT = 39.70 mm) collected along Neo Tiew Lane 2 on 3 Aug.2010.

Fig. 7. *Pseudorhynchus minor* male (ZRC.ORT.14, LT = 45.30 mm) collected along Neo Tiew Lane 2 on 3 Aug.2010.

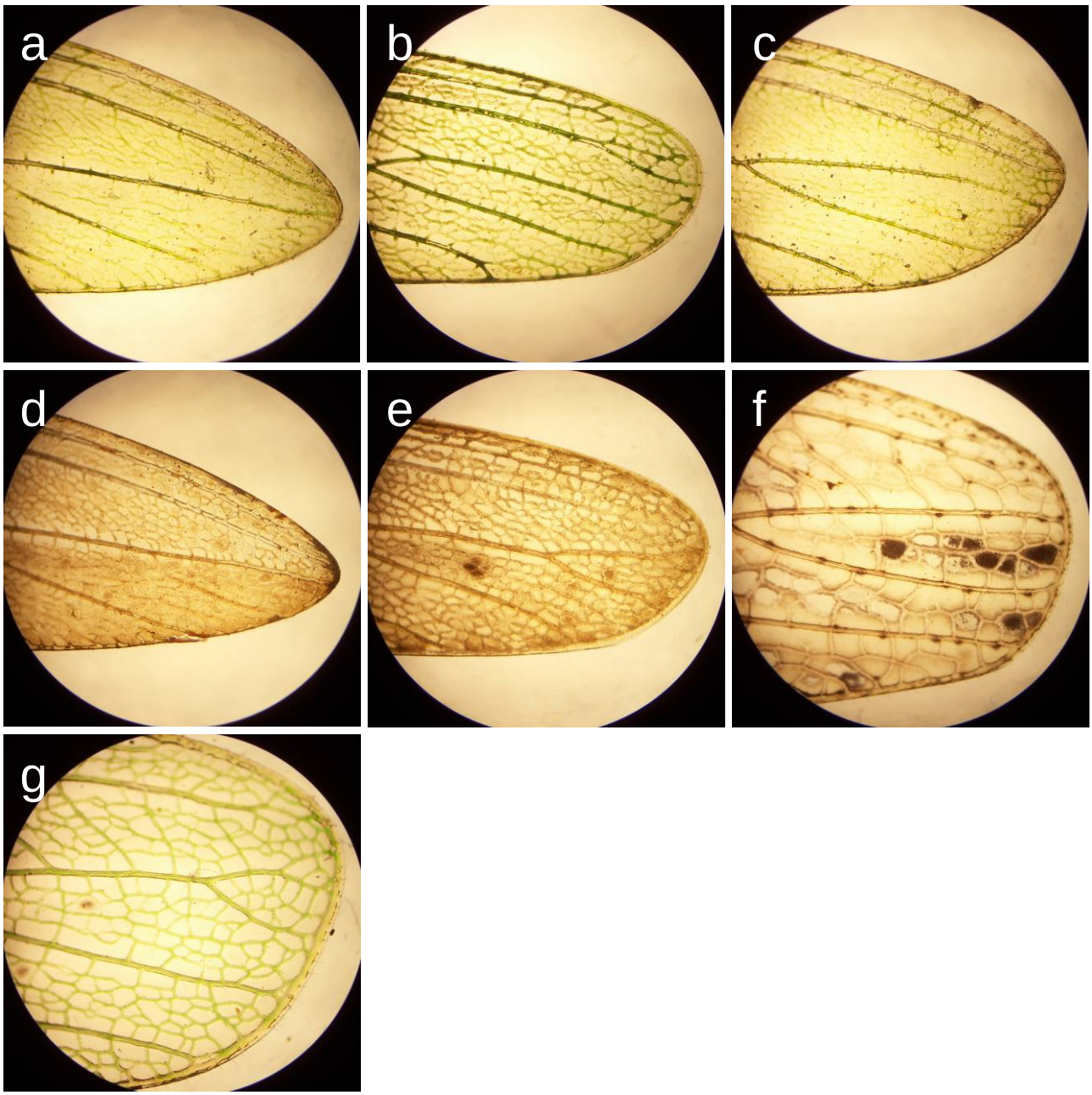

Fig. 8. Apices of tegmina (×40). a. *Euconocephalus pallidus*; b. *Euconocephalus nasutus*; c. *Euconocephalus varius*; d. *Euconocephalus mucro*; e. *Euconocephalus picteti*; f. *Xestophrys horvathi*; g. *Pseudorhynchus minor*.

