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Taxonomy and bioacoustics of scaly crickets (Orthoptera, Mogoplistidae, Mogoplistinae) from Borneo and Singapore

Running title: Mogoplistinae Singapore and Sabah

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Abstract

A species of scaly cricket is described here: *Ornebius lupus* **sp. nov.** from the mangrove forests in Singapore. *Ornebius pullus* Ingrisch, 2006 is recorded in eastern Sabah for the first time. The calling song of *Cycloptiloides bimaculatus* Tan et al., 2021 and *Ornebius pullus* from Sabah are described. We also revise the diagnosis of *Ectatoderus nigrofasciatus* Tan et al., 2021 from Brunei Darussalam.

Key words: calling song, diagnosis, new locality, new species, *Ornebius*, Southeast Asia

Introduction

Chopard pioneered the study of the taxonomy of Mogoplistinae —or commonly called the scaly crickets—in Southeast Asia (e.g., Chopard 1929, 1930, 1969). Since then, the taxonomy of scaly crickets from Southeast Asia has advanced considerably and many species are consequently discovered and described (Ingrisch, 1987, 1998, 2006; Tan & Ingrisch, 2013; Tan & Kamaruddin, 2013; Tan, 2014; Tan & Robillard, 2012; Tan et al., 2015, 2019, 2021; He et al., 2021). Only very recently, the bioacoustics of scaly crickets from this region was also investigated concertedly for the first time (Tan et al., 2022a under review).

Despite previous efforts to document the orthopteran diversity from the mangroves of Singapore (Tan & Robillard, 2012; Tan, 2013), we found another species of *Ornebius* from such a habitat which is new to science: *Ornebius lupus* **sp. nov.** We also examined new specimens of three species of scaly crickets from eastern Sabah: *Cycloptiloides bimaculatus* Tan et al., 2021, *Ectatoderus nigrofasciatus* Tan et al., 2021 and *Ornebius pullus* Ingrisch, 2006. The calling song of *Cycloptiloides bimaculatus* and *Ornebius pullus* from Sabah are described for the first time. New locality records for *Ornebius pullus* and *Cycloptiloides bimaculatus* in eastern Sabah are also reported. Lastly, we also revise the diagnosis of *Ectatoderus nigrofasciatus* from Brunei Darussalam.

Materials and Methods

Specimens from Sabah were collected during recent fieldwork (see Tan et al., 2022b). The specimens were preserved in absolute analytical-grade ethanol and later pinned and dry-preserved. Close-up images of morphological features (including male genitalia) were done using a macro photo lens MP-E 65 mm 1:2.8 USM (1–5×). Canon Macro Twin Lite MT24EX was used for lighting and flash. Image editing and line drawings were accomplished using Adobe Photoshop CC 2014. Measurements were done using ImageJ 1.51j8 (Wayne Rasband, Research Services Branch, National Institute of Mental Health, Bethesda, MD, USA). Terminology used to describe the male genitalia follows Ingrisch (2006).

A single leg was preserved in absolute analytic-grade ethanol for future molecular work. The specimens will eventually be deposited in:

FRC	Forest Research Centre (Sepilok), Sabah Forestry Department, East Malaysia
MNHN	Muséum national d'Histoire naturelle, Paris, France
ZRC	Zoological Reference Collection, Lee Kong Chian Natural History Museum, Singapore

Abbreviations for general morphology:

I, II, III = front, median, hind respectively (femora, legs, tibiae)

F = femur

FW = forewing (tegmen)

T = tibia

Ta = tarsus

MTa = metatarsus

Abbreviations for measurements:

BL = body length

PronL = pronotum length

PronW = pronotum width

FWL = forewing length

FWW = forewing width

FIIL = length of hind femur

TIIL = length of hind tibia

MTaIIL = length of hind metatarsus

The basic cricket song terminology follows Baker & Chesmore (2020) and Tan et al. (2022a). Analyses of the parameters of the temporal and frequency domains follow Tan et al. (2022a, b) using Raven Lite 2.0.0 and R software version 4.1.3.

Taxonomic Part

Superfamily Grylloidea Laicharting, 1781

Family Mogoplistidae Costa, 1855

Subfamily Mogoplistinae Costa, 1855

Cycloptiloides bimaculatus Tan, Japir & Chung, 2021

(Figs 1A, 2)

Cycloptiloides bimaculata Tan et al., 2021: 410

Cycloptiloides bimaculatus – Tan et al. 2022c: 600

Specimen examined. Holotype: EAST MALAYSIA • ♂; Sabah State, Sandakan, Sepilok, Rainforest Discovery Centre; N5.87580, E117.94299, 39.1±5.4 m.a.s.l.; 9 January 2019, 19h11; on the leaf litter; coll. M.K. Tan, R. Japir, M. Binti & J.L. Yukang; SDK.19.20 (FRC)

Additional specimens examined. EAST MALAYSIA • 1♂; Sabah State, Sandakan, Sepilok, Rainforest Discovery Centre; N5.87554, E117.94135, 54.5±6.1 m.a.s.l.; 11 May 2022, 20h58; on the leaf litter; coll. M.K. Tan & T. Robillard; SBH.22.19 (FRC) • 1♂; Sabah State, Sandakan, Sepilok, Rainforest Discovery Centre; N5.87416, E117.93786, 89.2±6.8 m.a.s.l.; 18 May 2022, 20h07; on the leaf litter; coll. M.K. Tan & T. Robillard; SBH.22.152 (MNHN) • 1♂; Sabah State, Sandakan, Sepilok, Rainforest Discovery Centre; N5.87328, E117.93749, 95.1±5.6 m.a.s.l.; 18 May 2022, 20h57; on the leaf litter; coll. M.K. Tan & T. Robillard; SBH.22.153 (FRC) • 1♂; Sabah State, Sepagaya Waterfall, near Lahad Datu; N4.98354, E118.14498, 182.4±7.4 m.a.s.l.; 13 May 2022, 11h39; on the leaf litter; coll. M.K. Tan & T. Robillard; SBH.22.50 (ZRC) • 1♂, 1♀; Sabah State, Mount Silam, lowland forest; N4.97589, E118.19060, 341 m.a.s.l.; 13 May 2022, 20h; on the leaf litter; coll. M.K. Tan & T. Robillard; TR22-10 (MNHN)

