HOKKAIDO UNIVERSITY

Title	Zorotypus in Peninsular Malaysia (Zoraptera: Zorotypidae), with the description of three new species
Author(s)	MASHIMO, YUTA; YOSHIZAWA, KAZUNORI; ENGEL, MICHAEL S. et al.
Citation	Zootaxa, 3717(4), 498-514 https://doi.org/10.11646/zootaxa.3717.4.4
Issue Date	2013-10
Doc URL	https://hdl.handle.net/2115/54885
Type	journal article
File Information	2013zora.pdf

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Authors: Mashimo, Y., Yoshizawa, K., Engel, M.S., Idris, A. B., Dallai, R., Beutel, R.G., Machida, R.

Corresponding author: Ryuichiro Machida (mail: machida@sugadaira.tsukuba.ac.jp)

Running title: Zoraptera from Peninsular Malaysia.

This paper includes 8 figures and 40 cited references.

Higher taxon: Insecta, Miscellaneous orders (Zoraptera)

Number of new taxa: 3 species (genus *Zorotypus*)

Zorotypus in Peninsular Malaysia (Zoraptera: Zorotypidae), with the description of three new species

Yuta Mashimo[1], Kazunori Yoshizawa[2], Michael S. Engel[3], Idris Abd. Ghani[4], Romano Dallai[5], Rolf G. Beutel[6], Ryuichiro Machida*[,1]

[1] Sugadaira Montane Research Center, University of Tsukuba, Sugadaira Kogen, Ueda, Nagano 386-2204, Japan

[2] Systematic Entomology, Hokkaido University, Sapporo, Hokkaido 060-8589, Japan

[3] Division of Invertebrate Zoology, American Museum of Natural History; Division of Entomology (Paleoentomology), Natural History Museum, and Department of Ecology & Evolutionary Biology, 1501 Crestline Drive – Suite 140, University of Kansas, Lawrence, Kansas 66045, U.S.A.

[4] School of Environmental and Natural Resource Sciences, Faculty of Sciences and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

[5] Department of Life Sciences, University of Siena, Via A. Moro 2, I-53100 Siena, Italy

[6] Institut für Spezielle Zoologie und Evolutionsbiologie mit Phyletischem Museum, Friedrich-Schiller-Universität Jena, Erbertstraße 1, 07743 Jena, Germany

***Corresponding author**

Tel.: +81-268-74-2002; fax: +81-268-74-2016

E-mail address: machida@sugadaira.tsukuba.ac.jp (R. Machida)

Sugadaira Montane Research Center, University of Tsukuba, Ueda, Nagano 386-2204, Japan

Abstract

Three new species of the uncommonly encountered insect order Zoraptera are described and figured from Peninsular Malaysia – *Zorotypus magnicaudelli* **sp.n.**, *Zorotypus cervicornis* **sp. n.**, and *Zorotypus impolitus* **sp. n.** Another species from the region, identified as *Zorotypus caudelli* Karny, 1927, was also collected and is re-evaluated herein based on new material. A brief discussion of characters used in zorapteran systematics is provided, and key to the species of Peninsular Malaysia provided. This is the first report for the order Zoraptera from Peninsular Malaysia.

Introduction

Few insect lineages are more generally unfamiliar than those species comprising the order Zoraptera. Zorapterans are small, generally less than 4 mm in length, and inconspicuous, living subcortically in decaying logs throughout the tropical and subtropical zones. Species superficially resemble barklice (Psocoptera) or even termites (Isoptera) and are gregarious, often living in loose colonies of up to 150 individuals (Engel 2009, 2012, in press). Serious inquiry into the order has been long neglected, although some significant advances have been made during the turn of the century, particularly in terms of their paleontology (*e.g*., Engel & Grimaldi 2000, 2002, Grimaldi & Engel 2005, Engel 2008), morphology (*e.g*., Beutel & Weide 2005, Friedrich & Beutel 2008, Dallai *et al*. 2011, 2012a, b, Mashimo *et al*. 2011), and taxonomy (*e.g*., Engel 2000, 2003, 2007, Engel & Grimaldi 2000, 2002, Rafael & Engel 2006, Rafael *et al*. 2008). Although phylogenetic relationship of Zoraptera to other insects remains controversial, their polyneopteran affinities are largely confirmed (*e.g*., Yoshizawa & Johnson, 2005, Yoshizawa 2007, 2011, Ishiwata et al., 2011, Simmon et al., 2012, Wang *et al*. 2013).

There is little doubt that the diversity of these cryptic insects remains underexplored. Prior to the present study, 36 extant species of Zoraptera have been described (Terry & Whiting 2012, Engel in press), all classified in the genus *Zorotypus*

Silvestri (Engel & Grimaldi 2000). Some authors have favored the use of a multigeneric system for living zorapterans and for which various names are available (*e.g.*, Chao & Chen 2000, Kukalová-Peck & Peck 1989); however, the validity of these groups is disputable (*e.g.*, Engel & Grimaldi 2000). Moreover, the extreme morphological homogeneity of non-genital features and the low specific diversity of the order demonstrate that the erection of multiple living genera is superfluous, and that a more conservative classification is warranted (Engel & Grimaldi 2000, 2002, Engel 2003). The only other genus that is presently considered valid is the Early Cretaceous *Xenozorotypus* Engel & Grimaldi (2002) which exhibits some distinctive external differences from all other species in the order.

Herein we provide a brief overview of zorapteran diversity from Peninsular Malaysia. Four species were recovered from the fauna, three of which were new, while the fourth was *Zorotypus caudelli* Karny, 1927, originally described from southern Sumatra (Karny 1922, 1927) but also known from eastern Malaysia (New 2000). *Zorotypus caudelli* is apparently one of the most common zorapterans in Peninsular Malaysia, and we provide a re-evaluation of the species in the context of the newly described species. Contrary to the prevailing opinion that Zoraptera are rare or highly endemic, with many species described from merely a few specimens, we discovered

zorapterans at all localities during a survey of Peninsular Malaysia. This revelation matches well with other reports of some species being relatively widespread and, with hunting in appropriate habitats, that their scarcity is illusory (*e.g.*, New 2000, Engel 2001, in press, Hinojosa-Díaz *et al*. 2006, Engel & Falin 2008). Indeed, in suitably tropical areas zorapterans are apparently rather common, and the true diversity of the order likely remains to be discovered. Therefore, we hope that the present contribution will stimulate collectors and researchers to focus more clearly on this minute, sadly ignored, but greatly fascinating order of insects. The new species described herein raises the number of extant Zoraptera to 39, and with the fossil species included, the ordinal diversity rises to 48.

Materials and methods

Specimens were preserved in 80% ethanol. For observation of particular anatomical structures, material was placed in a 10% KOH solution at room temperature for 1 h, then washed with distilled water and returned to 80% ethanol for storage. Antennae, mouthparts, and legs were dissected and slide-mounted with Euparal. A Nikon OPTIPHOT light microscope was used principally for examination and illustration of morphological details. Following Engel (2008), we have used the terms

apteron for individuals of the apterous morph, *alate* for fully winged individuals with developed compound eyes and ocelli, and *deälate* for those alates who have shed their wings.

Type depositories are abbreviated as follows: UKM (Universiti Kebangsaan Malaysia, Bangi, Malaysia), SMRC (Sugadaira Montane Research Center, Ueda, Japan), SEHU (Laboratory of Systematic Entomology, Hokkaido University, Sapporo, Japan). All holotypes are deposited in UKM.

Systematics

Genus *Zorotypus* Silvestri

***Zorotypus caudelli* Karny (Figs. 1, 2, 5)**

'*Zorotypus* aus Wai Lima'; Karny, 1922: 14–29.

Zorotypus caudelli Karny, 1927: 1–5; New, 2000: 77–82; Mashimo *et al*., 2011: 230–237; Dallai *et al*., 2011: 531–547; Dallai *et al*., 2012: 51–63.

Zorotypus sp. MY1: Yoshizawa & Johnson, 2005: 579; Yoshizawa, 2011: 384.

Zorotypus.325: Yoshizawa, 2010: Supplementary data.