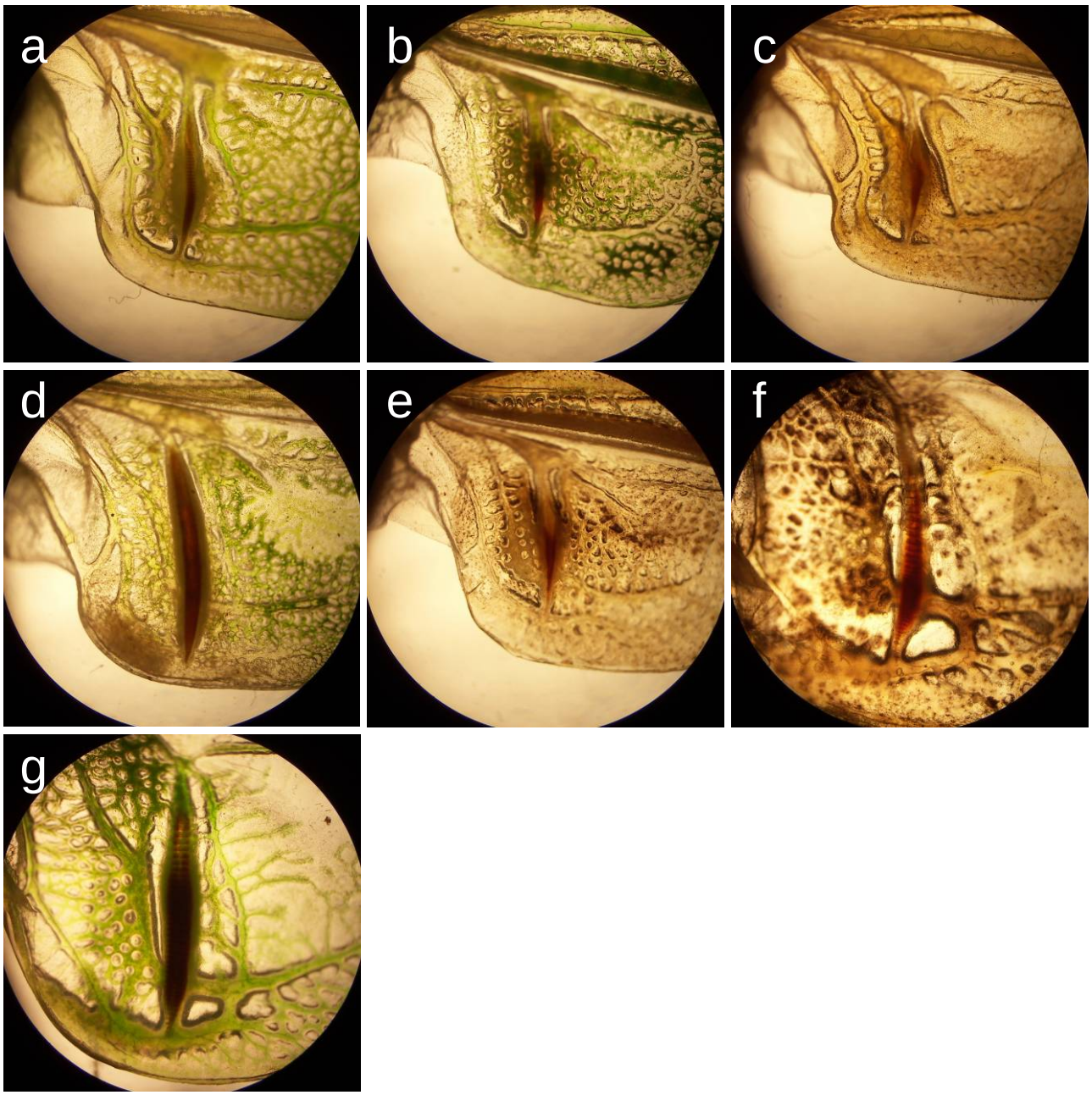

Fig. 9. Male left stridulatory files (×40). a. *Euconocephalus pallidus*; b. *Euconocephalus nasutus*; c. *Euconocephalus varius*; d. *Euconocephalus mucro*; e. *Euconocephalus picteti*; f. *Xestophrys horvathi*; g. *Pseudorhynchus minor*.

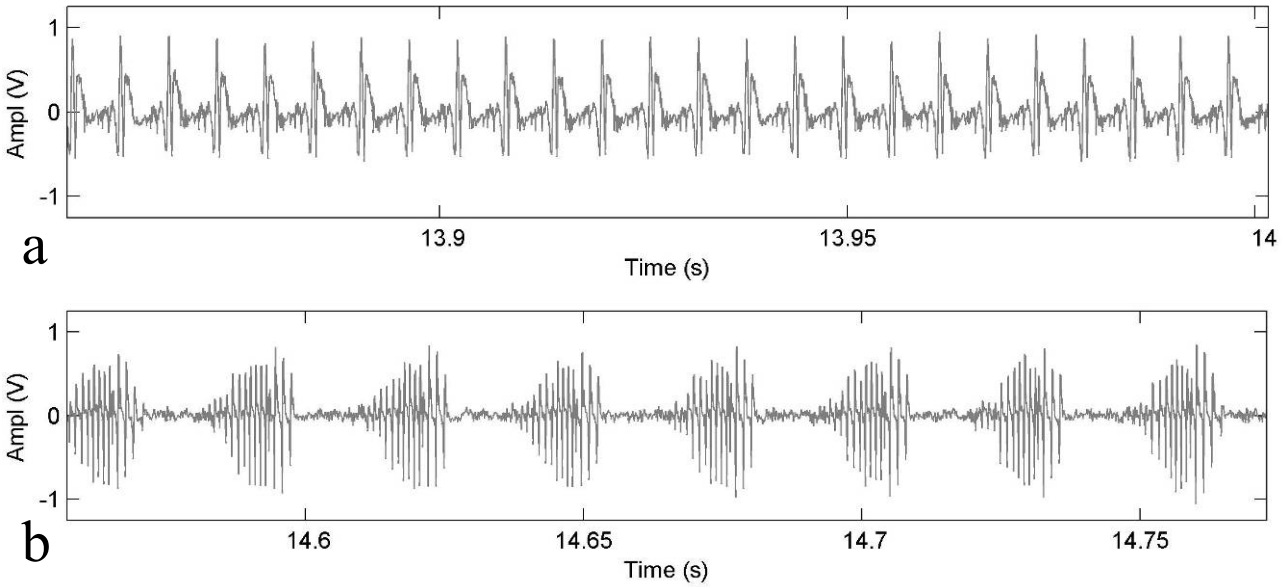

Fig. 10. Oscillograms of male stridulation. a. *Euconocephalus pallidus* (recorded along Bedok South Avenue 3 on 6 Nov.2010); b. *Euconocephalus mucro* (recorded along Upper Aljunied Road on 31 Oct.2010). Within human range of hearing, the differences between the songs of the two species are due to differences in peak frequency.

Fig. 11. A *Xestophrys horvathi* nymph (ca. body length = 22.5 mm) feeding on grass stems (Gramineae or Poaceae). It was observed to use its mandibles to cut through and peel the stems. Photographed along Bedok South Avenue 3 on 17 Sep.2010.

Fig. 12. A female adult *Euconocephalus pallidus* (ca. LT = 42 mm) feeding on the fruits and seeds of a sedge (Cyperaceae). Photographed along Bedok South Avenue 3 on 31 Aug.2010.