Distribution. Borneo, Sabah State: Sepilok, Sepagaya near Lahad Datu [new locality record]

Type locality. EAST MALAYSIA, Sabah State, Sepilok

Calling song (1 ♂, in captivity, 26.4°C) (Fig. 2). The calling song generally consists of a sequence of echemes which can be highly variable in duration (8–26 s). The echeme sequence typically begins with the echemes more erratic in terms of number of syllables, syllable durations and intervals. Each echeme is made up of

4–10 syllables (= pulses), and has an average duration of 140.9 ± 65.3 ms (78.0–249.1 ms). Consecutive echemes have an average interval of 371.6 ± 86.3 ms (285.6–474.3 ms). The average syllable duration is 14.1 ± 1.5 ms (11.9–15.6 ms) and the average interval between consecutive syllables is 7.2 ± 1.6 ms (5.4–9.7 ms). The dominant frequency is 8.34 kHz.

Compared to the continuous trill of *Cycloptiloides timah* Ingrisch, 2006 from Singapore (see Tan et al., 2022a), the calling song of *C. bimaculatus* also differs by a distinctly shorter syllable duration (14.1 ms in *C. bimaculatus* vs. 25.7 ms in *C. timah*) and by the intervals between consecutive syllables (7.2 ms vs. 104.5 ms). The dominant frequency is also distinctly lower (8.3 kHz vs. 9.1 kHz). It should be noted that the average temperature of the recordings for the two species are different (26.5°C in *C. bimaculatus* vs. 30.5°C in *C. timah*), which may have contributed partly to the differences in the call parameters between the two species.

***Ectatoderus nigrofasciatus* Tan & Wahab, 2021**

(Fig. 3)

Ectatoderus nigrofasciatus Tan et al., 2021: 412

Ectatoderus nigrofasciatus – Tan et al. 2022c: 600

Ectatoderus sp. – Tan & Wahab 2018: 132

Specimen examined. Holotype: BRUNEI DARUSSALAM • ♂; Belait District, Jalan Labi near Andulau Forest Reserve, N4.63354, E114.51047, 76.6 ± 5.0 m.a.s.l.; 7 July 2019, 20h42; on rattan foliage; coll. M.K. Tan; BRU.19.70 (UBDM)

Additional specimens examined. BRUNEI DARUSSALAM • 1♂; Temburong District, Kuala Belalong Field Studies Centre, along Sungei Mata Ikan, N4.54742, E115.15715, 73.8 ± 27.9 m.a.s.l.; 22 September 2016, 22h33; on a foliage of a tree after rain; coll. M.K. Tan; KB.16.4 (MHNH) • 1♂; Temburong District, Kuala Belalong Field Studies Centre, along Sungei Mata Ikan, N4.54733, E115.15720, 113.4 ± 14.2 m.a.s.l.; 23 September 2016, 19h00; on a foliage of a tree after rain; coll. M.K. Tan; KB.16.15 (ZRC)

Remarks. When *Ectatoderus nigrofasciatus* Tan et al., 2021 was first described, the basal part of the male genitalia of the holotype was not examined (Tan et al., 2021: Fig. 7). The apical part of the male genitalia, previously thought to be the complete genitalia, was considered to resemble that of *Ectatoderus argentatus* Ingrisch, 2006 from Thailand. However, after examining more specimens collected from Brunei Darussalam, it was found that the basal half of the male genitalia of *E. nigrofasciatus* has in fact the medial valve curved to a spiral. This character is more similar to that in *Ectatoderus angusticollis* Chopard, 1969 from Singapore (Fig. 3). Below, the diagnosis is revised accordingly.

Revised diagnosis. The species is characterised by the scapus being dorsally black, but ventrally and laterally brown, and the antennae being entirely black basally; the head has a distinct black band behind eyes; and the male phallic complex is very large and forming a spiral. The new species is most similar and closest in distribution to *E. angusticollis*. In both species, the pronotum is more strongly widening toward apex, and the TIs and TIIs are provided with black dorsal stripes. The male phallic complex is very similar to that of *E. angusticollis*, including the spiral-shaped medial valve and the shape of the ventro-external sclerite. The species differs from *E. angusticollis* by the male phallic complex being exceptionally larger despite of having equal body size (Fig. 3); the scapus and antennae being black (instead of testaceous); and the head being provided with a distinct black band behind eyes. The new species is also similar to *E. argentatus* having the pronotum strongly widening apically and the frons dark; it differs by the scapus and basal antennal segments being darkened instead of yellowish brown, and by the male phallic complex forming a spiral at base instead of being merely curved.

Distribution. Borneo, BRUNEI DARUSSALAM: Belait and Temburong [new locality record] Districts

Type locality. BRUNEI DARUSSALAM, Belait District, near Andulau Forest Reserve

***Ornebius pullus* Ingrisch, 2006**

(Figs 1B, 4, 5)

Ornebius pullus Ingrisch, 2006: 157

Ornebius pullus – He et al. 2021: 88 [assigning to species group *Ornebius (flori)* Ingrisch, 1998]; Tan et al. 2021: 416 [notes on new locality and variations with Singapore specimens]; Tan et al. 2022a: under review [calling songs from Singapore]

Ornebius cf. *pullus* – Tan 2012: 34; Tan & Ingrisch 2013: 25; Tan 2017: 55; Tan 2019: 335

Specimens examined. EAST MALAYSIA • 1 ♂; Sabah State, Tabin Wildlife Reserve; N5.19496, E118.50326, 117.1±10.3 m.a.s.l.; 15 May 2022, 22h17; on the branch of a small tree; coll. M.K. Tan, T. Robillard & R. Japir; SBH.22.95 (FRC)

Remarks. The specimen collected from Sabah exhibits some differences compared to *O. pullus* collected from Belait (Brunei Darussalam) and Singapore: legs with more whitish marmoration, supra-anal plate whitish when alive. However, we could not identify clear-cut differences in the genitalia, including both the sclerotized median valve and the membranous lateral valves between the specimen from Sabah and those from Brunei Darussalam (Fig. 5). As Tan et al. (2021) have also suggested that there might be a polymorphic species and that more evidence was needed (e.g., DNA or acoustics) to better understand the species boundaries. At the moment, the external morphology and genitalia morphology are not congruent between specimens from Brunei Darussalam, Singapore and Sabah; we also do not have acoustic data for the Brunei population; and no molecular data are available.

