Towards a better understanding of the genus *Scelimena* (Orthoptera, Tetrigidae, Scelimeninae): New insights and notes on the taxonomy, ecology, and physiology of the genus in Peninsular Malaysia

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Abstract

One of the two *Scelimena* Serville, 1838 species described from Peninsular Malaysia, *Scelimena gombakensis* Muhammad, Tan & Skejo, 2018 occupies a wide distributional range across the country, contrary to the range described in the original description of the species. Extended research has shown that the species occurs in many localities in Peninsular Malaysia, which is interesting given that such findings are uncommon in the study of Tetrigidae. This paper provides new distribution localities, some ecological and physiological notes, and photographs of living specimens of *Scelimena gombakensis*. Other species synonymized here include *Scelimena razalii* Mahmood, Idris, & Salmah, 2007 **syn. nov.** of species *Falconius dubius* Günther, 1938.

Keywords

citizen science, distribution, iNaturalist, pygmy grasshoppers, Scelimenini, Southeast Asia, synonymy

Introduction

Malaysian Tetrigidae still remains an understudied group of animals since papers on them mostly highlight taxonomy, i.e., species description and occurrence. Examples of such papers from Peninsular Malaysia are Mahmood et al. (2007), Tan and Kamaruddin (2014), Tan and Kamaruddin (2016), Skejo and Bertner (2017), Storozhenko and Pushkar (2017), and Muhammad et al. (2018). In Sabah and Sarawak, Ito and Mohamed (2001), Storozhenko (2012), Kočárek et al. (2015), and Skejo et al. (2019) also focused on taxonomy, with the exception of a paper by Kuřavová et al. (2017) that described Bornean Tetrigidae feeding patterns, offering an ecological insight. Other papers that briefly mention Malaysian Tetrigidae include Zha et al. (2016), Xin and Deng (2019), and Adžić et al. (2020). One of the first papers to cover this family in Peninsular Malaysia was Mahmood et al. (2007). However, some misidentifications from the paper were reported in later publications (Storozhenko and Dawwrueng 2015, Muhammad et al. 2018), and certain species identifications from this paper require future revision.

So far, only two *Scelimena* Serville, 1838 species have been found in Peninsular Malaysia (Cigliano et al. 2022): *Scelimena razalii* Mahmood, Idris & Salmah, 2007 and *Scelimena gombakensis* Muhammad, Tan & Skejo, 2018. While *S. gombakensis* belongs to the *Scelimena discalis* Hancock 1915 species group, *S. razalii* has not been assigned to any due to insufficient evidence and vague descriptions and drawings from Mahmood et al. (2007). Moreover, it is only described in Kuala Lompat, Pahang, Malaysia.

In this study, we synonymized *Scelimena razalii* Mahmood, Idris & Salmah, 2007 **syn. nov.** with *Falconius dubius* Günther, 1938 after close examination of the type specimens of *S. razalii*. We also looked into the distribution of *S. gombakensis* by reporting on all known specimen observation localities and linking this updated distribution of the species with its ecological (i.e., habitat) and physiological (i.e., swimming ability) characteristics. Photos of both living and pinned specimens of *S. gombakensis* and *F. dubius*, detailed scanning electron microscopy (SEM) photos of morphological characters of hind leg tarsi and tibiae of *S. gombakensis*, and a distribution map of *S. gombakensis* are provided.

Material and methods

Institutional abbreviations.—

CIS (UKM)	Center for Insect Systematics, Universiti Kebangsaan Malaysia, Selangor, Malaysia;
FRIM	Forest Research Institute Malaysia, Peninsular Malaysia;
MZUM (UM)	Museum of Zoology, Universiti Malaya, Kuala Lumpur, Malaysia;
ZRC	Zoological Reference Collection, Lee Kong Chian Natural History Museum, Singapore.

Both physical records (specimen) and virtual records (online database) were assessed. *Falconius dubius* specimens were examined at MZUM (UM) and CIS (UKM), whereas *Scelimena gombakensis* specimens were examined at MZUM (UM), ZRC, and FRIM. Photographs used in this manuscript were taken using an Olympus Compact Stereo Microscope SZ61 with an Olympus Microscope Digital Camera DP22 connected to a desktop computer during museum examination. A Canon EOS 600D camera with 100 mm f/2,8 macro lens attached was used for *in situ* photography. Records of type specimens described in Muhammad et al. (2018) deposited in ZRC, MZUM, and FRIM were assessed by Amira Aqilah Muhammad. Data screening on the iNaturalist website was done using the keywords "*Scelimena gombakensis*," in which the online observations were additionally confirmed by the authors. Supplementary information (i.e., dates of publishing, location names, GPS coordinates, and website identification numbers) are listed in Table 1. Only iNaturalist observation data available prior to the date of this paper's submission (29 August 2022) were included in this paper. The tabulated coordinates were input into QGIS version 3.16.13 to visualize the distribution on a map.

Table 1. Observations of *Scelimena gombakensis* Muhammad, Tan & Skejo, 2018 specimens in Peninsular Malaysia found on iNaturalist platform (www.inaturalist.org) (the last column refers to iNaturalist observation ID).