Revised description. **Apteron male**. Body length *ca.* 2 mm (exclusive of antennae), color glossy brown except membranous regions and yellowish white cercus; head

subtriangular, slightly wider than pronotum, with whitish area in posterolateral corner; cephalic chaetotaxy as depicted in Figure 1A; compound eyes and ocelli absent; antennae 9-segmented, distal three antennomeres paler (Fig. 5A), antennomere I slightly curved outward, antennomere II faintly curved, short, about one-half length of antennomere III, antennomeres III–IX longer than wide, length of each subequal to that of antennomere I (Fig. 5A); both mandibles with five apical teeth and well-developed molar region (Fig. 5B, B'). Pronotum subrectangular, slightly narrowed posteriorly; mesonotum trapezoidal, slightly shorter than pronotum; metanotum trapezoidal, distinctly wider than long, shorter than mesonotum; thorax sparsely setose as depicted in Figure 1C. Legs with setae of moderate length; tibiae and tarsi of all legs paler in color; anterior surface of profemur broadly setose, posterior and dorsal surfaces covered with setae of moderate length only distally; protibia covered with setae of moderate length, bristles arranged like a comb in distal half along ventral surface, two apical spurs; mesofemur slightly narrower than profemur, anterior surface broadly setose, posterior and dorsal surfaces covered with setae of moderate length on distal half and several short setae on proximal half; mesotibia covered with setae of moderate length, two apical spurs; metafemur broader than profemur, more swollen proximally than distally as in Figure 5D, anterior surface broadly setose, posterior and dorsal surfaces

covered with setae of moderate length on distal half and several short setae on proximal half, ventral surface with four long stout bristles (Fig. 5D); metatibia covered with setae of moderate length, with two apical spurs. Abdominal terga 1 to 6 (T1–6) with a single transverse row of four to six setae of moderate length and a few lateral, short setae on each side of midline (Fig. 2A); T7 with a single transverse row of one long erect seta and three moderate-length setae, and a few short setae laterally on each side of midline (Fig. 2A); T8 with a single transverse row of one short seta, two long erect setae, and four moderate-length setae on each side of midline (Fig. 2A); T9 short, with anterior trapezoidal expansion extending beneath T8 (Fig. 2A, B); T10 posteromedially incised, with several moderate-length setae on each side of midline, one pair of stout setae near incision (Fig. 2B); T11 with small median upcurved projection (= male mating hook) and two lateral, subtriangular sclerites, several moderate-length setae on each sclerite (Fig. 2B); epiproct and paraproct unsclerotized; cercus unsegmented, oval, with one long apical seta, three or four subapical moderate-length setae, several short setae, and very long, fine setae (Fig. 2A); surface covered with numerous minute spicules except at base and apex (too minute to be included in drawing); sternum 1 (S1) scarcely sclerotized; S2 weakly sclerotized (Fig. 2D); S3 with a single transverse row of several moderate-length setae (Fig. 2D); S4–5 with a single transverse row of four to six

moderate-length setae on each side of midline (Fig. 2D); S6–7 with two transverse rows of moderate-length setae, anterior row with several setae, posterior row with five or six setae on each side of midline (Fig. 2D); S8 (hypandrium) wider than long, with evenly scattered, moderate-length setae, two longer setae on posterior margin on each side of midline (Fig. 2D); S9 trapezoidal, with small, fine setae; posterior margin with two moderate-length setae on each side of midline (Fig. 2D); S10 invaginated beneath S9, not visible externally; S11 with two lateral sclerites, each with small setae (Fig. 2B). Genitalia symmetrical (Fig. 5E); basal plate well sclerotized, posteriorly bifurcate, with long, anterior tongue-like process; flagellum long, sclerotized, coiled; aedeagus with hook (Fig. 5E).

Apteron female. General features correspond to those of males, except for the following: T10 not posteromedially incised, with three or four setae of moderate length on each side of midline (Fig. 2C); T11 evenly sclerotized, not divided into two halves (hemitergites), with small scattered setae and a pair of paramedian setae of moderate length apically (Fig. 2C); S2 well sclerotized, with a pair of small setae apically (Fig. 2E); S3 with a single transverse row of six moderately long and short setae of on each side of midline (Fig. 2E); S8 (hypandrium) extensive, sparsely covered with setae of moderate length, posteromedially with irregular round membranous region; S9 short

and roughly trapezoidal; basad, bifurcate projection extending beneath S8 (Fig. 2F), several small setae and two pairs of setae of moderate length along posterior margin (Fig. 2C, E).

Alate. General features as with those of apteron except for the following: body glossy, blackish brown; compound eyes and three black ocelli present (Fig. 1B). Mesonotum indistinctly divided into slightly pointed prescutum, large mesoscutum and smaller mesoscutellum (Fig. 1D). Wings as shown in Figure 5C.

Materials examined. Two apteron male, 2 apteron female, 1 deälate male, 1 deälate female, Selangor, Ul Gombak (altitude: *ca*. 200-400 m) and Rawang (altitude: *ca*. 100 m), 10-12 IV 2011, coll. Y. Mashimo & R. Machida. Two apteron male, 2 apteron female, 1 alate female, 1 deälate male, Perak, Tapha (altitude: *ca*. 400-900 m), 13 IV 2011, coll. Y. Mashimo & R. Machida. Four apteron male, 2 apteron female, Pahan, Bukit Fraser, 6 III 2003, coll. K. Yoshizawa. 1 apteron male, 4 apteron female, Pahan, Endau, 9 VII 2003, coll. K. Yoshizawa. Apteron and alate specimens were collected under the bark of rotting wood.

***Zorotypus magnicaudelli* Mashimo, Engel, Dallai, Beutel, & Machida, sp. n. (Fig. 6)**

Type series. Holotype, apteron male, **MALAYSIA:** Cameron Highland, Gunung

Brinchang (altitude: *ca.* 1,800 m), 13 IV 2011, coll. Y. Mashimo & R. Machida (UKM). Paratypes, 7 apteron male, 6 apteron female, 1 alate female, 1 deälate male, same data as holotype (UKM, SMRC, SEHU). Apteron and alate specimens were collected under the bark of rotting wood.

Diagnosis. This species closely resembles *Z. caudelli* but can be distinguished from that species by the following features: body size approximately 1.5 times larger; six to eight long, stout bristles on ventral surface of metafemur *vs*. only four in *Z. caudelli* (Figs. 5D and 6D); and basal plate of male genitalia much more robust than in *Z. caudelli* (*cf*. Figs. 5E and 6E).

Etymology. The specific epithet is combination of the Latin term *magnus* (meaning, "great") and *caudelli*, and is a reference to its larger relative size.

Apteron male. Body length *ca*. 3.5 mm (exclusive of antennae), color glossy brown except for membranous regions and yellowish white cercus; head subtriangular, slightly wider than pronotum, with whitish area in posterolateral corner, with evenly scattered moderate-length setae; compound eyes and ocelli absent; antennae 9-segmented, distal three antennomeres paler (Fig. 6A), antennomere I slightly curved outward, antennomere II weakly curved, short, about one-half length of antennomere III, antennomeres III–IX longer than wide, length of each subequal to that antennomere I

(Fig. 6A); both mandibles with five apical teeth and well-developed molar region (Fig. 6B, B'). Pronotum subrectangular, slightly narrowed posteriorly; mesonotum trapezoidal, slightly shorter than pronotum; metanotum trapezoidal, distinctly wider than long, shorter than mesonotum; thorax with evenly scattered, moderate-length setae. Legs with moderately-long setae; tibiae and tarsi of all legs paler in color; anterior surface of profemur broadly setose, posterior and dorsal surfaces covered with moderately-long setae distally; protibia with moderate-length setae, bristles arranged as comb in distal half along ventral surface, two stout setae ventroapically; mesofemur slightly narrower than profemur, anterior surface with broad setose area, posterior and dorsal surfaces with setae of moderate length on distal half and several short setae on proximal half; mesotibia with setae of moderate length and two apical spurs; metafemur broader than profemur, more swollen proximally than distally as in figure 6D, anterior surface broadly setose, posterior and dorsal surfaces with setae of moderate length on distal half and several short setae on proximal half, ventral surface with six to eight long, strong bristles (Fig. 6D); metatibia with setae of moderate length and two apical spurs. Abdominal T1–6 with a single transverse row of four to six moderate-length setae and a few short lateral setae on each side of midline; T7 with a single transverse row of one long erect seta and three moderate-length setae, and a few short lateral setae on each

side of midline; T8 with a single transverse row of one short seta, two long erect setae, and four moderate-length setae on each side of midline; T9 short, with anterior trapezoidal expansion extending beneath T8; T10 posteromedially incised, with several moderate-length setae on each side of midline, one pair of stout setae near incision; T11 with small median upcurved projection (= male mating hook) and two lateral, subtriangular sclerites, several moderate-length setae on each sclerite; epiproct and paraproct unsclerotized; cercus unsegmented, oval, with one long apical seta, three or four subapical moderate-length setae, several short setae, and very long and fine setae; surface covered with numerous minute spicules except base and apex (too minute to be included in drawing); S1 scarcely sclerotized; S2 weakly sclerotized; S3 with a single transverse row of several moderate-length setae; S4–5 with a single transverse row of four to six moderate-length setae on each side of midline; S6–7 with two transverse rows of moderate-length setae, anterior row composed of several setae, posterior row of five or six setae on each side of midline; S8 (hypandrium) wider than long, with moderate-length setae evenly scattered and two longer setae on posterior margin on each side of midline; S9 trapezoidal, with small, fine setae; posterior margin with two moderate-length setae on each side of midline; S10 invaginated beneath S9, not visible externally; S11 with two lateral sclerites, each with small setae. Genitalia symmetrical

(Fig. 6E); basal plate well sclerotized, with broad, robust, anterior tongue-like process, and posteriorly bifurcated; with long, sclerotized, coiled flagellum; aedeagus hooked (Fig. 6E).