Furthermore, the specimen from Sabah also shares some similarities (but also with clear differences) in the external morphology of *Ornebius minusculus* (Chopard, 1929) from Sipura Island (Sumatra) (<http://coldb.mnhn.fr/catalognumber/mnhn/eo/ensif4531>), although the genitalia for this species has not been examined. As such, without more specimens from Sabah to examine variations, we refrained from describing it as a new species, tentatively identified it as *O. pullus* and preferred to revise its taxonomy when the chance arises.

Distribution. Brunei Darussalam (Belait and Brunei-Muara Districts), East Malaysia (Sabah State) [new locality record], Singapore.

Type locality. BRUNEI DARUSSALAM, Brunei-Muara District, near bridge over river Sungai Lubang Barus on road coming from Tutong.

Calling song (1 ♂, in captivity, 31.5°C) (Fig. 4). The calling song generally consists of a sequence of syllables (= pulses), which can be highly variable in duration (2–14 s or 4–25 syllables). The average syllable duration is 37.5±5.0 ms (31.0–46.0 ms) and the average interval between consecutive syllables is 501.2±20.4 ms (469.3–538.4 ms). The dominant frequency is 7.97±0.13 kHz (7.78–8.16 kHz).

Compared to the calling song of *Ornebius pullus* from Singapore (see Tan et al., 2022a), the calling song of this specimen from Sabah has a similar call structure (i.e., the calls of both species are made up of a sequence of syllables). The biggest difference is in the interval between consecutive syllables being distinctly longer (501.2 ms vs. 400.0 ms) than that from Singapore. The syllable is only marginally longer in duration on average (37.5 ms vs. 32.4 ms) and the dominant frequency is not different (8.0 kHz vs. 8.1 kHz).

***Ornebius lupus* Tan, sp. nov.**
(Figs 1C, 1D, 6, 7)

Ornebius sp. – Tan et al. 2022a: under review [calling songs from Singapore]

Specimens examined. Holotype: SINGAPORE • 1 ♂; Pasir Ris mangrove boardwalk; N1.37805, E103.95147; 19 March 2022, night time; on foliage of mangrove tree; coll. M.K. Tan; ZRC

Paratypes: SINGAPORE • 1 ♂; Pasir Ris mangrove boardwalk; N1.37805, E103.95147; 2 May 2022, night time; on foliage of mangrove tree; coll. M.K. Tan; MNHN-EO-ENSIF11343

Diagnosis. The new species has genitalia which appear most similar to those in the species group *Ornebius (rufonigrus)* Ingrisch, 1987, but differs by the dark-grey colouration; the maxillary palps being not so elongated (more similar to *Ornebius alvarezi* Tan, Ingrisch, Baroga-Barbecho & Yap, 2019 from the Philippines; elongated oblong in *Ornebius dumoga* Ingrisch, 2006 from Sulawesi and in *Ornebius consternus* Ingrisch, 2006 from Sulawesi), the FW colouration darker (orange in *O. dumoga* and in *Ornebius rufonigrus* Ingrisch, 1987 from Indochina and Malay Peninsula) and less covered by the pronotum (compared to *O. consternus*). The male genitalia of this new species differ from congeners from the species group by the internal sclerites at base being smaller instead of expanded.

We also compared the new species with other species currently not placed in any species group (i.e., with unknown male genitalia). Our species resembles species with wholly dark/ black or smoky FWs, such as *Ornebius obscuripennis* (Chopard, 1930) from Sarawak and *Ornebius fuscipennis* (Chopard, 1929) from Sumatra (including Padang, Pulau Sipura, Pulau Telo and Batu Islands). The new species differs from *O. obscuripennis* by the pronotal lateral lobe and lateral parts of the head being dark-grey (i.e., unicolorous with dorsal parts) instead of forming a yellow lateral band. It also differs from *O. fuscipennis* by much smaller body size (BL 8.4 vs. 10.5 mm; PL 2.8 vs. 4.5 mm; TL 2.5 vs. 2 mm; FIIL 4.4 vs. 7 mm); by the FW more uniformly coloured instead of smoky with posterior margin blackish; by the apical segment of the maxillary palps longer than subapical and third; by the pronotal disc not covered with yellow-brown scales; and by the legs that are not unicolourous yellowish.

Lastly, the new species also differs from a syntopic species, *Ornebius tampines* Tan & Robillard, 2012 by the overall body and FW colouration, the body shape is more typical of *Ornebius*, instead of slenderly built, the shape

of the male genitalia and by the calling songs (see Tan et al., 2022a). It is also somewhat similar to a sympatric species, *O. pullus* by the wholly black FWs, but differs by the lack of white margins along the lateral lobe and the posterior margin of the dorsal disc of the pronotum, by the shape of male genitalia and by the calling songs (see Tan et al., 2022a).

Etymology. The species name refers to the dark-grey colouration, resembling the grey-wolf, *Canis lupus*.

Description. Small species; habitus of male as shown in Fig 1C, 1D. Dorsum of head flattened, covered with dark-grey scales (Figs. 6A). Frontal rostrum 2.0 times wider than scapus (Fig. 6A). Scapus dark-grey (Fig 6A); basal antennal segments black, thereafter brown with some segments black (Figs 6B, 6C). Frons and mouthparts of dark colour (Fig. 6B). Maxillary palps pale grey; with apical (= fifth) segment longer than subapical (= fourth) segment, third segment of subequal length as subapical segment; apical segment pyriform (Fig. 6C). Lateral parts of head, including genae, of dark colour, without bands (Fig. 6C). Pronotal disc brown and wholly covered with dark-grey scales, about 1.3 times longer than wide, with anterior margin narrow and straight; lateral margin widening slightly posteriorly; covering only base of mirror of FW; posterior margin convex (Fig. 6D). Lateral lobe of pronotum also wholly covered with dark-grey scales (Figs 1D, 6C). TI with internal tympanum small and oval; without external tympanum. FIII 1.4–1.5 times longer than TIII; TIII 2.6 times longer than MTaIII. Femora generally pale, covered with marmoration of dark-grey scales except in basal parts. Tibiae and tarsi generally grey. Abdominal tergites covered with dark-grey scales; sternites pale. Abdominal apex darkened. Cercus covered with grey scales.