Observer	Date	Locality	Coordinates	Observation ID
Fabio Cianferoni	Jul. 4, 2008	Hulu Perak, Perak, Malaysia	5°30'10"N, 101°26'11"E	45968367
CheongWeei Gan	Dec. 5, 2009	Hulu Yam, Selangor, Malaysia	3°24'11"N, 101°41'4"E	127199050
CheongWeei Gan	Dec. 5, 2009	Hulu Yam, Selangor, Malaysia	3°19'55"N, 101°42'6"E	127199054
Phil Benstead	Aug. 26, 2013	Hulu Langat, Selangor, Malaysia	3°7'48"N, 101°53'17"E	71201238
Erland Refling Nielsen	Aug. 30, 2013	Gombak, Selangor, Malaysia	3°19'27"N, 101°44'54"E	63194111
Kees van Reenen	Jan. 29, 2019	Seremban, Negeri Sembilan, Malaysia	2°47'55"N, 101°48'3"E	35679667
Yiquan Chin	Feb. 23, 2019	Timur Laut, Penang, Malaysia	5°26'2"N, 100°17'46"E	20687721
Alexius L.Z.L	Dec. 19, 2019	Timur Laut, Penang, Malaysia	5°25'54"N, 100°17'55"E	36773269
Vatcharavee Sriprasertsil	June 2021	Waeng, Narathiwat, Thailand	5°47'43"N, 101°49'42"E	84546541
Chloe Alison	Dec. 14, 2021	Genting Highlands, Pahang, Malaysia	3°24'40"N, 101°47'40"E	103086028
Alexius L.Z.L	Dec. 11, 2021	Mukim 17, Penang, Malaysia	5°21'35"N, 100°29'32"E	102908617
Puteri Nuraida Syuhada Binti Abdullah	Dec. 11, 2021	Hulu Langat, Selangor, Malaysia	3°12'37"N, 101°50'33"E	102847175
Albert Kang	Mar. 1, 2022	Tanjung Bungah, Penang, Malaysia	5°27'54"N, 100°16'55"E	107814195
Aiman Azmi	May 13, 2022	Pasir Puteh, Kelantan, Malaysia	5°45'49"N, 102°24'32"E	116921973

Field observation was done at the type locality—Ulu Gombak Field Study Center, Ulu Gombak, Selangor, Malaysia—where the authors focused on several aspects of tetrigid behavior during the daytime, including food preference and locomotion (utilization of legs and hindwings). Several individuals were collected and preserved in 95% ethanol to observe the leg structure under Hitachi's Table Top Scanning Electron Microscope (SEM) TM3030. The specimens' legs were mounted on a conductive double-sided tape on a specimen stub that was then set on a holder before the height level was adjusted by controlling the height gauge. The stage was then carefully placed in the chamber before closing, and the imaging process followed the instructions given by the user's manual. Scanned images were edited using TM3030 software installed on a desktop computer connected to the SEM machine.

Results

Taxonomy

Family Tetrigidae Rambur, 1838
Subfamily Scelimeninae Bolívar, 1887
Tribe Scelimenini Bolívar, 1887

***Falconius dubius* Günther, 1938**

Falconius dubius Günther, 1938: 399, 404, 419.
Scelimena razalii Mahmood, Idris & Salmah, 2007, syn. nov. – Mahmood, Idris and Salmah 2007: 1279; Muhammad et al. 2018: 53; Maitlo and Panhwar 2021: 34.

Material examined.—MALAYSIA, **Selangor** • 2 ♂; holotype and paratype of *Scelimena razalii*; 24 July 2004; Rezwana Rezali leg.; CIS (UKM) • 2 ♂; Ulu Langat; 16 Mar. 1964; AAM leg.; MZUM IOt 002323, 002324 • 1 ♂; Ulu Langat; 7 Mar. 1964; AAM leg.; MZUM IOt 002353 • 1 ♂; Ulu Gombak Bt 16; 7 Mar. 1964; AAM leg.; MZUM IOt 002370 • 1 ♀; same data as for preceding; MZUM IOt 002377 • 1 ♂; Ulu Gombak; 15 July 2019; Adzic, K. leg.; MZUM • 1 ♂; Ulu Gombak; 15 July 2019; Deranja, M. leg.; MZUM • 1 ♂; Ulu Gombak, 24 July 2019; Muhammad, A. A. leg.; MZUM • 1 ♂; Ulu Gombak; 29 July 2019; Adzic, K. leg.; MZUM. • 1 ♀; same data as for preceding. **Negeri Sembilan** • 1 ♀; Negeri Sembilan, Pasoh; 26 June 1997; Rina Silviana leg.; MZUM IOt 002383. **Pahang** • 1 ♂; Eko Rimba Lentang; 22 July 2019; Adzic, K. leg.; MZUM • 1 ♀; Eko Rimba Lentang; 22 July 2019; Deranja, M. leg.; MZUM.

Justification of the synonymy.—After examination of the *Scelimena razalii* Mahmood, Idris & Salmah, 2007 type material, we consider it to be a synonym of *Falconius dubius* Günther, 1938. We found many *Falconius* Bolívar, 1898 specimens in the UKM collection, but none were identified as belonging to the genus *Falconius* as described in Mahmood et al. (2007). The genus can easily be distinguished from other Scelimenini genera by the swollen hind tarsi in females (Fig. 1D, indicated by an arrow. Note that this character is present in *Eufalconius* Günther, 1938 as well), a relatively stout head with the most prominent feature being the frontal costa forking relatively close to the fastigium, the anterior margin of the eyes raised slightly above the fastigium, and a relatively high position of the paired ocelli and the antennal grooves in relation to the compound eyes (Bolivar 1898, Muhammad et al. 2018). Upon further comparison with photographs of the type material of *F. dubius* available on Orthoptera Species File (OSF) database, we found no differences between these two species. We cannot be certain that the *S. razalii* specimens reported from Pakistan (Maitlo and Panhwar 2021) also belong to this species because we did not