Apteron female. General features as in male except as follows: Abdominal T10 not posteromedially incised, with three or four moderate-length setae on each side of midline; T11 uniformly sclerotized, not divided into halves (*i.e.*, not divided into hemitergites), with small setae and a pair of moderate-length setae; S2 well sclerotized with a pair of small setae; S3 with a single transverse row of six short or moderately long setae on each side of midline; S8 (hypandrium) extensive, sparsely covered with moderate-length setae, posteromedially with round membranous region; S9 short trapezoidal; bifurcated basad projection present extending beneath S8, several small setae and two pairs of moderate-length setae along posterior margin.

Alate. General features as in apteron except for the following: body glossy with blackish brown coloration. Compound eyes and three black ocelli present. Mesonotum indistinctly divided into slightly pointed prescutum, large mesoscutum, and smaller mesoscutellum. Wings as in Figure 6C, C'.

***Zorotypus cervicornis* Mashimo, Yoshizawa, & Engel, sp. n. (Fig. 7)**

Zorotypus sp. MY2: Yoshizawa & Johnson, 2005: 579.

Zorotypus.328: Yoshizawa, 2010: Supplementary data.

Type series. Holotype, apteron male, **MALAYSIA:** Pahang, Endau, 9 VII 2003, coll. K. Yoshizawa (UKM). Paratypes, 8 apteron male, 11 apteron female, same data as holotype (UKM, SEHU, SMRC).

Diagnosis. This species resembles *Z. caudelli* and *Z. magnicaudelli* but can be distinguished from both by the following features: paler body color, six long stout bristles on ventral surface of metafemur (*versus* different number in the other two species); antler-shaped basal plate of male genitalia; female anteromedian projection of S9 not bifurcated.

Etymology. The specific epithet is combination of the Latin terms *cervis* (deer) and *cornis* (horn), and is a reference to the antler-shaped basal plate of the male genitalia.

Description. Apteron male. Body length *ca*. 2.5 mm (exclusive of antennae), color glossy, yellowish brown except membranous regions and yellowish white cercus; head subtriangular, slightly wider than pronotum, with whitish area in posterolateral corner; with moderate-length setae evenly scattered; compound eyes and ocelli absent; antennae 9-segmented, distal three antennomeres paler (Fig. 7A), antennomere I slightly curved outward, antennomere II faintly curved, short, about one-half length of antennomere III, antennomeres III–IX longer than wide, length of each subequal to that antennomere I

(Fig. 7A); both mandibles with five apical teeth and well-developed molar region (Fig. 7B, B'). Pronotum subrectangular, slightly narrowed posteriorly; mesonotum trapezoidal, slightly shorter than pronotum; metanotum trapezoidal, distinctly wider than long, shorter than mesonotum; thorax with moderate-length setae evenly scattered. Legs with moderate-length setae; tibiae and tarsi of all legs paler in color; anterior surface of profemur broadly setose, posterior and dorsal surfaces covered with moderate-length setae only distally; protibia with moderately long setae, bristles arranged as comb in distal half along ventral surface, with two apical spurs; mesofemur slightly narrower than profemur, anterior surface broadly setose, posterior and dorsal surfaces with moderate-length setae on distal half and several short setae on proximal half; mesotibia with moderate-length setae and two apical spurs; metafemur broader than profemur, more swollen proximally than distally as in Figure 7C, anterior surface with broad setose area, posterior and dorsal surfaces covered with moderate-length setae on distal half and several short setae on proximal half, ventral surface with five or six long stout bristles (Fig. 7C); metatibia with moderate-length setae and two apical spurs. Abdominal T1–6 with a single transverse row of four to six moderate-length setae and a few short lateral setae on each side of midline; T7 with a single transverse row of one long erect seta and three moderately long setae, and a few short lateral setae on each

side of midline; T8 with a single transverse row of one short seta, two long erect setae, and four moderate-length setae on each side of midline; T9 short, with anterior trapezoidal expansion beneath T8; T10 posteromedially incised, with several moderate-length setae on each side of midline and one pair of stout setae near incision; T11 with small median upcurved projection (male mating hook) and two lateral, subtriangular sclerites each with several moderately long setae; epiproct and paraproct unsclerotized; cercus unsegmented, oval, with one long apical seta, three or four subapical setae of moderate length, several short setae, and very long and fine setae; surface covered with numerous minute spicules except base and apex (too minute to be included in drawing); S1 scarcely sclerotized; S2 weakly sclerotized; S3 with a single transverse row of several moderately long setae; S4–5 with a single transverse row of four to six moderate-length setae on each side of midline; S6–7 with two transverse rows of moderate-length setae, anterior row with several setae, posterior one with five or six setae on each side of midline; S8 (hypandrium) wider than long, with moderate-length setae evenly scattered, and two longer setae on posterior margin on each side of midline; S9 trapezoidal, with small, fine setae; posterior margin with two pairs of moderately long setae; S10 invaginated beneath S9, not visible externally; S11 with two lateral sclerites (hemitergites), each with small setae. Genitalia symmetrical

(Fig. 7D); basal plate well sclerotized with short, broad anterior tongue-like process, posterior region bifurcated into long, paired branches, each bearing two small projections; long, sclerotized, coiled flagellum present; aedeagus hooked (Fig. 7D).

Apteron female. General features as in male except as follows: abdominal T10 posteromedially not incised, with three or four pairs of moderate-length setae; T11 uniformly sclerotized, not divided into hemitergites, with several small setae and a pair of moderate-length setae; S2 well sclerotized, with a pair of small setae; S3 with a single transverse row of six moderately long or short setae on each side; S8 (hypandrium) extensive, sparsely covered with moderate-length setae, posteromedially with round membranous region; S9 short and trapezoidal, anteromedian part extended anteriorly, not bifurcated, several small setae and two pairs of moderate-length setae along posterior margin (Fig. 7E).

~~**Remarks.** Yoshizawa & Johnson (2005) used this species as source for both morphological and genetic datamaterials, designating it as Zorotypus sp. MY2.~~

***Zorotypus impolitus* Mashimo, Engel, Dallai, Beutel, & Machida, sp. n. (Figs. 3, 4, 8)**

Type series. Holotype, apteron male, **MALAYSIA:** Selangor, Ul Gombak (altitude: *ca*.

200-400 m), 10 IV 2011, coll. Y. Mashimo & R. Machida (UKM). Paratypes, 3 apteron male, 3 apteron female, 1 alate female, same data as holotype (SEHU, SMRC, UKM). Apteron and alate specimens were collected under the bark of rotting wood.

Diagnosis. This species is similar to *Z. sinensis* and *Z. medoensis* but can be distinguished from them by the following: body size distinctly smaller, 2 mm *vs*. 3–4 mm; long stout bristles on ventral surface of metafemur, proximal 1st and 3rd bristles longer than others *vs*. more distad bristles shorter; male hypandrium without posterior extension of posteromedial part; and in the shape of the male genitalia (*cf*. Hwang 1976: Figs. 3–6).

Etymology. The specific epithet is based on the Latin *impolitus*, referring to the unpolished brown coloration of the body.