Male. FW mostly infumated black, dorsal field darkest at posterior margin (Fig. 6D); lateral field likewise in some areas with infumated white veins (Fig. 6E). Supra-anal plate with last abdominal tergite and epiproct distinctly separated by a transverse suture. Last abdominal tergite transverse, posterior margin abruptly indented in middle; with oval pale spot in middle (not obvious in dry-pinned specimen) (Fig. 6F vs. 6G); posterior margin on either side of the indentation with two patches of short and strong setae. Supra-anal plate less transverse than last abdominal tergite, black coloured, apex subtruncate (Figs 6F, 6G). Subgenital plate black (Fig. 6H). Paraproct process black, elongate, cylindrical and tapering into a subacute apex (Fig. 6H). Genitalia as in Fig. 7. Central lobe of phallus with lateral valves (lv) elongate, apical area curved slightly ventrad in lateral view; tapering into obtuse apex, in apical area with inner margin curved in dorsal view; both sides together almost forming a dorsally and ventrally open tube. External sclerite (es) well developed, with external part more strongly sclerotized than inner part (in dorsal view). Medial valve (mv) membranous with base widened (in dorsal view) and upcurved (in lateral view). Internal sclerites (is) at base small but widened and curled, afterwards straight and elongate.

Female. Unknown.

Measurements (2♂, in mm). ♂ Holotype: BL = 8.4; PronL = 2.8; PronW = 2.2; FWL = 2.5; FWW = 2.3; FIIL = 4.4; TIIL = 3.1; MIIL = 1.2. ♂ paratype: BL = 8.4; PronL = 2.8; PronW = 2.2; FWL = 2.5; FWW = 2.3; FIIL = 4.4; TIIL = 2.9; MIIL = 1.1.

Ecology. This species is found among foliage of mangrove trees, occurring in syntopy with another mangrove-specialist, *Ornebius tampines*.

Distribution. SINGAPORE

Type locality. SINGAPORE, Pasir Ris mangrove

Calling song. Described in Tan et al. (2022a). The calling song of this species is similar to that of *Ornebius rufonigrus* Ingrisch, 1987 from the same species group with regard to echeme duration and dominant frequency, although the new species produces echeme-sequences composed of triple-chirps instead of double-chirps as in *O. rufonigrus*.

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Figure captions

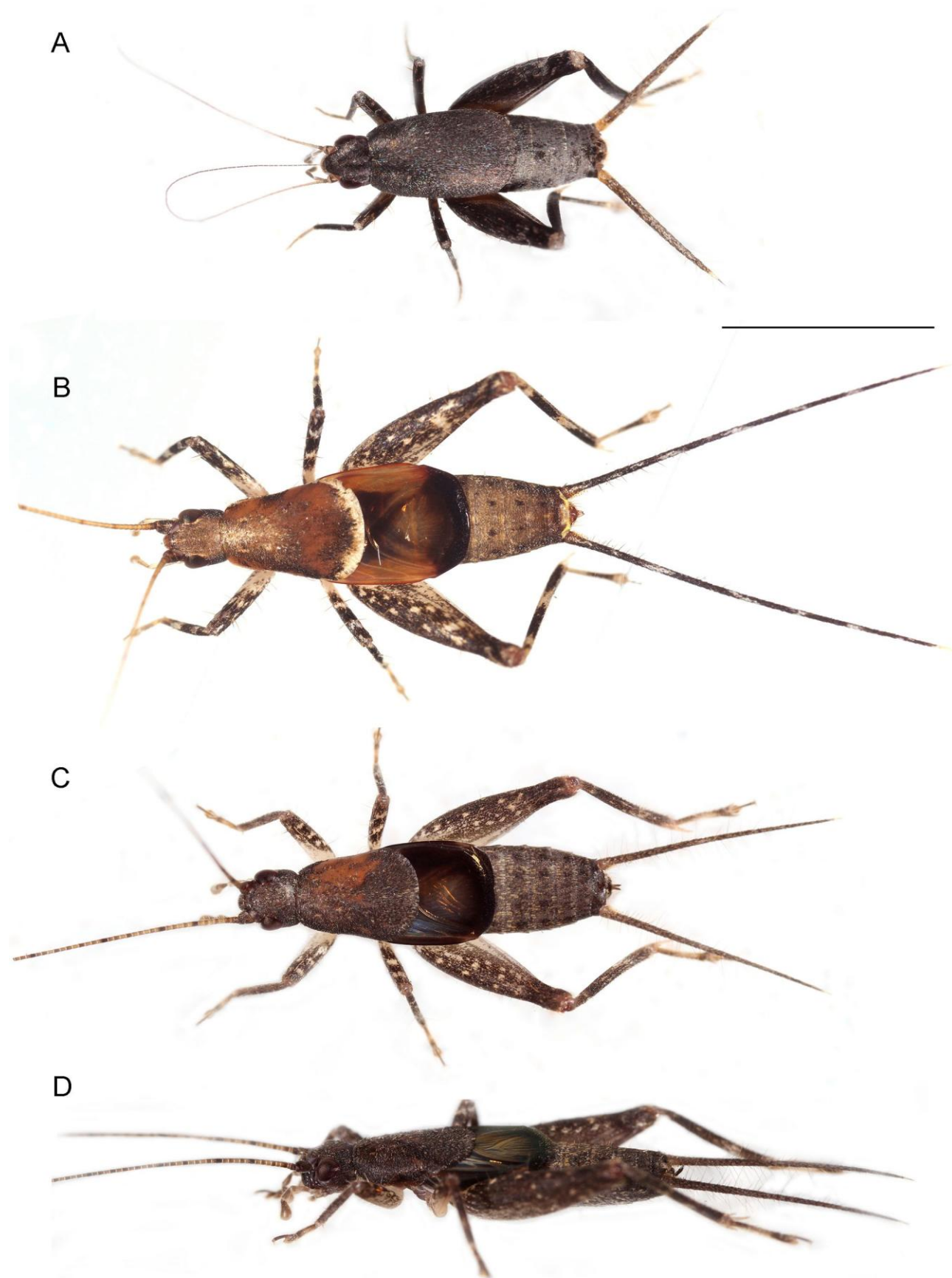


FIGURE 1. ♂ habitus of *Cycloptiloides bimaculatus* Tan et al., 2021(A), *Ornebius pullus* Ingrisch, 2006 (B) and *Ornebius lupus* sp. nov. (C, D) in dorsal (A–C) and dorso-lateral view (D). Scale bar: 5 mm.