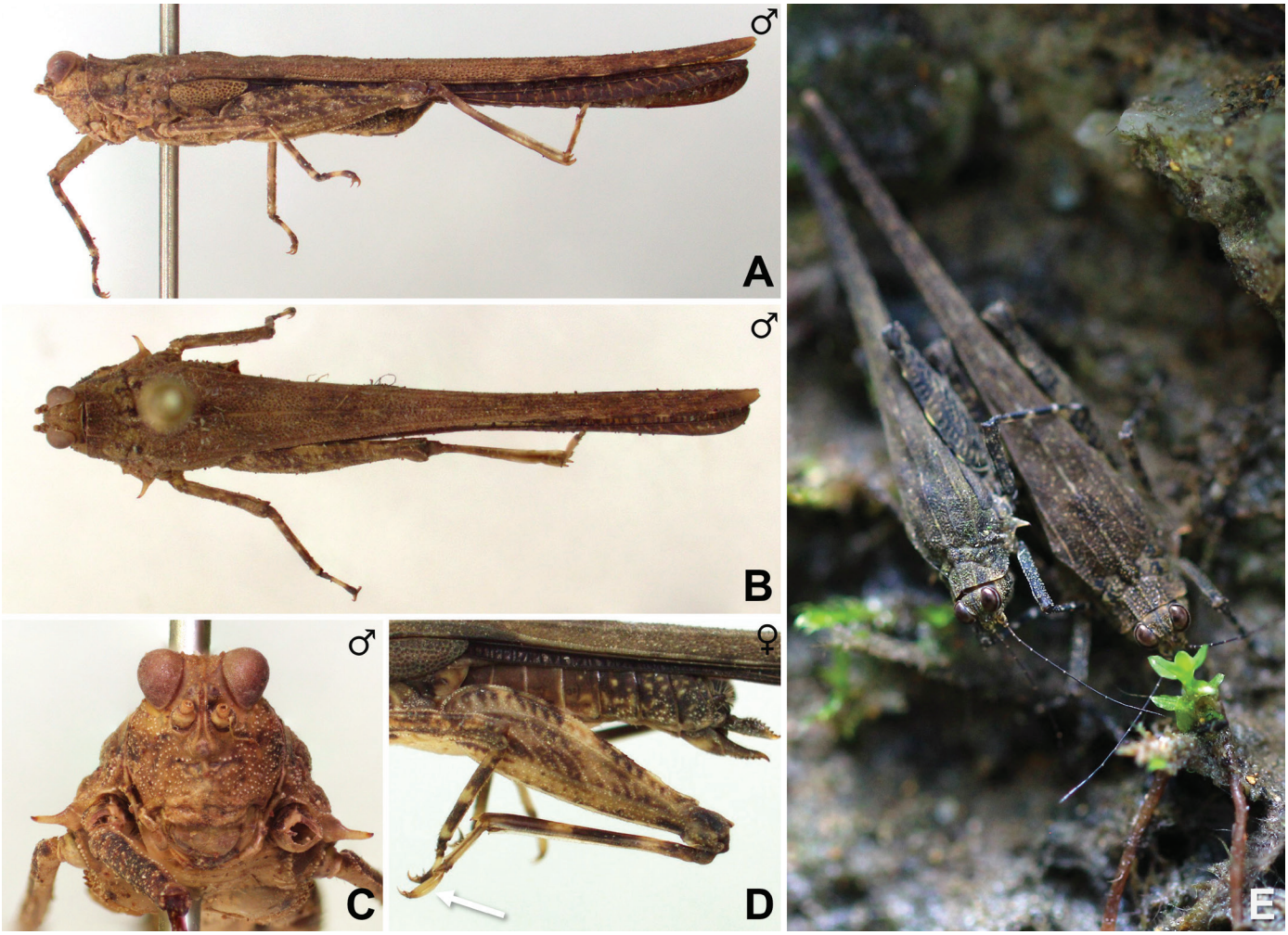

Fig. 1. Specimens of *Falconius dubius* Günther, 1938 from Peninsular Malaysia. **A–C.** Holotype of *Scelimena razalii* Mahmood, Idris & Salmah, 2007 **syn. nov.**; **D.** A female specimen from Universiti Malaya collection; **E.** The morphology of living specimens in their natural habitat in Ulu Gombak, Selangor, Peninsular Malaysia, both male and female.

have the opportunity to examine this material. Hence, those specimens should be re-examined in the future.

This paper is the first official record for the species from Peninsular Malaysia (following data from Adžić (2021); note that the type material specimens are listed incorrectly in the thesis, which is corrected in this paper) (Fig. 1).

***Scelimena gombakensis* Muhammad, Tan & Skejo, 2018**

Scelimena producta (Serville, 1838) - Mahmood et al. 2007: 1279; Storozhenko and Dawwrueng 2015: 543).
Scelimena gombakensis Muhammad, Tan & Skejo, 2018: 6, 46.

Examined material.—**Holotype:** PENINSULAR MALAYSIA, **Selangor** • 1 ♂; Ulu Gombak Field Studies Centre; 24 Sept. 2017; Muhammad, A. A., Muhammad Hafiz Mohd Amin & Afyza Maisarah Azizan leg.; ZRC. **Paratypes:** PENINSULAR MALAYSIA, **Selangor** • 1 ♀; Ulu Gombak Field Study Centre; 9 Mar. 2018; Muhammad, A. A. & Abdullah, N. A. leg.; ZRC • 1 ♂; same data as of preceding; FRIM • 1 ♀; same data as of preceding; FRIM • 2 ♂; same data as of preceding; MZUM • 1 ♀; Ulu Gombak Field Study Centre; 24 Sept. 2017; Muhammad, A. A., Muhammad Hafiz Mohd Amin & Afyza Maisarah Azizan leg.; FRIM • 1 ♀; same data as of preceding; MZUM.