Description. Apteron male. Body length *ca.* 2 mm (exclusive of antennae), color mat brown except membranous regions and yellowish white cercus; head subtriangular, slightly wider than pronotum, with whitish area in posterolateral corner; cephalic chaetotaxy as in Figure 3A, curly setae grouped on vertex (likely associated with fontanelle gland as in males of some other species); compound eyes and ocelli absent; antennae 9-segmented, distal three antennomeres paler (Fig. 8A), antennomere I slightly curved outward, antennomere II faintly curved, short, about one-half length of

antennomere III, antennomeres III–IX longer than wide, length subequal to that of antennomere I (Fig. 8A); both mandibles with five apical teeth and well-developed molar region (Fig. 8B, B'). Pronotum subrectangular, slightly narrowed posteriorly; mesonotum trapezoidal, slightly shorter than pronotum; metanotum trapezoidal, distinctly wider than long, shorter than mesonotum; thorax setose as in Figure 3B. Legs with moderate-length setae; tibiae and tarsi of all legs paler in color; anterior surface of profemur covered with short setae, posterior and dorsal surfaces covered with moderate-length setae; protibia with moderate-length setae, bristles arranged as comb in distal half along ventral surface, with two apical spurs; mesofemur slightly narrower than profemur, anterior surface broadly setose, posterior and dorsal surfaces covered with moderate-length setae only distally; mesotibia covered with moderate-length setae and two apical spurs; metafemur broader than profemur, more swollen proximally than distally as in Figure 8D, anterior surface broadly setose, posterior and dorsal surfaces with moderate-length setae on distal half and several short setae on proximal half, ventral surface with eight or nine stout bristles, proximal first and third bristles longer than others (Fig. 8D); metatibia with moderate-length setae and two apical spurs. Abdominal tergal chaetotaxy as in Figure 3D; T1 with a single transverse row of short setae, and a few small setae laterally (Fig. 3D); T2–7 with regular vestiture of numerous

setae of short and moderate length and a pair of longer setae along posterior margin (Fig. 3D); T8 with numerous fine, small setae, three pairs of moderate-length setae and a pair of long, erect setae (Figs. 3D, 4B); T9 short, scarcely sclerotized (Figs. 3D, 4C); anterior half of T10 sclerotized, posterior half membranous; with numerous fine, small setae and median spatula-like, upcurved projection (Figs. 3D, 4B; asterisk in Fig. 4C); T11with long and strongly upcurved median projection and two smaller, lateral sclerites each bearing three or four moderate-length setae (Figs. 3D, 4B; star in Fig. 4C); epiproct and paraproct unsclerotized (Fig. 4B); cercus unsegmented, conical, with one long apical seta, three or four subapical moderate-length setae, several short setae, and very long and fine setae (Fig. 3D), surface covered with numerous minute spicules except base and apex (too minute to be included in drawing); chaetotaxy of sterna as in Figure 4A; S1 scarcely sclerotized; S2 weakly sclerotized with two or three short setae on each side (Fig. 4A); S3–4 with two transverse rows of short setae (Fig. 4A); S5 with short setae evenly scattered and a pair of scarcely sclerotized circular areas (Fig. 4A); S6–7 with evenly scattered short setae (Fig. 4A); S8 (hypandrium) wider than long, with evenly scattered, moderate-length setae (Fig. 4A) and a pair of longer setae (Fig. 4B); S9 fused to S8; S10 invaginated beneath S8+9, not visible externally; S11 with two lateral subtriangular sclerites (hemitergites), each with several setae of short and

moderate length (Fig. 4B). Genitalia asymmetrical, without elongate coiled flagellum and well defined basal plate; dorsal sclerite weakly sclerotized, with anterior end curved; middle sclerite twisted and curved; spatula-like ventral sclerite present beneath middle sclerite (Fig. 8E).

Apteron female. Generally as in male except as follows: Head without curly setae grouped on vertex. Abdominal T10 uniformly sclerotized with four or five setae on each side and a pair of setae of moderate length (Fig. 4E); T11 uniformly sclerotized, with small setae and a pair of setae of moderate length (Fig. 4E); S8 and 9 not fused; S8 (hypandrium) wider than long, with short setae evenly scattered and two pairs of moderate-length setae, posteromedially with round membranous region (Fig. 4D); S9 short and trapezoidal; several small setae and two pairs of moderate-length setae along posterior margin (Fig. 4D).

Alate. General features as in apterous form except as follows: unpolished, blackish brown coloration. Compound eyes and three black ocelli present. Mesonotum indistinctly divided into slightly pointed prescutum, large mesoscutum, and smaller mesoscutellum (Fig. 3C). Wings as in Figure 8C, C'.

Key to species of Zorotypus *in Peninsular Malaysia*

1. Mat brown in coloration; abdominal T2–6 covered with short setae; S5 with a pair of weakly sclerotized circular areas …… *Zorotypus impolitus* **sp. n.**

—. Glossy brown in coloration; abdominal T2–6 with a single transverse row of moderately-long setae; S5 without weakly sclerotized circular areas ……2

2. Male genitalia with posterior region bifurcate, forming slender, paired branches; female S9 with anteromedian projection not bifurcated ……..…*Zorotypus cervicornis* **sp. n.**

—. Male genitalia with posterior region bifurcated, forming stout, paired branches; female S9 with anteromedian projection bifurcated ……...…… 3

3. Body size *ca.* 2 mm; male genitalia with long, slender anterior tongue-like process ……..…… *Zorotypus caudelli*

—. Body length much greater than 3 mm; male genitalia with broad, robust anterior tongue-like process …… *Zorotypus magnicaudelli* **sp. n.**

Discussion

We examined and considered a broad spectrum of structures but with focused in particular on the shape of the basal antennomeres, the chaetotaxy of the ventral

surface of the metafemur, and the structure of the male genitalia, characters traditionally recognized as useful for classifying Zoraptera. The first two of these character sets (shape of antennomeres and chaetotaxy) have little variation between closely related species (*e.g.*, Hwang 1974, 1976, Paulian 1949, 1951), and are therefore of limited use for separating or circumscribing species with close phylogenetic affinities. Nevertheless, such traits may be phylogenetically relevant for reconstructing relationships of broader subgroups across *Zorotypus*. In contrast, it has been noted repeatedly, and not surprisingly, that closely related species with very similar external features can be clearly discriminated based on the male genitalia (Gurney 1938, Paulian 1949, 1951, Hwang 1974, 1976, New 1978, Rafael & Engel 2006, Rafael *et al*. 2008). This certainly has held true for *Z. caudelli* and *Z. magnicaudelli* **sp. n.**, which although quite similar externally, differed distinctly in their male genitalia (*vide supra*). In clades such as Zoraptera with overall uniform general morphology, a detailed investigation of male genitalia is obviously indispensable for unambiguous circumscription of species.

Dallai *et al*. (2011, 2012a, b) noted that zorapterans exhibit an extraordinary degree of variation in reproductive morphology and spermatozoan structure, in striking contrast to the overall uniform external morphology, apparently as a result of different selective pressures on these character systems. This observation correlates with

profound differences in reproductive behavior and strategy. *Zorotypus caudelli*, *Z. magnicaudelli* **sp. n.**, and *Z. cervicornis* **sp. n.** share a unique form of male genitalia, *i.e*., with a strongly elongate and coiled flagellum. So far this condition is known only for *Z. cramptoni* Gurney, 1938, *Z. gurneyi* Choe, 1989, *Z. hamiltoni* New, 1978 and *Z. snyderi* Caudell, 1920. We assume as a working hypothesis that this represents a complex synapomorphy of these species and predict that they likely exhibit a similar reproductive behavior. They share not only the coiled flagellum but also similar forms in other portions of the male postabdomen. It appears plausible that these seven species comprise a clade within *Zorotypus*, but confirmation by a formal character analysis is required. Unfortunately, the presently available morphological (and molecular) data are insufficient and much basic biodiversity (*i.e*., taxonomic, behavioral) work is needed across the order before meaningful analyses can be conducted and hypotheses formulated.

Choe (1997) made a detailed study on the mating behavior of Zoraptera using two American species *Zorotypus gurneyi* and *Zorotypus barberi*, and parallel to the present study Dallai *et al*. (in prep.) carried out a study on the mating behavior in the species treated here. It is desirable that similar observations on zorapterans from other regions (*e.g*., Africa, South America) be carried out, in combination with detailed

morphological and molecular studies. For a robust evolutionary interpretation of the intriguing dualism in Zoraptera, *i.e.,* highly conservative general morphology *versus* strikingly variable genitalic system and mating behavior, a well-founded, species-level phylogeny for the order is critical (*e.g.*, Engel 2003). Even though inquiry into the Zoraptera has increased greatly in recent years, much remains to be undertaken. Although zorapterans are typically inconspicuous, they are nevertheless an intriguing group, the study of which may eventually help to unravel several fascinating evolutionary mechanisms and perhaps serve as a model for investigating similar phenomena in other insect lineages.