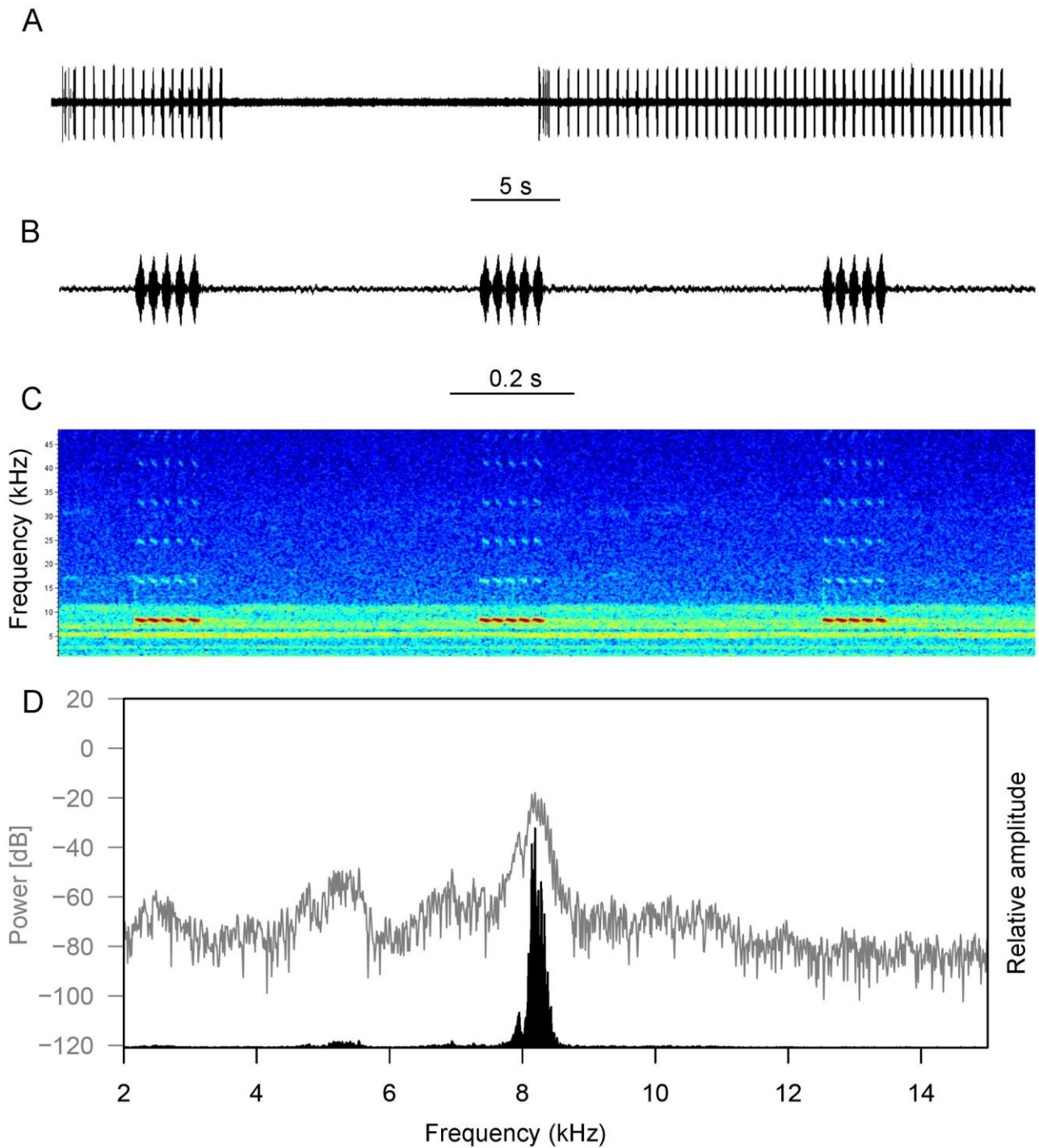


FIGURE 2. *Cycloptiloides bimaculatus* Tan et al., 2021 ♂ calling song: oscillograms showing two echeme-sequences (A) and three echemes (B); spectrogram of the same echemes (C); power spectra of a syllable (D) where the grey line represents the power [dB] (axis name and scale in grey) and the black solid peak represents the relative amplitude (axis name in black).