Other material: PENINSULAR MALAYSIA, **Selangor** • 8 ♂; Ulu Gombak; 7 Mar. 1964; AAM leg.; MZUM IOt 002350, 002351, 002355, 002361, 002362, 002366, 002367, 002369 • 3 ♀; same data as of preceding; MZUM IOt 002357, 002363, 002379 • 1 ♂; Ulu Gombak 16ms. [miles]; 27 May 1964; AAM leg.; MZUM IOt 002347 • 2 ♂; Ulu Gombak, 16ms. [miles]; 15 Apr. 1964; AAM leg.; MZUM IOt 002371, 002373 • 1 ♂; Ulu Gombak, 12ms; 15 Apr. 1964, AAM leg.; MZUM IOt 002372 • 3 ♂; Ulu Gombak, Bt [Batu] 16; 7 Mar. 1964; AAM leg.; MZUM IOt 002348, 002349, 002356 • 4 ♀; same data as of preceding; MZUM IOt 002358 to 002360, 002365 • 7 ♂; Ulu Langat; 16 Mar. 1964; AAM leg.; MZUM IOt 002333, 002334, 002340, 002342 to 002345 • 2 ♀; same data as of preceding; MZUM IOt 002339, 002341 • 1 ♀; Ulu Gombak; 15 Jul. 1969; JAB leg.; MZUM IOt 002428 • 1 ♂; Ulu Gombak; 15 Sept. 1974; Chua Eng Lok leg.; MZUM IOt 002407 • 1 ♂; same data as of preceding; L. Teo leg.; MZUM IOt 002408 • 1 ♂; same data as of preceding; B. H.Voon leg.; MZUM IOt 002415 • 1 ♀; same data as of preceding; Aru leg.; MZUM IOt 002413 • 1 ♀; same data as of preceding; K. C. Tung leg.; MZUM IOt 002414 • 1 ♀; Ulu Langat; 27 Oct. 1974; Wong Yow Sin leg.; MZUM IOt 002411, • 1 ♀; same data as of preceding; P. F. K. leg.; MZUM IOt 002412 • 1 ♀; Pansoon; 27 Oct. 1974; Heng. L. P. leg.; MZUM IOt 002409 • 1 ♀; same data as of preceding; Hoo Ah Teng leg.;

MZUM IOt 002416 • 1 ♂; Sg. [Sungai] Tua; 27 July 1979; C. L. leg.; MZUM IOt 002406 • 1 ♀; Ulu Gombak; 1 Dec. 1982, Zuraidah Mian leg.; MZUM IOt 002388 • 1 ♀; Ulu Gombak; 21 Oct. 1984; Daiqah leg.; MZUM IOt 002410 • 1 ♀; Ulu Gombak; 18 Sept. 1995; Hasleyza leg.; MZUM IOt 002386 • 1 ♂; Ulu Gombak; 7 July 1997; Rosliza leg.; MZUM IOt 002430 • 1 ♂; Ulu Gombak; MZUM IOt 002391. **Negeri Sembilan** • 1 ♂; Ulu Bendul; 12 Aug. 1989; ZZ leg.; MZUM IOt 002427. **Pahang** • 1 ♂; Ketari; 7 June 1961; MZUM IOt 002385 • 1 ♀; same data as of preceding; MZUM IOt 002387 • 1 ♂; Nenasi; 17 Nov. 1974; W. C. Kang leg.; MZUM IOt 002404 • 1 ♀; Lentang; 2 Dec. 1995; Rohaya leg.; MZUM IOt 002426. **Perak** • 1 ♀; Grik; 17 Feb. 1991, McGyver leg.; MZUM IOt 002418 • 1 ♂; Perlok; 20 May 1997, Khaironizam Md. Zain leg.; MZUM IOt 002399. **Johor** • 1 ♂; B[atu] Pahat; 20 Nov. 1974; M. Ali-S leg.; MZUM IOt 002403 • 1 ♂; Duhsun; 17 Nov. 1974; Salleh leg.; MZUM IOt 002417. **Terengganu** • 1 ♂; Jerangau; 2 Mar. 1974; Baki leg.; MZUM IOt 002405. **Kelantan** • 1 ♂; Kg Senyul; 15 June 1962; KJK leg.; MZUM IOt 002375 • 1 ♀; same data as of preceding; MZUM IOt 002374 • 1 ♀; F[ort] Brooke; 15 Apr.1962; JAB leg.; MZUM IOt 002381.