Acknowledgments

We are grateful to Drs. M. Fukui, H. Kojima, S. Nomura, K. Sekiya, T. Uchifune, Y. Uchifune, Messrs. M. Fujita, Y. Nakagaki, S. Shimizu, S. Tomizuka, Kim Hong Yap, and Shahrul Nazly B. Mahmud for their assistance in collecting material. This study was supported by a Sasakawa Scientific Research Grant (22-504) from The Japan Science Society to YM and a Grant-in-Aid from the JSPS (Scientific Research C: 21570089) to RM. KY's field work was supported by a Grant-in-Aid from the JSPS (Scientific Research (A) (2): 14255016, project leader: O. Yata). This is a contribution from the Sugadaira Montane Research Center, University of Tsukuba.

References

Beutel, R.G. & Weide, D. (2005). Cephalic anatomy of *Zorotypus hubbardi* (Hexapoda: Zoraptera): New evidence for a relationship with Acercaria. *Zoomorphology*, **124**, 121–136.

Caudell, A.N. (1920). Zoraptera not an apterous order. *Proceedings of the Entomological Society of Washington*, **22**, 84–97.

Chao, R.-F. & Chen, C.-S. (2000). *Formosozoros newi*, a new genus and species Zoraptera (Insecta) from Taiwan. *Pan-Pacific Entomologist*, **76**, 24−27.

Choe, J.C. (1989). *Zorotypus gurneyi*, new species, from Panama and redescription of *Z. barberi* Gurney (Zoraptera: Zorotypidae). *Annals of the Entomological Society of America*, **82**, 149–155.

Choe, J.C. (1997). The evolution of mating systems in the Zoraptera: Mating variations and sexual conflicts. *In*: Choe, J.C. & Crespi, B.J. (Eds.), *The evolution of mating systems in Insects and Arachnids*. Cambridge University Press, Cambridge, pp. 130–145.

Dallai, R., Mercati, D., Gottardo, M., Machida, R., Mashimo, Y. & Beutel, R.G. (2011). The male reproductive system of *Zorotypus caudelli* Karny (Zoraptera): Sperm structure and spermiogenesis. *Arthropod Structure & Development*, **40**, 531–547.

Dallai, R., Mercati, D., Gottardo, M., Dossey, A.T., Machida, R., Mashimo, Y. & Beutel, R.G. (2012). The fine structure of the female reproductive system of *Zorotypus caudelli* Karny (Zoraptera). Arthropod Structure & Development, **41**, 51–63.

Dallai, R., Mercati, D., Gottardo, M., Dossey, A.T., Machida, R., Mashimo, Y. & Beutel, R.G. (2012). The male and female reproductive systems of *Zorotypus hubbardi* Caudelli, 1918 (Zoraptera). *Arthropod Structure & Development*, **41**, 337–359.

Engel, M.S. (2000). A new *Zorotypus* from Peru, with notes on related Neotropical species (Zoraptera: Zorotypidae). *Journal of the Kansas Entomological Society*, **73**, 11–20.

Engel, M.S. (2001). New neotropical records for three *Zorotypus* species (Zoraptera: Zorotypidae). *Entomological News*, **112**, 278–280.

Engel, M.S. (2003). Phylogeny of the Zoraptera. *Entomologische Abhandlungen*, **61**, 147–148.

Engel, M.S. (2007). The Zorotypidae of Fiji (Zoraptera). *Occasional Papers of the Bernice P. Bishop Museum*, **91**, 33–38.

Engel, M.S. (2008). A new apterous *Zorotypus* in Miocene amber from the Dominican

Republic (Zoraptera: Zorotypidae). *Acta Entomologica Slovenica*, **16**, 127–136.

Engel, M.S. (2009). Zoraptera. *In*: Resh, V.H. & Cardé, R.T. (Eds.), *Encyclopedia of Insects* [2nd Edition]. Academic Press, New York, pp. 1069–1070.

Engel, M.S. (2012). Zoraptera. *In*: *McGraw-Hill Encyclopedia of Science and Technology. Vol. 19* [11th Edition]. McGraw-Hill, New York, pp. 841–842.

Engel, M.S. (in press). Zoraptera. *In*: Roig-Juñent, S., Claps, L.E. & Morrone, J.J. (Eds.), *Biodiversidad de Artrópodos Argentinos. Vol. 3*. Sociedad Entomológica Argentina, Buenos Aires, Argentina.

Engel, M.S. & Falin, Z.H. (2008). The zorapteran *Zorotypus huxleyi* in Guyana (Zoraptera: Zorotypidae). *Journal of the Kansas Entomological Society*, **81**, 394–395.

Engel, M.S. & Grimaldi, D.A. (2000). A winged *Zorotypus* in Miocene amber from the Dominican Republic (Zoraptera: Zorotypidae), with discussion on relationships of and within the order. *Acta Geologica Hispanica*, **35**, 149–164.

Engel, M.S. & Grimaldi, D.A. (2002). The first Mesozoic Zoraptera (Insecta). *American Museum Novitates*, **3362**, 1–20.

Friedrich, F. & Beutel, R.G. (2008). The thorax of *Zorotypus* (Hexapoda, Zoraptera) and a new nomenclature for the musculature of Neoptera. *Arthropod Structure and Development*, **37**, 29–54.

Grimaldi, D.A. & Engel, M.S. (2005). *Evolution of the Insects*. Cambridge University Press, Cambridge, UK, xv+755 pp.

Gurney, A.B. (1938). A synopsis of the order Zoraptera, with notes on the biology of *Zorotypus hubbardi* Caudell. *Proceedings of the Entomological Society of Washington*, **40**, 57–87.

Hinojosa-Díaz, I.A., Bonaccorso, E. & Engel, M.S. (2006). The potential distribution of *Zorotypus hubbardi* Caudell (Zoraptera: Zorotypidae) in North America, as predicted by ecological niche modeling. *Proceedings of the Entomological Society of Washington*, **108**, 860–867.

Hwang, F.-S. (1974). *Zorotypus chinensis*, a new species from China. *Acta Entomologica Sinica*, **17**, 423–427. [in Chinese, English summary].

Hwang, F.-S. (1976). A new species of Zoraptera. *Acta Entomologica Sinica*, **19**, 225–227. [in Chinese, English summary].

Karny, H.H. (1922). Zorapteren aus Süd-Sumatra. *Treubia*, **3**, 14–29.

Karny, H.H. (1927). Spolia Mentawiensia. Zoraptera. *Treubia*, **9**, 1–5.

Kukalová-Peck, J. & Peck, S.B. (1989). Zoraptera wing structures: Evidence for new genera and relationship with the blattoid orders (Insecta: Blattoneoptera). *Systematic Entomology*, **18**, 333–350.

Mashimo, Y., Machida, R., Dallai, R., Gottardo, M., Mercati, D. & Beutel, R.G. (2011). Egg structure of *Zorotypus caudelli* Karny (Insecta, Zoraptera, Zorotypidae). *Tissue and Cell*, **43**, 230–237.

New, T.R. (1978). Notes on neotropical Zoraptera, with descriptions of two new species. *Systematic Entomology*, **3**, 361–370.

New, T.R. (2000). Zoraptera (Insecta) in east Malaysia: notes on *Zorotypus caudelli* Karny. *Oriental Insects*, **34**, 77–82.

Paulian, R. (1949). Découverte de l'ordre des Zoraptères à Madagascar et description d'une nouvell espèce. *Mémoires de l'Institut Scientifique de Madagascar (A)*, **3**, 77–80.

Paulian, R. (1951). Découverte de l'ordre des Zoraptères a l'île Maurice. *Zorotypus vinsoni*, n. sp. *La Naturaliste Malgache*, **3**, 33–35.

Rafael, J.A. & Engel, M.S. (2006). A new species of *Zorotypus* from central Amazonia, Brazil (Zoraptera: Zorotypidae). *American Museum Novitates*, **3528**, 1–11.

Rafael, J.A., Godoi, F.S.P. & Engel, M.S. (2008). A new species of *Zorotypus* from

eastern Amazonia, Brazil (Zoraptera: Zorotypidae). *Transactions of the Kansas Academy of Science*, **111**, 193–202.

Terry, M.D. & Whiting, M.F. (2012). *Zorotypus novobritannicus* n. sp., the first species of the order Zoraptera (Zorotypidae) from the Australasian Ecozone. *Zootaxa*, **3260**, 53–61.

Wang, Y., Engel, M.S., Rafael, J.A., Dang, K., Wu., H., Wang, Y., Xie, Q. & Bu, W. (2013). A unique box in 28S rRNA is shared by the enigmatic insect order Zoraptera and Dictyoptera. *PLOS ONE* **8**: e53679. [doi:10.1371/journal.pone.0053679]

Yoshizawa, K. (2007). The Zoraptera problem: evidence for Zoraptera + Embiodea from the wing base. *Systematic Entomology*, **32**, 197–204.