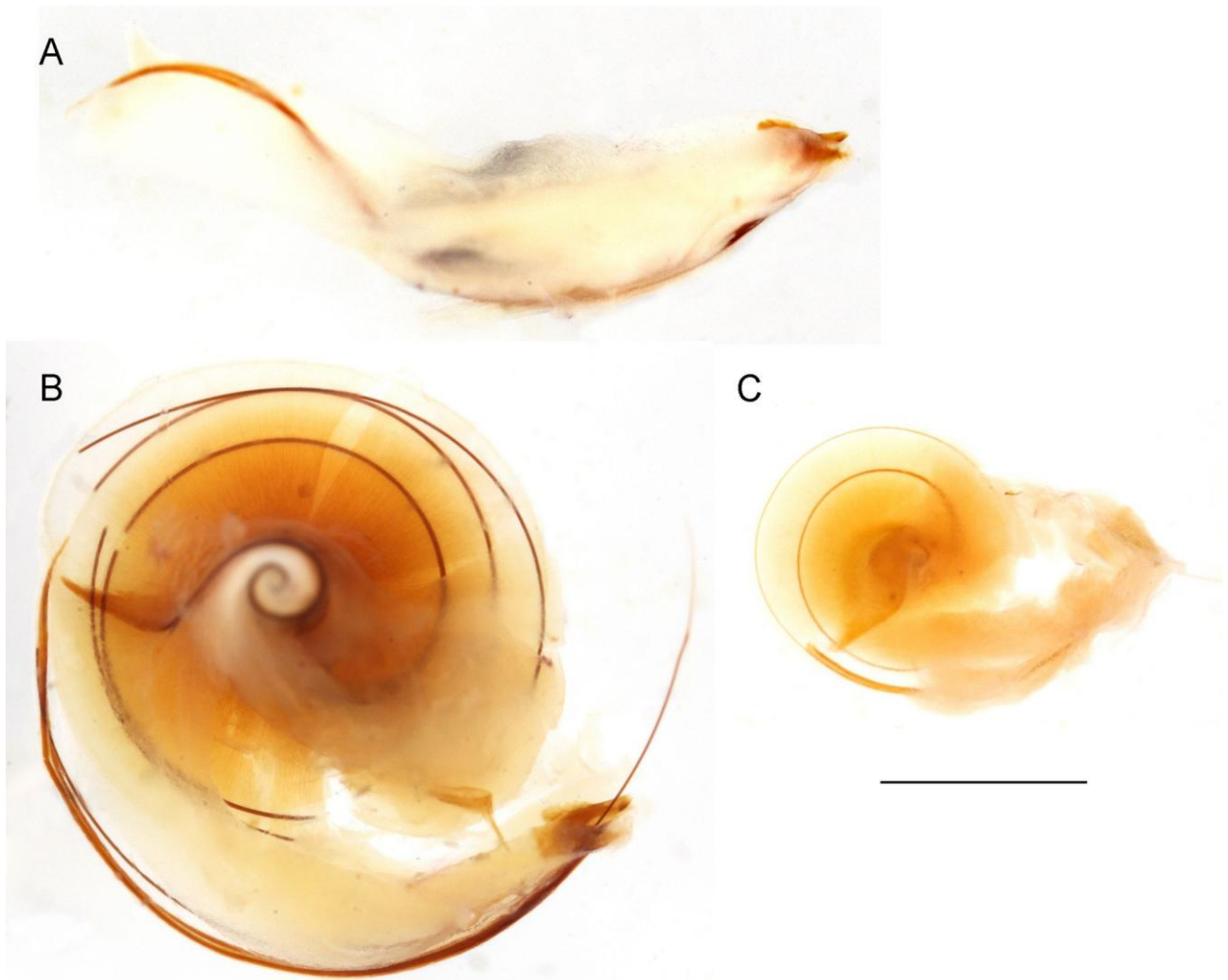


FIGURE 3. ♂ genitalia of *Ectatoderus nigrofasciatus* Tan et al., 2021 (A, B) and *Ectatoderus angusticollis* Chopard, 1969 (C). (A) shows only the apical half of the genitalia of the holotype. Scale bar: 1 mm.

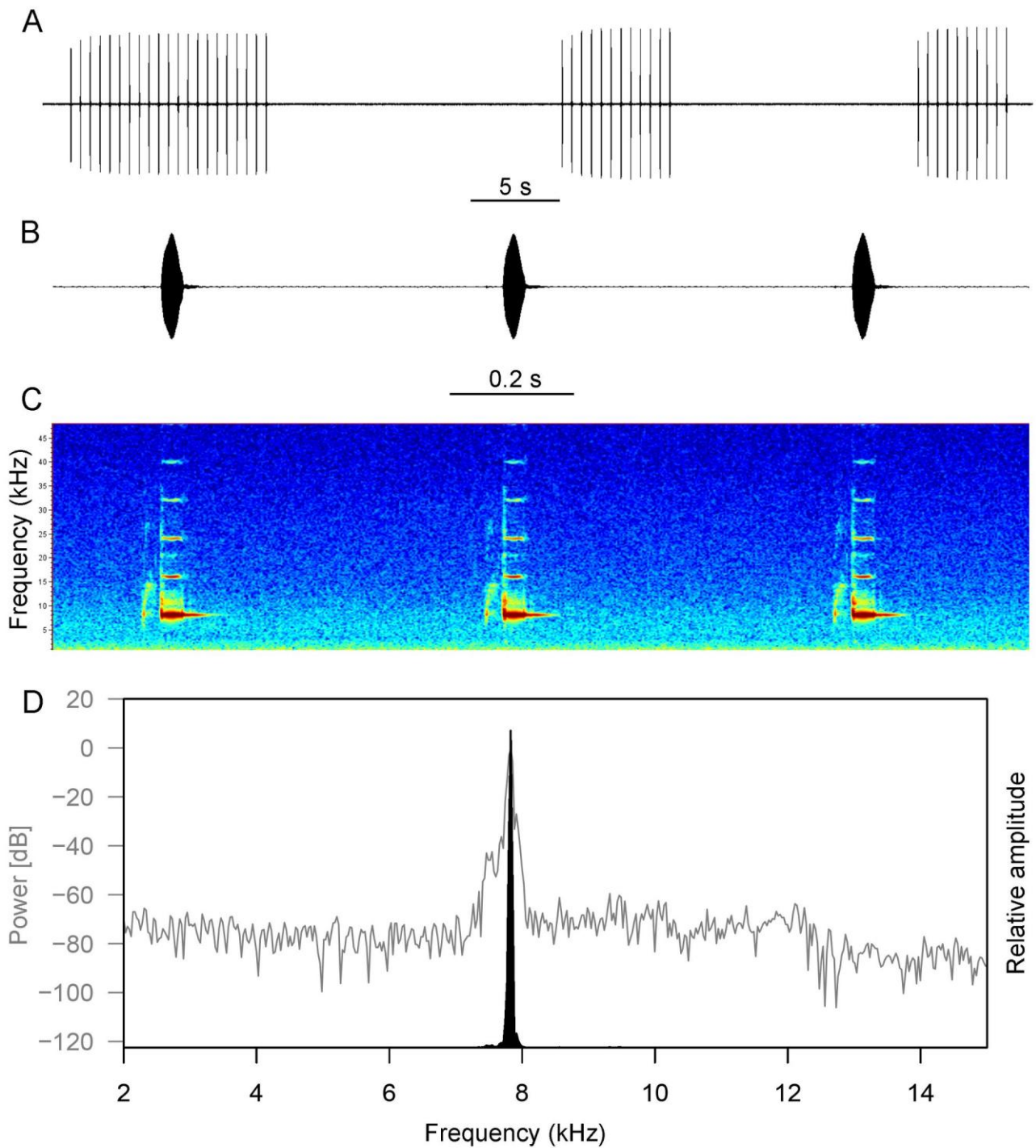


FIGURE 4. *Ornebius pullus* Ingrisch, 2006 ♂ calling song: oscillograms showing three echemes (A) and three syllables (B); spectrogram of the same syllables (C); power spectra of a syllable (D) where the grey line represents the power [dB] (axis name and scale in grey) and the black solid peak represents the relative amplitude (axis name in black).