iNaturalist observation.—PENINSULAR MALAYSIA, **Perak** • Hulu Perak; 5°30'10"N, 101°26'11"E; 4 July 2008; Fabio Cianferoni leg.; iNaturalist.org: https://www.inaturalist.org/observations/45968367. **Selangor** • Hulu Yam; 3°24'1"N, 101°41'4"E; 5 Dec. 2009; CheongWeei Gan leg.; iNaturalist.org: https://www.inaturalist.org/observations/127199050 • Hulu Yam; 3°19'55"N, 101°42'6"E; 5 Dec. 2009; CheongWeei Gan leg.; iNaturalist.org: https://www.inaturalist.org/observations/127199054 • Hulu Langat; 3°7'48"N, 101°53'17"E; 26 Aug. 2013; Phil Benstead leg.; iNaturalist.org: https://www.inaturalist.org/observations/71201238 • Gombak; 3°19'27"N, 101°44'54"E; 30 Aug. 2013; Erland Refling Nielsen leg.; iNaturalist.org: https://www.inaturalist.org/observations/63194111 • Hulu Langat; 3°12'37"N, 101°50'33"E; 11 Dec. 2021; Puteri Nuraida Syuhada Binti Abdullah leg.; iNaturalist.org: https://www.inaturalist.org/observations/102847175. **Negeri Sembilan** • Seremban; 2°47'55"N, 101°48'3"E; 29 Jan. 2019; Kees van Reenen leg.; iNaturalist.org: https://www.inaturalist.org/observations/35679667. **Penang** • Timur Laut; 5°26'2"N, 100°17'46"E; 23 Feb. 2019; Yiquan Chin leg.; iNaturalist.org: https://www.inaturalist.org/observations/20687721 • Timur Laut; 5°25'54"N, 100°17'55"E; 19 Dec. 2019; Alexius L.Z.L leg.; iNaturalist.org: https://www.inaturalist.org/observations/36773269 • Mukim 17; 5°21'35"N, 100°29'32"E; 11 Dec. 2021; Alexius L.Z.L leg.; iNaturalist.org: https://www.inaturalist.org/observations/102908617 • Tanjung Bungah; 5°27'54"N, 100°16'55"E; 1 Mar. 2022; Albert Kang leg.; iNaturalist.org: https://www.inaturalist.org/observations/107814195. **Pahang** • Genting Highlands; 3°24'40"N, 101°47'40"E; 14 Dec. 2021; Chloe Alison leg.; iNaturalist.org: https://www.inaturalist.org/observations/103086028. **Kelantan** • Pasir Puteh; 5°45'49"N, 102°24'32"E; 13 May 2022; Aiman Azmi leg.; iNaturalist.org: https://www.inaturalist.org/observations/116921973. THAILAND, **Narathiwat** • Waeng; 5°47'43"N, 101°49'42"E; June 2021; Vatcharavee Sriprasertsil leg.; iNaturalist.org: https://www.inaturalist.org/observations/84546541.

Examination of the specimens deposited at FRIM, MZUM, and ZRC revealed that the species was previously known from the region but was not recognized as a separate species. *S. gombakensis* had been wrongly identified by researchers as *Scelimena producta* (Serville, 1838) (Mahmood et al. 2007, D.K. McE. Kevan's notes on specimen labels in the UM collection). *S. producta producta* has been described from Java and has a similar body coloration to *S. gombakensis* (see specimen photographs available on OSF). However, it can be morphologically differentiated by two characteristics: pointed tubercles at humeral angles to the pronotum (rounded in *S. gombakensis*) and numerous clearly visible teeth on the ventral side of its hind femora (while *S. gombakensis* has only two small teeth) (Muhammad et al. 2018). Thus, we correct previous identifications and consider all listed specimens to belong to *S. gombakensis*, making these identifications new locality records for the species.

Variability.—Thanks to the large number of specimens that we were able to examine, we found *S. gombakensis* to be a rather variable species, especially in terms of body size (♂: 18.0–24.0 mm; ♀: 24.0–31.0 mm). Nymphs do not differ much from adults, having similar coloration and general appearance, although they do have significantly shorter pronotum, making them easily distinguished from other Tetrigidae in Peninsular Malaysia. During the fieldwork, we observed one specimen belonging to *S. gombakensis* with unique coloration—the specimen's general body coloration was brown (opposed to the common dark green coloration) with orange markings (opposed to yellow markings; Fig. 2E, indicated by an arrow). This coloration could be recessive given its rarity, or it could be caused by some kind of infection.

A change of coloration was also observed in pinned specimens (Fig. 2A–D), which is a very interesting but rarely mentioned observation in Tetrigidae (an example of such observation was described by Mathieu et al. (2021)). In the MZUM collection, which holds a large number of *S. gombakensis* specimens, we observed color degradation in the older specimens. The colors of the older specimens were generally faded more than in recent ones, which gradually lost their dark green coloration with yellow markings and became generally brown in coloration. However, it is important to note that not all specimens had lost their color to the same extent, as some specimens from the 1960s are not as faded as the one represented in this paper (Fig. 2A). Since all the specimens were collected around the same time and were all stored in the same box under the same conditions, it is possible that pre-pinning conditions play a vital role in coloration preservation in *S. gombakensis* specimens. Such factors might be influenced by the sampling and euthanization methods, duration of pinning of the specimens, preservation techniques, etc. Since we did not have information on the pre-pinning conditions older specimens were exposed to, this hypothesis requires consideration in the future.

Distribution of S. gombakensis.—At first, it was hypothesized that this species would have general ecological traits similar to those of other Tetrigidae, including the fact that Tetrigidae are, in general, highly confined to water bodies, as they are often found in close proximity to fast-flowing rocky rivers (Tan et al. 2017). Even so, we have also observed specimens flying long distances and maneuvering well during flight. It is likely that this species, like many other Tetrigidae, is tightly linked to large flowing bodies of water and disperses passively by water during diving as an escape behaviour.

With recently described species such as *S. gombakensis*, additional knowledge on species distribution, behavior, and other aspects of the species' ecology are frequently understudied and incomplete. Revisiting old specimens deposited in museums or private collections is thus an important next step in understanding a species, as these repositories might hold historical specimens belonging to the species. Muhammad et al. (2018) stated that *S. gombakensis* is restricted to Sungai Gombak of the Gombak Catchment in Selangor, Peninsular Malaysia. Revision of specimens deposited