Yoshizawa, K. (2011). Monophyletic Polyneoptera recovered by wing base structure. *Systematic Entomology*, **36**, 377–394.

Yoshizawa, K. & Johnson, K.P. (2005). Aligned 18S for Zoraptera (Insecta): Phylogenetic position and molecular evolution. *Molecular Phylogenetics and Evolution*, **37**, 572–580.

Figure legend

FIGURE 1. *Zorotypus caudelli*: A: head of apteron male, dorsal view; B: head of alate female, dorsal view; C: thorax of apteron male, dorsal view; D: thorax of alate female, dorsal view.

FIGURE 2. *Zorotypus caudelli*: A: abdomen of male, dorsal view; B: terminalia of male, posterior view; C: terminalia of female, posterior view; D: abdomen of male, ventral view; E: abdomen of female, ventral view; F: abdominal sternum 9 of female. Ep, epiproct; S9, 11, abdominal sterna 9 and 11; T9-11, abdominal terga 9 to 11.

FIGURE 3. *Zorotypus impolitus* **sp. n.**: A: head of apteron male, dorsal view; B: thorax of apteron male, dorsal view; C: thorax of alate female, dorsal view; D: abdomen of male, dorsal view, as for the asterisk and star, see the description.

FIGURE 4. *Zorotypus impolitus* **sp. n.**: A: abdomen of male, ventral view; B: terminalia of male, posterior view; C: terminalia of male, posterolateral view; D: abdomen of female, ventral view; E: terminalia of female, posterior view, as for the asterisk and stars, see the description. Ep, epiproct; S9, 11, abdominal sterna 9 and 11; T9-11, abdominal terga 9 to 11.

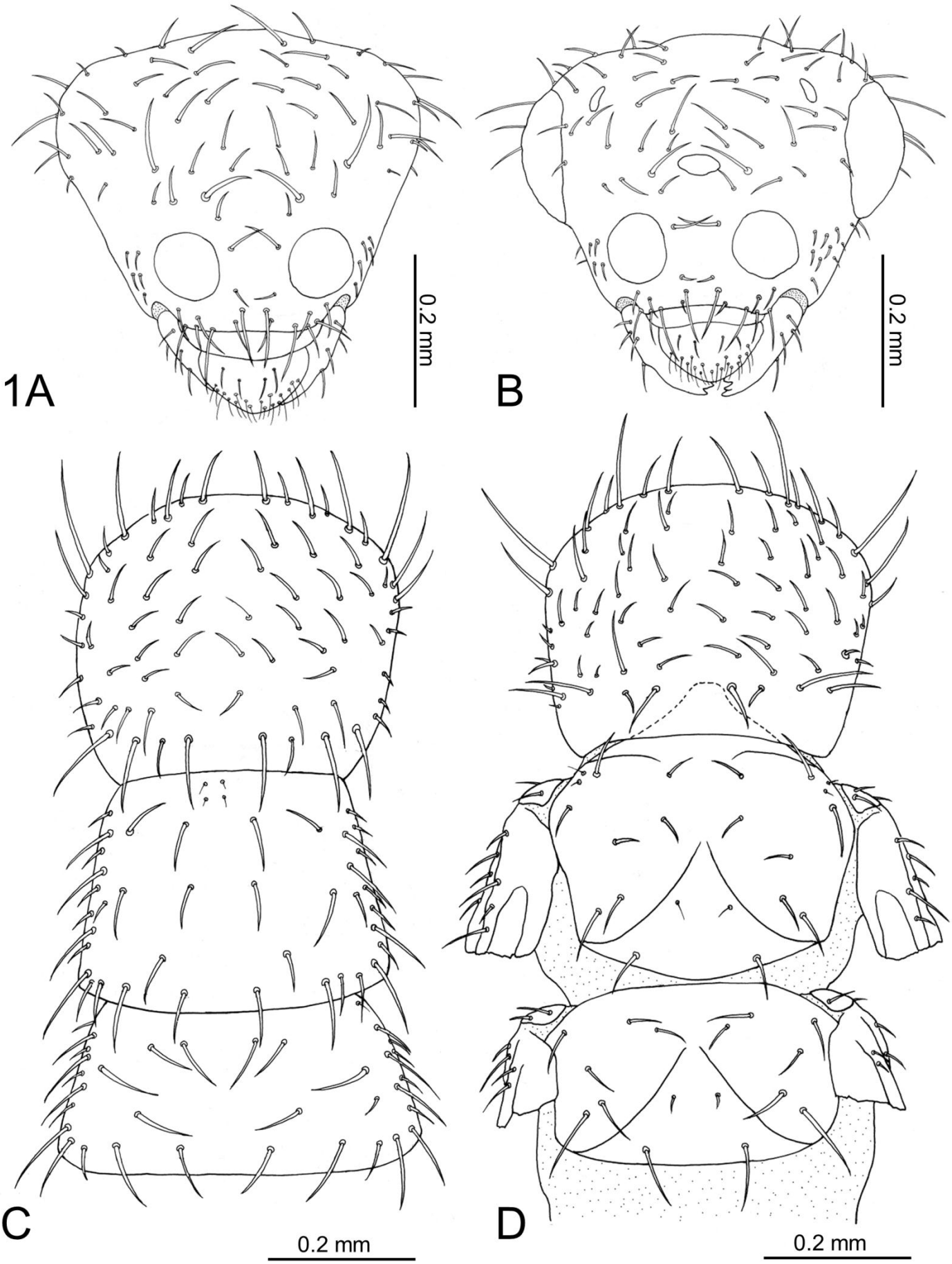
FIGURE 5. *Zorotypus caudelli*: A: antenna; B: left mandible, anterior view; B': right

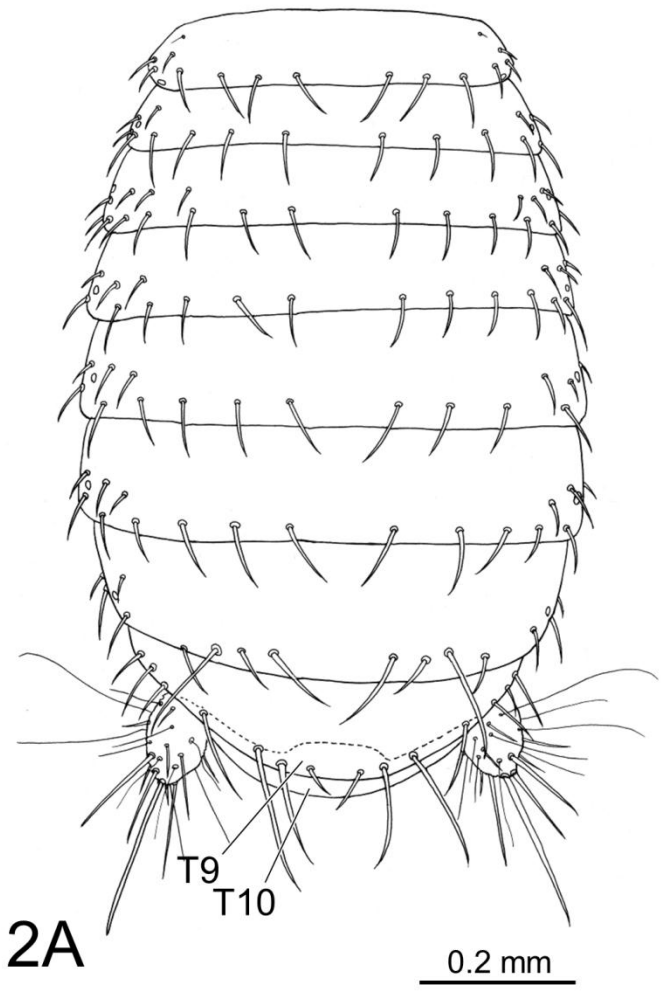
mandible, anterior view; C: wings; D: right metaleg, anterior view; E: male genitalia, posterior to the bottom. AH, aedeagus hook; BP, basal plate; F, flagellum.

FIGURE 6. *Zorotypus magnicaudelli* **sp. n.**: A: antenna; B: left mandible, anterior view; B': right mandible, anterior view; C: forewing; C': hindwing; D: right metaleg, anterior view; E: male genitalia, posterior to the bottom. AH, aedeagus hook; BP, basal plate; F, flagellum.