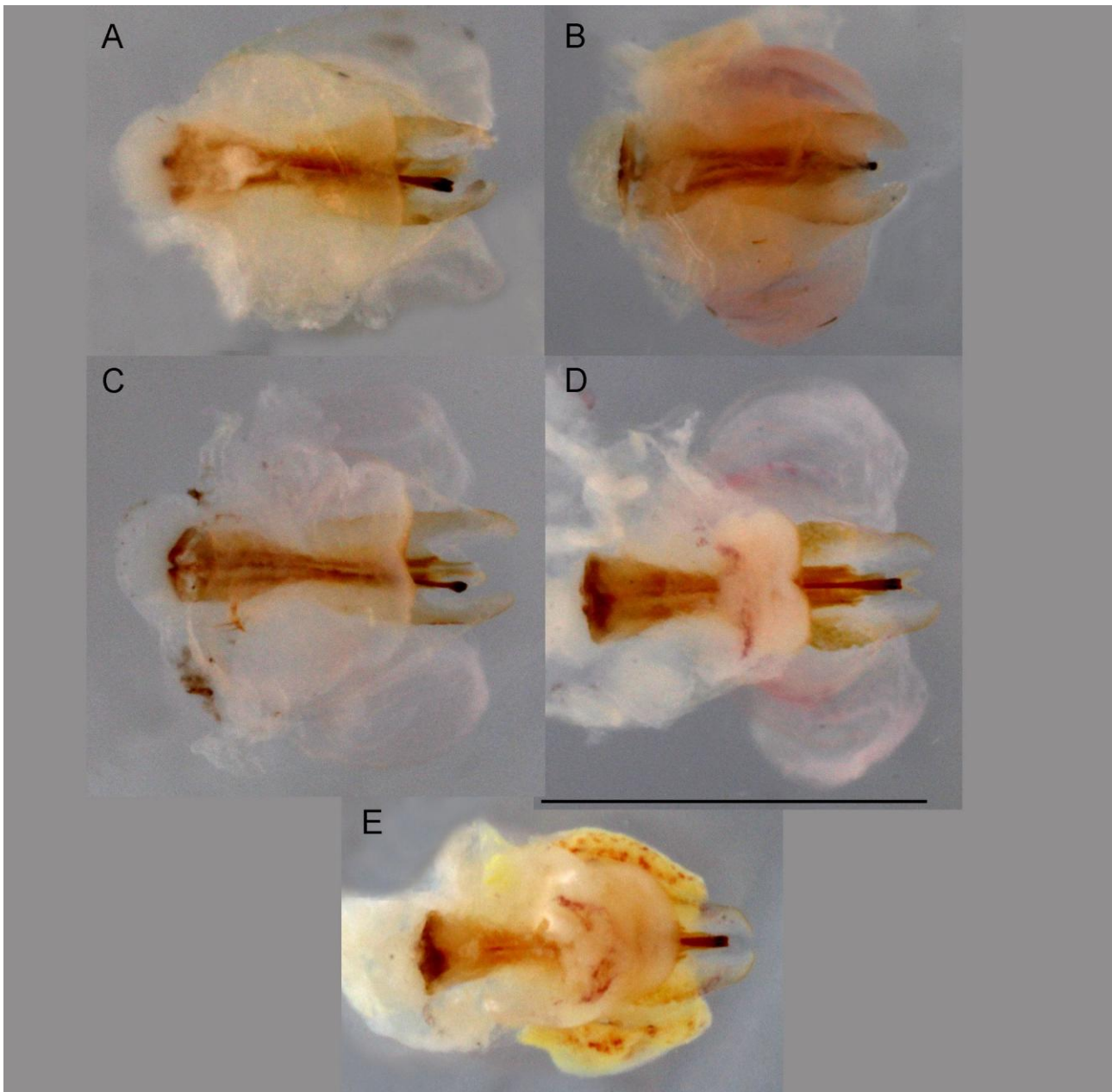


FIGURE 5. *Ornebius pullus* Ingrisch, 2006 male genitalia of specimen from Singapore (A), Belait (Brunei Darussalam) (B, C) and Sabah (D, E). Genitalia were cleaned with KOH (A–D) and with membraneous parts still present after dissection (E). The genitalia of the respective specimens were ordered according to the FWs colouration: the specimen from Singapore has a wholly black/ dark FW, followed by specimens from Belait (dark brown FW with a black posterior band) and specimen from Sabah (brown FW with a black posterior band). Scale bar: 1 mm.