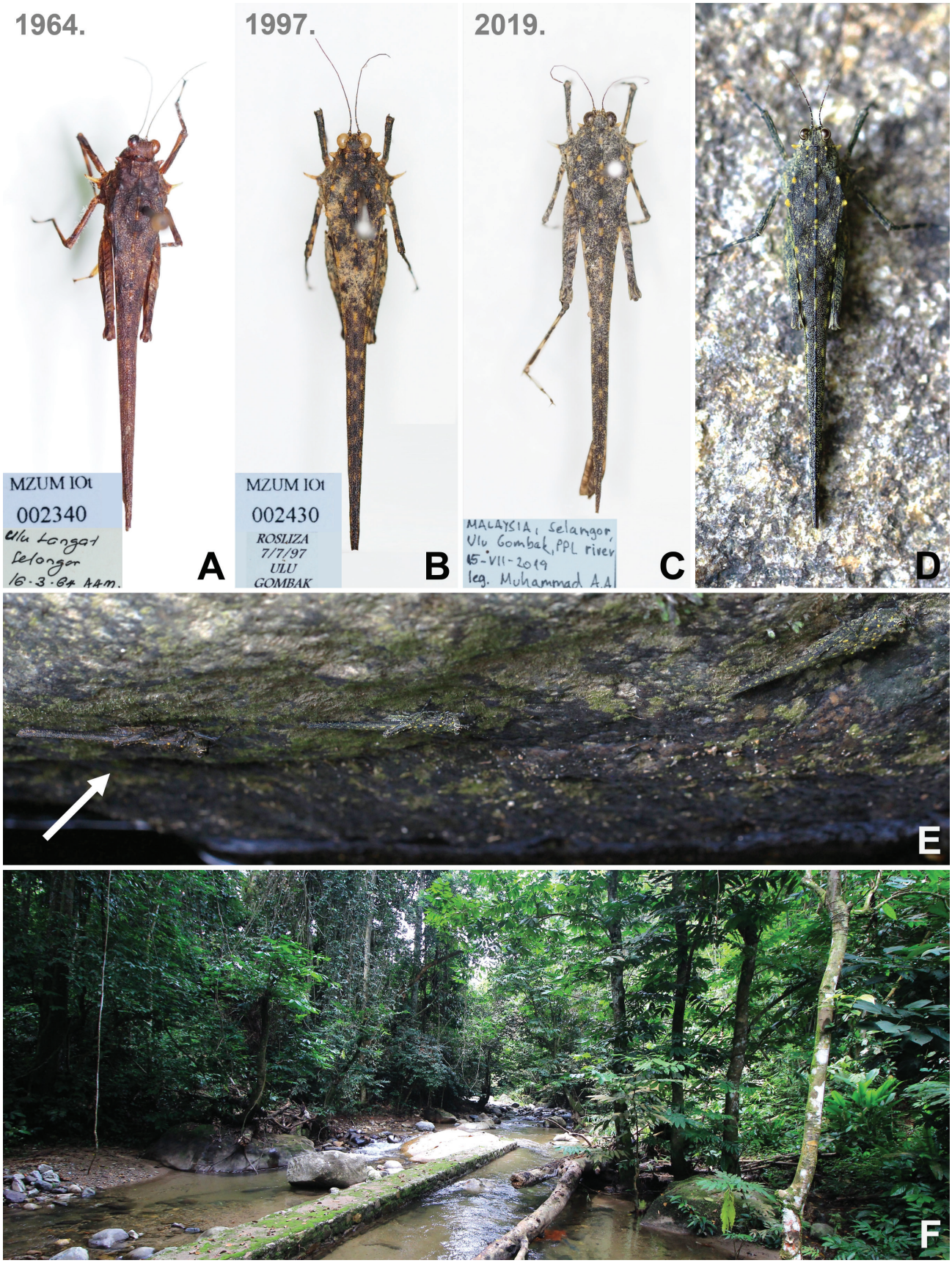

Fig. 2. Change of coloration in pinned specimens of *Scelimena gombakensis* Muhammad, Tan & Skejo, 2018 compared to the living specimen. **A–C.** Pinned *S. gombakensis* specimens; **D.** Living *S. gombakensis* specimens. **E.** Coloration variability and camouflage of three living *S. gombakensis* specimens; **F.** Natural habitat of *S. gombakensis* at the type locality Ulu Gombak, Selangor, Malaysia.

in museum collections (UKM, UM, FRIM, and ZRC) and photos on online databases have shown that the species is, in fact, widely distributed across the country, especially along the West coast (Fig. 3). Social media observations on iNaturalist have greatly contributed to understanding species distribution (Table 1), once again demonstrating how useful citizen science can be (for other examples of the contributions of citizen science to the study of Tetrigidae, see Skejo et al. 2019, Kasalo et al. 2021, and Pavlović et al. 2022).

S. gombakensis is an example of a species that is easily recognized through photographs and highly unlikely to be misidentified in Peninsular Malaysia, making identification using iNaturalist very reliable. Additionally, thanks to iNaturalist, we were able to discover an observation of *S. gombakensis* in the Waeng district of Narathiwat, Thailand, very close to the border of Peninsular Malaysia; this represents the first official record of the species outside of Peninsular Malaysia, making this the first record for the country (Fig. 3, Table 1). Further clarification of the species' distribution is possible by comparing this species with *Scelimena discalis* Hancock, 1915 specimens from Thailand (Storozhenko and Dawwrueng 2015), which may include some misidentified specimens. For now, we refrain from comparing *S. gombakensis* to *S. discalis* due to the inaccessibility of physical specimens and the lack of molecular and online data.