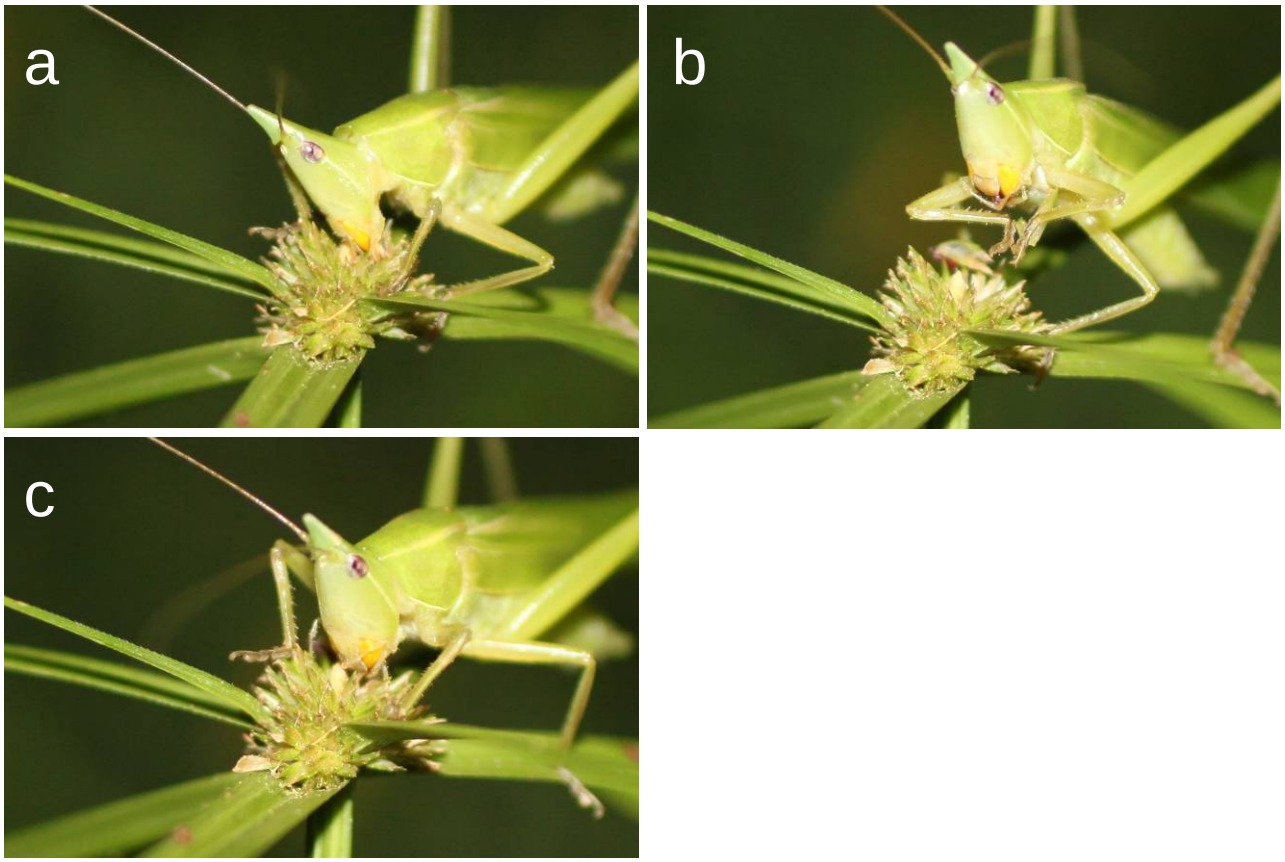

Fig. 13. An adult *Euconocephalus* species (ca. LT = 35 mm) feeding on the fruits and seeds of sedge (Cyperaceae). a. Detachment of individual seed from the seed pod; b. Ingestion of seed; c. Repetition of process. Photographed along Upper Aljunied Road on 31 Jul.2010.

Fig. 14. A female *Euconocephalus* species nymph (LT = ca. 40 mm) of the final instar believed to have died as a result of unsuccessful moulting. Photographed along Upper Aljunied Road on 9 Sep.2010.