FIGURE 7. *Zorotypus cervicornis* **sp. n.**: A: antenna; B: left mandible, anterior view; B': right mandible, anterior view; C: right metaleg, anterior view; D: male genitalia, posterior to the bottom; E: abdominal sternum 9 of female. AH, aedeagus hook; BP, basal plate; F, flagellum.

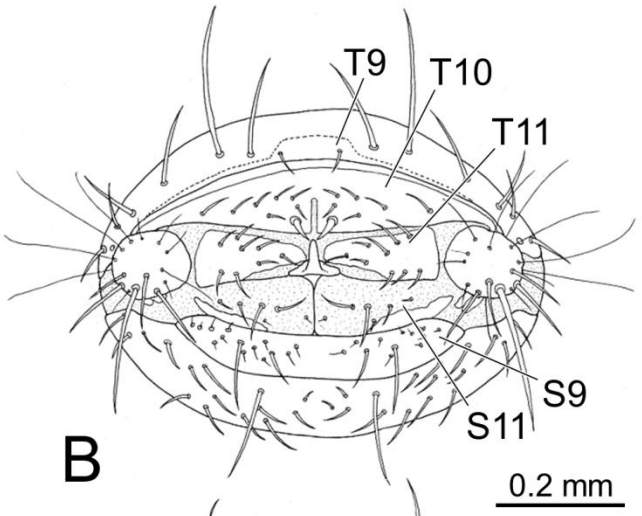
FIGURE 8. *Zorotypus impolitus* **sp. n.**: A: antenna; B: left mandible, anterior view; B': right mandible, anterior view; C: forewing; C': hindwing; D: right metaleg, anterior view; E: male genitalia, posterior to the left. DS, dorsal sclerite; MS middle sclerite; VS, ventral sclerite.