Ecology and habitat of Scelimena gombakensis.—Muhammad et al. (2018) noted that *S. gombakensis* can be found perched on river rocks in lowland secondary rainforest where it is cool and very humid, especially in areas shadowed by tree canopies. Further field observation revealed that high moisture and indirect sunlight may be key to their survival, in tandem with the abundance of lichens and mosses that are their food source (Zha et al. 2017). On the rocks, *S. gombakensis* tends to crowd near the water surface, where the high turbidity of the flowing stream creates a suitable humid biota. Juveniles are more likely to be observed close to the water surface than adults, as they are more susceptible to desiccation due to their immature exoskeletons. The juveniles are also less agile and unable to fly; hence, staying close to the water surface might increase their

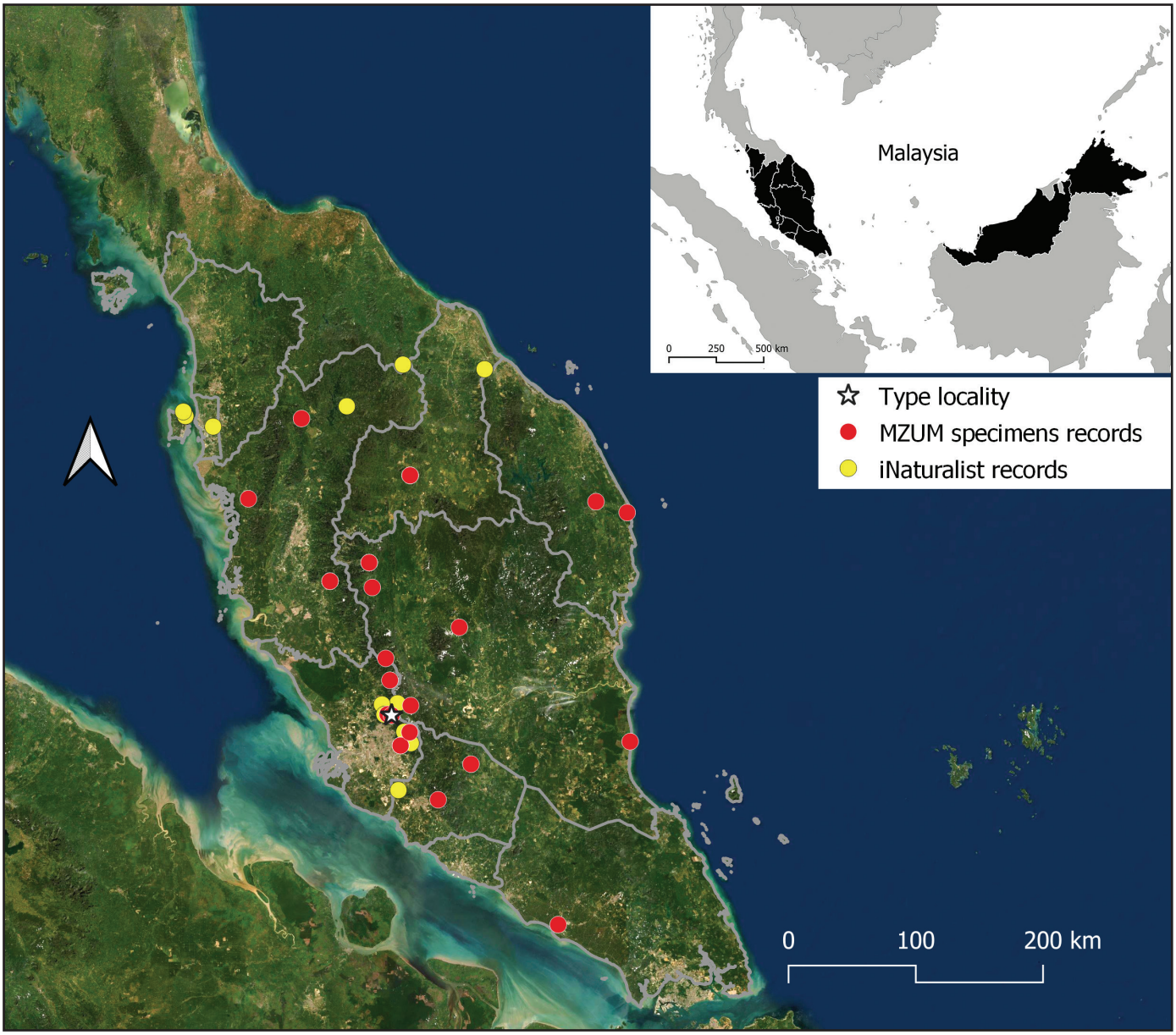

Fig. 3. Distribution map of species *Scelimena gombakensis* Muhammad, Tan & Skejo, 2018 based on museum collection and iNaturalist data.