Fig. 15. A male adult *Xestophrys horvathi* (ZRC.ORT.68a, LT = 41.15 mm) with wings infested with red mites (superorder Acariformes) collected along Tampines Avenue 1 on 11 Jul.2010.

Fig. 16. Two red mites (superorder Acariformes) with their mandibles attached to the tegmen of an adult *Euconocephalus pallidus*. Body length of lower mite = 0.85 mm.

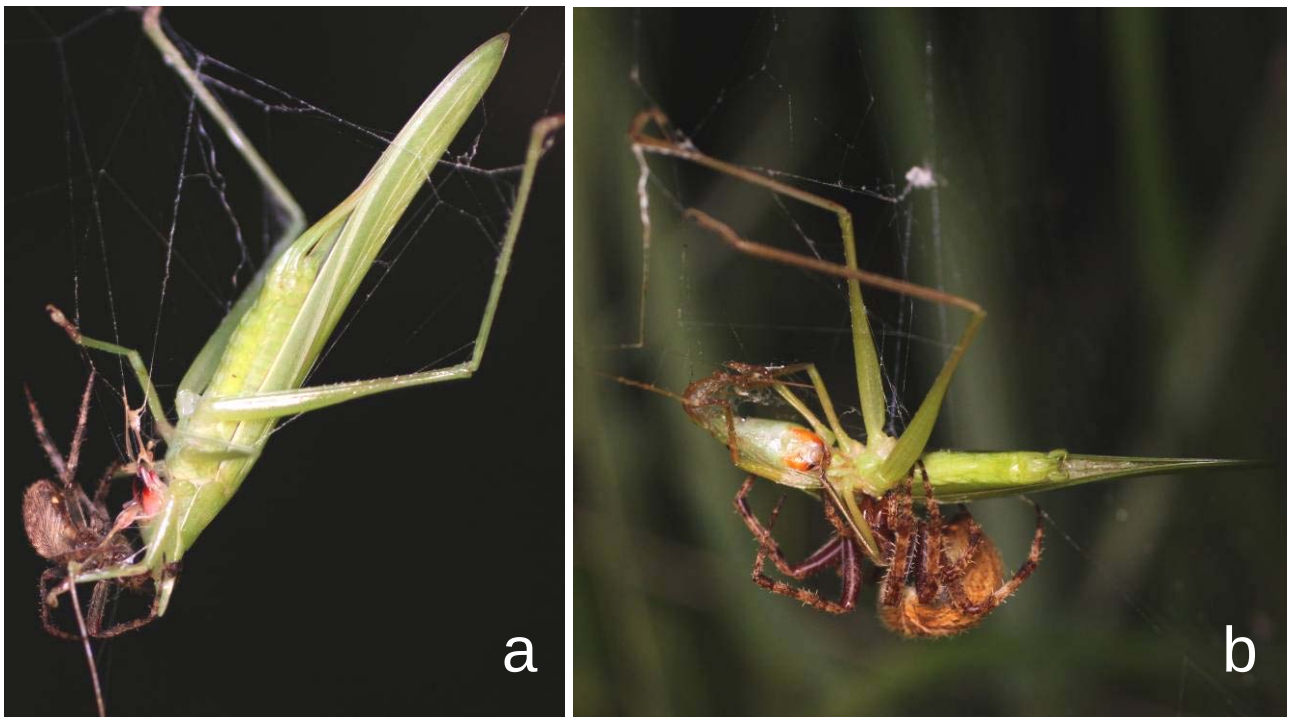

Fig. 17. a. A female adult *Euconocephalus mucro* (ca. LT = 42 mm) preyed upon by a spider (family Araneidae). For 15 minutes, the spider struggled to paralyse the trapped, but resilient katydid. Photographed along Upper Aljunied Road on 22 Aug.2010. b. A spider (family Araneidae) inserting its fangs into a male adult *Euconocephalus* species (ca. LT = 38 mm). Photographed along Upper Aljunied Road on 9 Sep.2010.