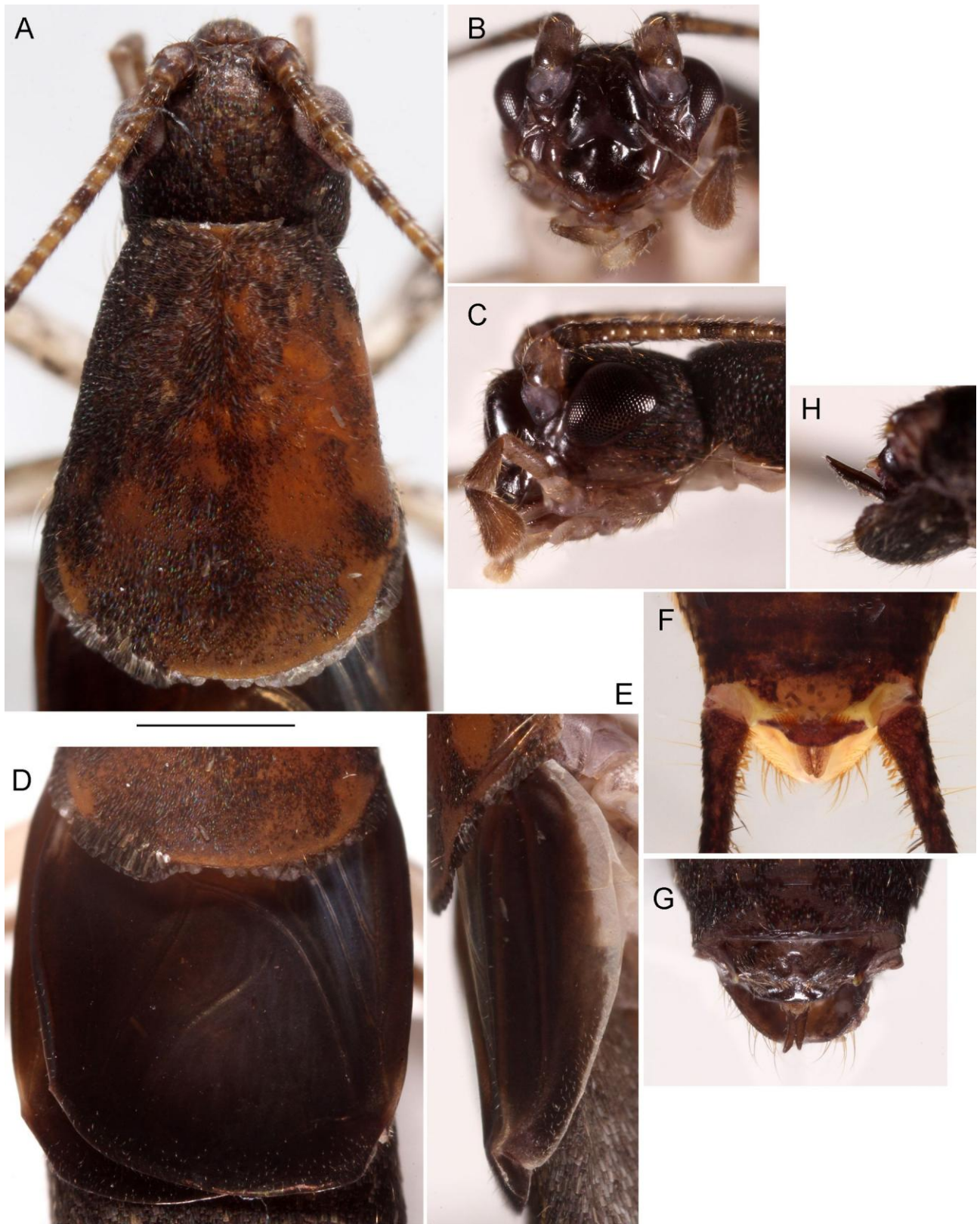


FIGURE 6. *Ornebius lupus* **sp. nov.** ♂ holotype: head and pronotum in dorsal view (A); head in anterior (B) and lateral (C) views; FWs in dorsal (D) and lateral (E) views; abdominal apex in dorsal (F, G) and lateral (H) views. (F) shows the specimen preserved in ethanol and (G) shows the specimen dry-pinned. Scale bar: 1 mm.

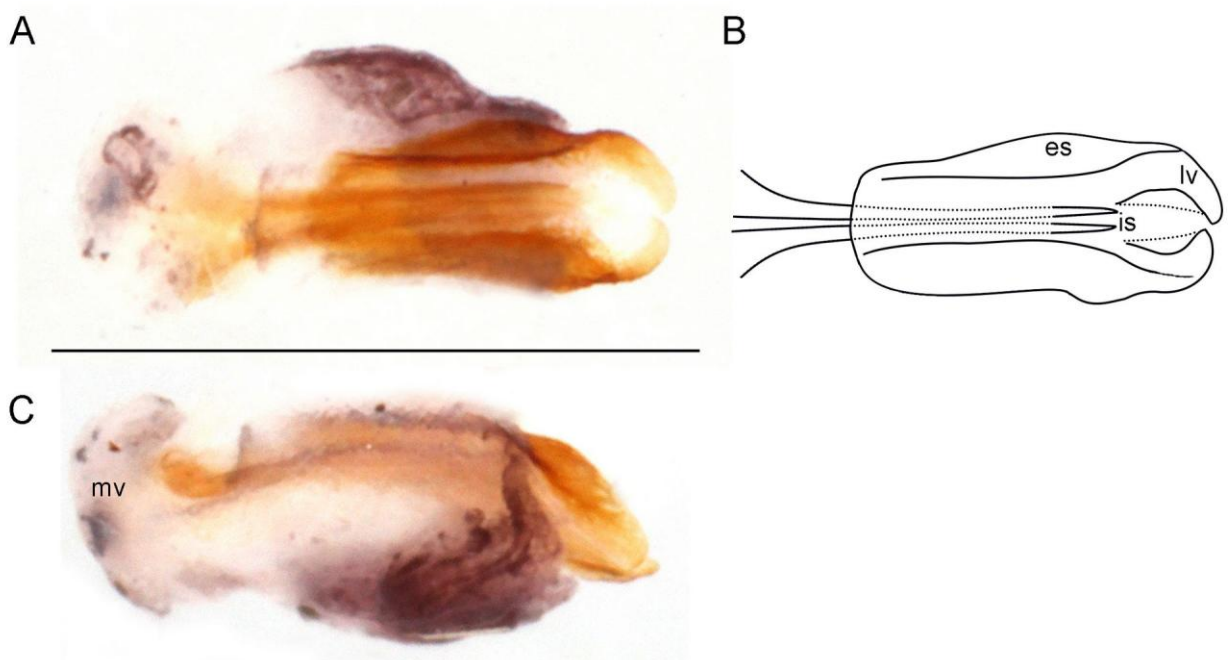


FIGURE 7. *Ornebius lupus* **sp. nov.** ♂ holotype genitalia in dorsal (A, B) and lateral (C) views. es = external sclerite, is = internal sclerite, lv = lateral valve, mv = medial valve. Scale bar: 1 mm.