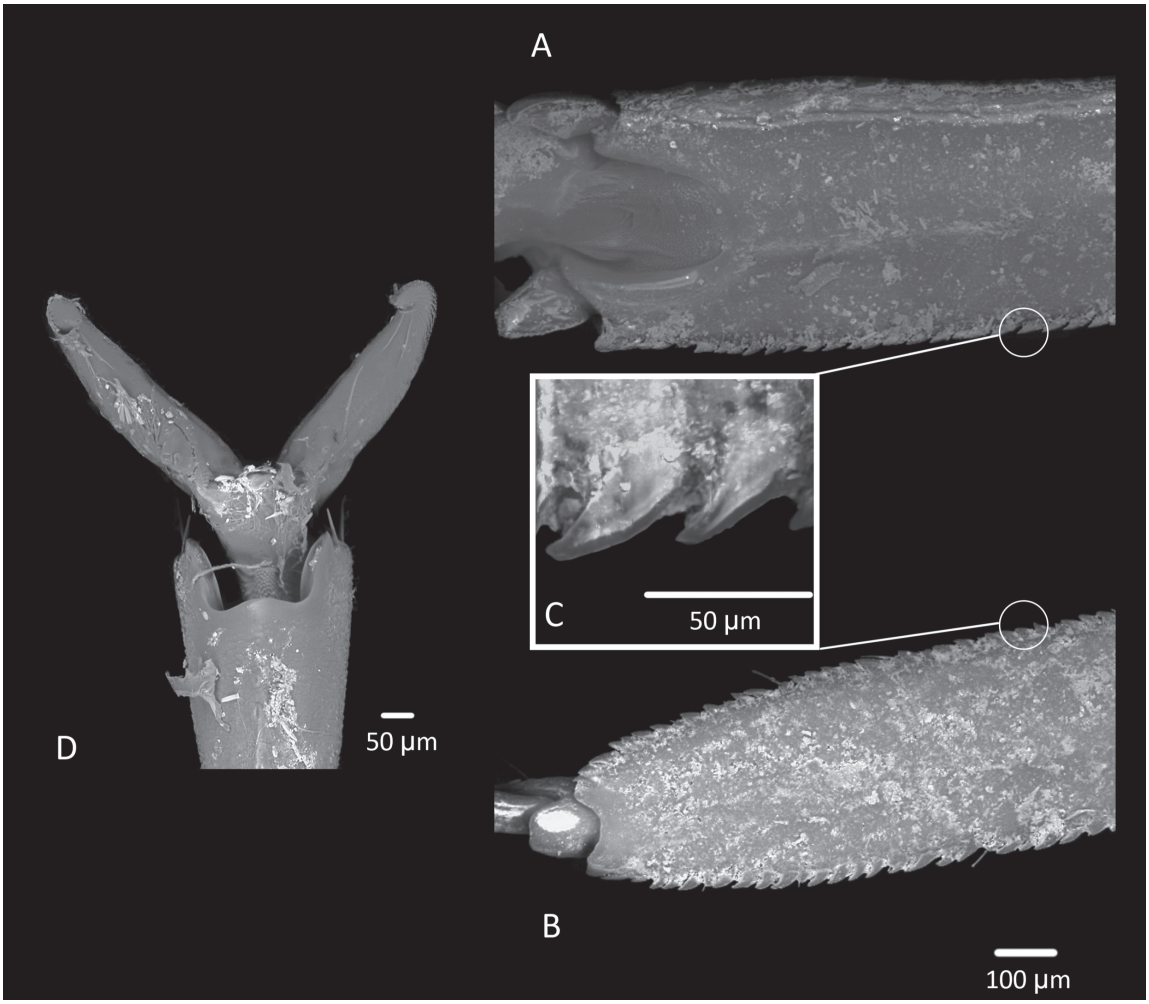

Fig. 4. Scanning electron micrographs of the hind leg of *S. gombakensis* in ventral view. **A.** Hind tibia; **B.** First tarsal segment; **C.** Magnified view of the serration lining the edges of both tibia and tarsal segment; **D.** Tarsal claw. Scale bars: 100 µm (**A, B**); 50 µm (**C, D**).

success rate when escaping from predators by diving underwater. Although individuals of various life stages can be found on the same rock, the place where *S. gombakensis* lays their eggs remains a mystery. For some *Scelimena* species, it is speculated that the eggs are laid elsewhere, such as in the sand along the riverbanks, and are perhaps well adapted to waterlogged conditions (Zha et al. 2017).

Physiology of Scelimena gombakensis *as key to adaptation to a semi-aquatic environment.*—Closer observation of the characteristics of the hind legs of *S. gombakensis* elucidates their swimming ability (Fig. 4). A close-up of the insect's hind tibia and its first tarsal segment under a scanning electron microscope (SEM) reveals the following hydrodynamic characters: the first tarsal segment is laterally compressed along the whole length, and serration exists along the lateral edges of both the first tarsal segments and the hind tibiae (Fig. 4A, B, C). The lateral compression provides a wider surface area for paddling underwater and likely aids in better propulsion during swimming. The serration along the lateral edges could serve multiple functions, but the tarsal serration most likely enhances the legs' grip on wet and slippery rock surfaces since the arolium is absent underneath the claws (Fig. 4D). Thus, the presence of microscopic serrations means porous rock surfaces offer more grip to the species' limbs. Morphologically similar to riblet-like shark skin, another possible function of the serrations is to improve hydrodynamics by reducing the water drag acting upon its serrated tibiae when propelling underwater, reducing the formation of vortices and making swimming more energy efficient. The orientation of both microscopic structures is also parallel to the flow of water, hinting at functional homology (Han et al. 2008, Zhang et al. 2011).

Our observations suggest that *S. gombakensis* utilizes both its hind legs and hindwings for navigation and survival, unlike *Scelimena songkrana* Zha & Wen, 2017 from Thailand, which seldom flies but often jumps, as described by Zha et al. (2017). On the other hand, *Scelimena melli* Günther, 1938 from China behaves similarly to *S. gombakensis* except for the fact that *S. melli* leaps further (for 10 meters or more). The mating behavior of *S. gombakensis* is consistent with that of other *Scelimena* (Zha et al. 2017), in which the male securely positions itself on top of the female.

Conclusions

Scelimeninae of Peninsular Malaysia is poorly known because few specimens have been collected in the region, and comprehensive taxonomic research of pygmy grasshoppers in the region is lacking. The short discussion on *Scelimena razalii* given in this paper has resulted in its synonymisation with *Falconius dubius*. The authors recognize only one valid species of the genus *Scelimena* as inhabiting the region, although further research is likely to result in the dis-

covery of new species. Likewise, *Scelimena gombakensis* was found to have a wider distribution range than originally considered, and it is expected that new localities will be discovered with further research. In this paper, we summarized a wide array of information concerning the ecology and physiology of *S. gombakensis* and provided comments and hypotheses that should serve as inspiration and motivation for further research of this genus in Peninsular Malaysia.

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