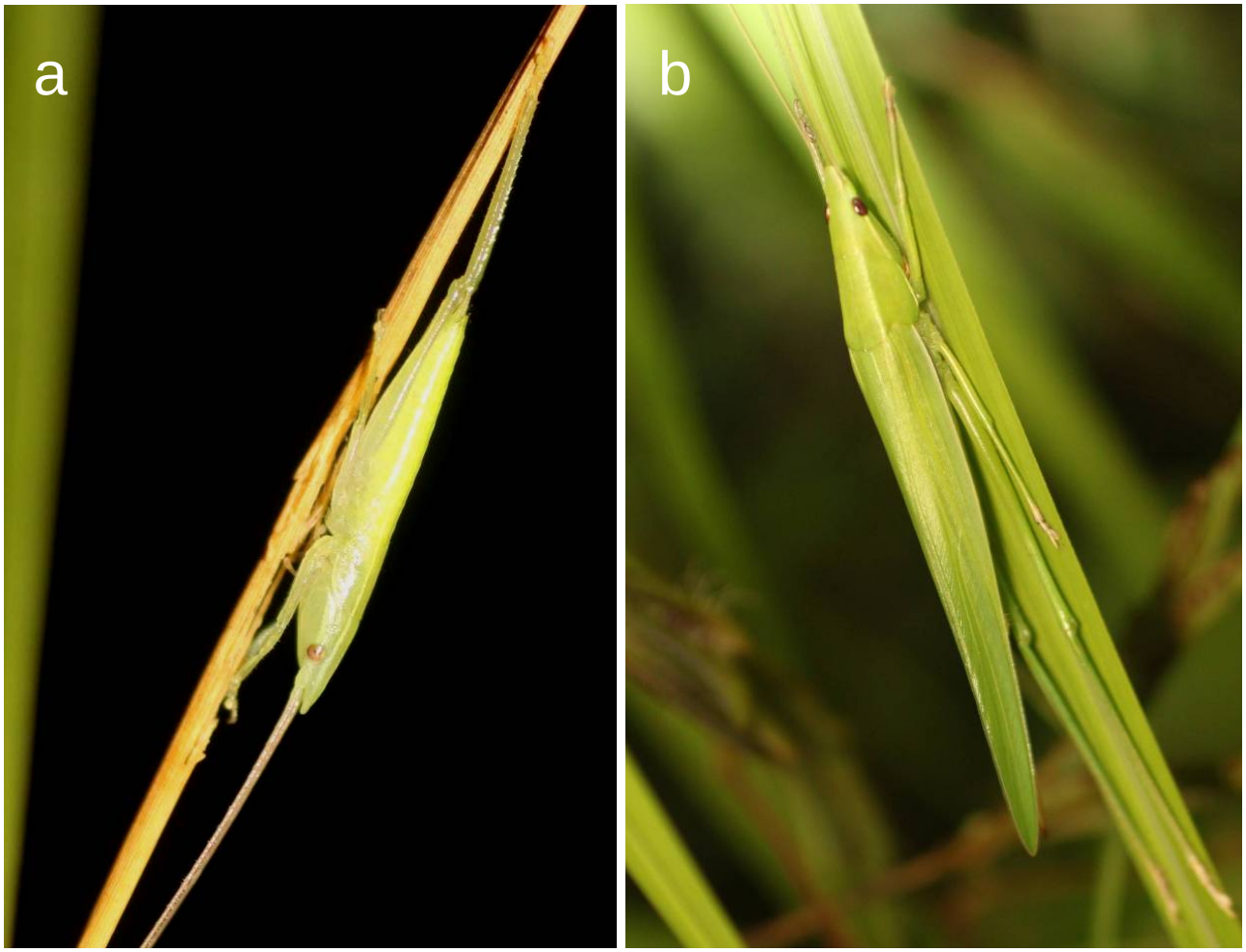

Fig. 18. The cryptic position in which the (a) nymph (ca. body length = 15 mm) and (b) adult *Euconocephalus* species (ca. LT = 42 mm) may take up upon detection of potential threat. Photographed along Upper Aljunied Road on 13 Aug.2010.