1A
0.2 mm
B
0.2 mm
C
0.2 mm
D
0.2 mm



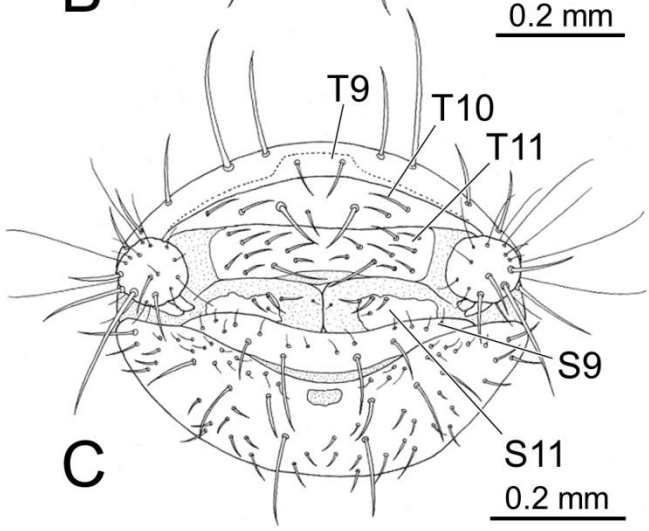
2A

0.2 mm



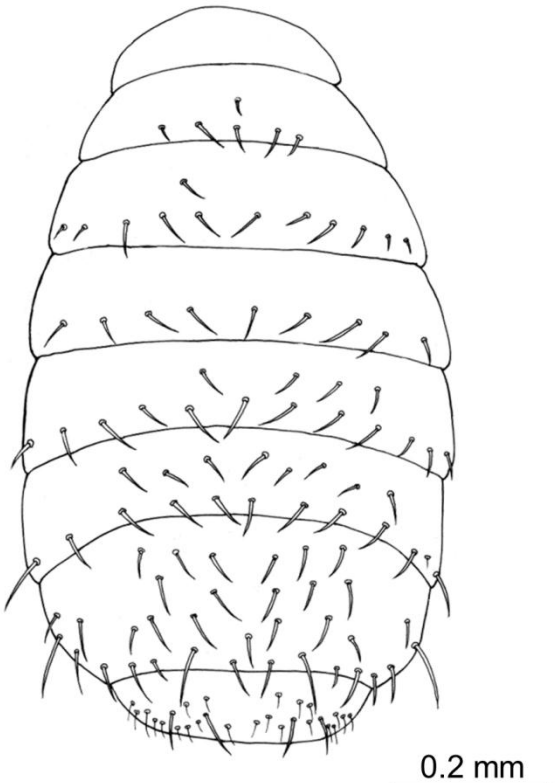
B

0.2 mm



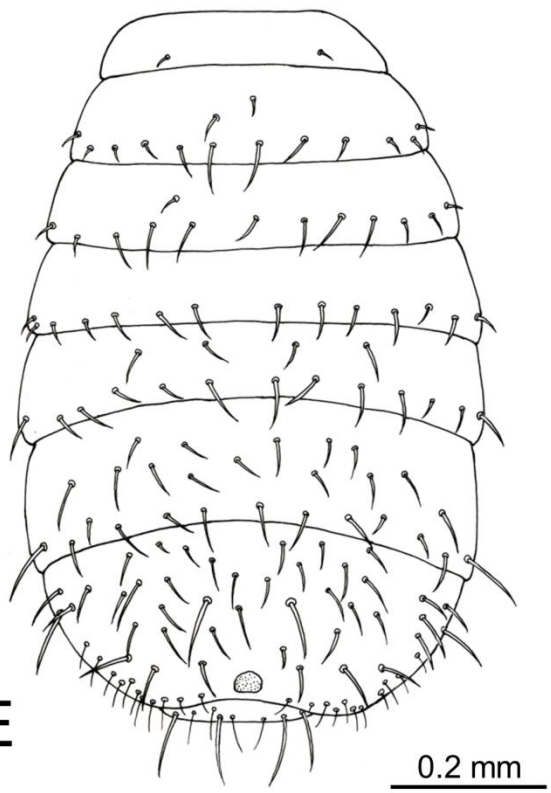
C

0.2 mm



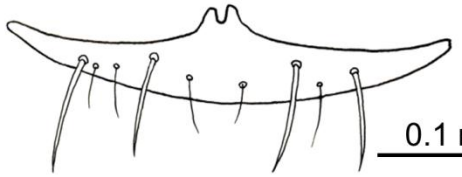
D

0.2 mm



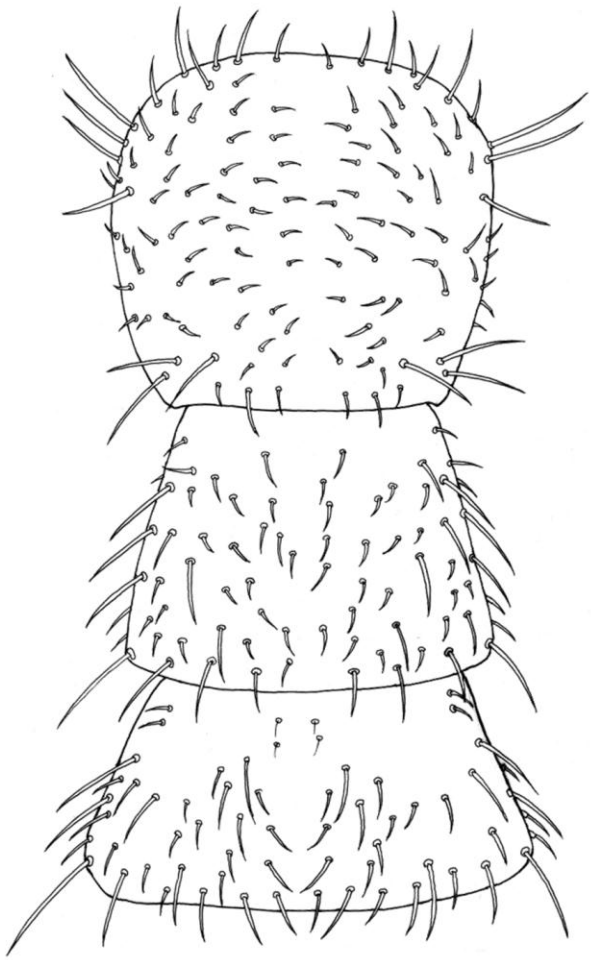
E

0.2 mm



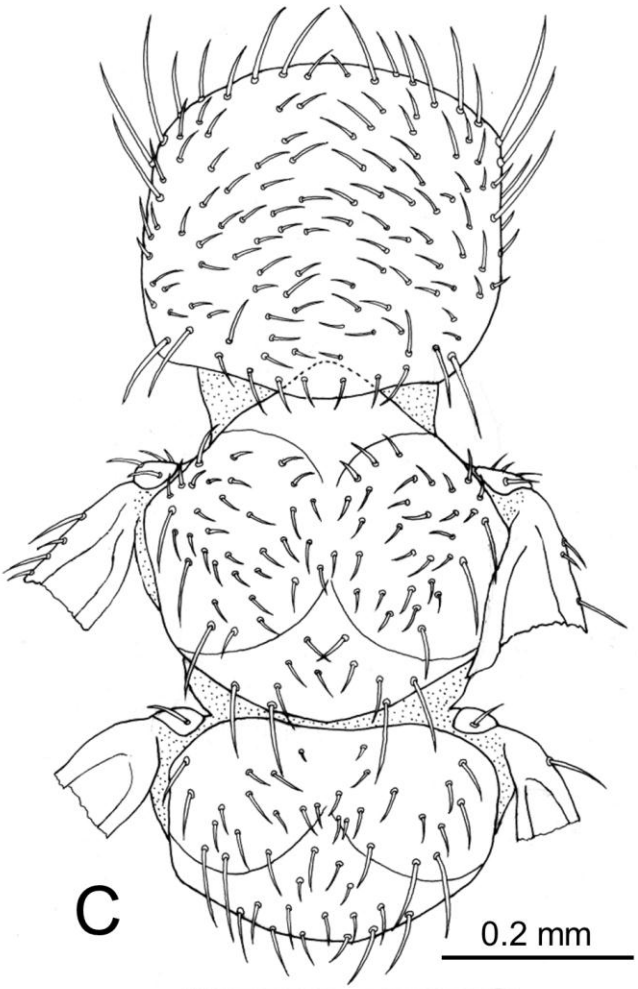
F

0.1 mm



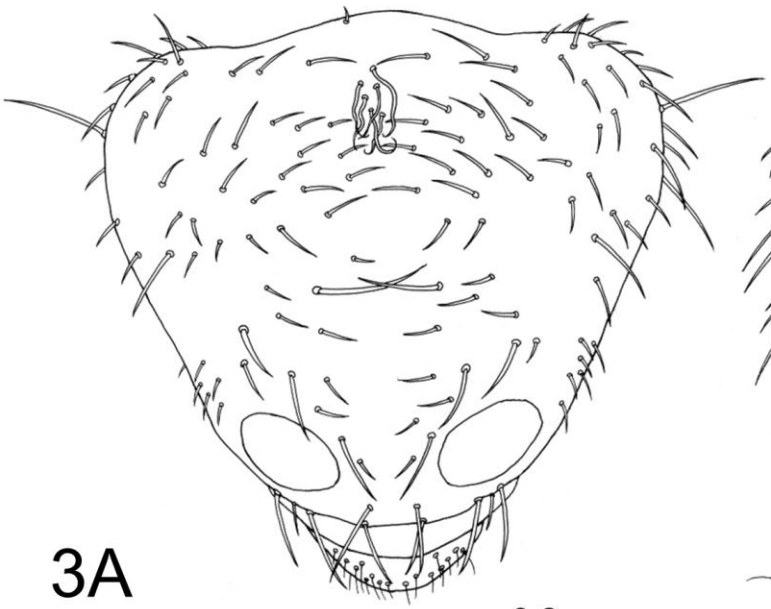
B

0.2 mm



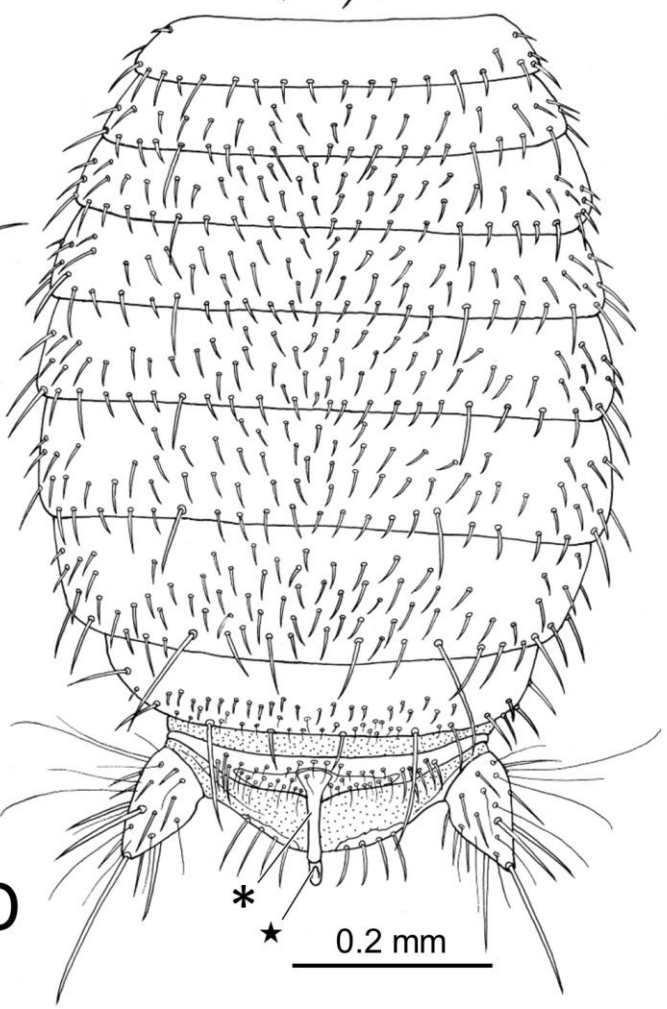
C

0.2 mm



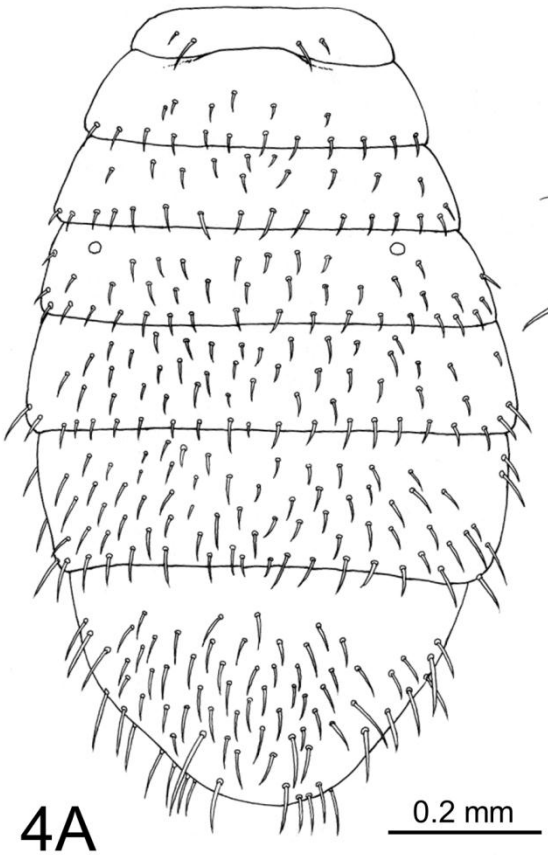
3A

0.2 mm



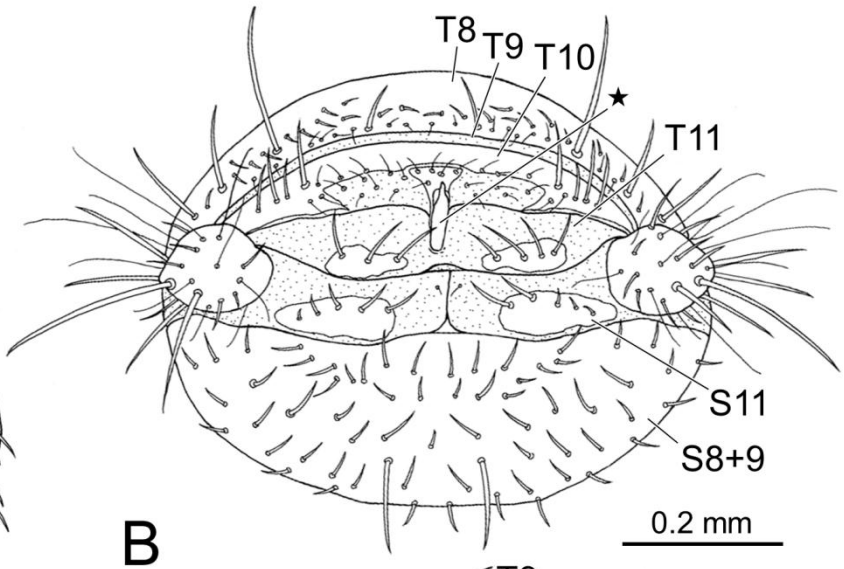
D

0.2 mm



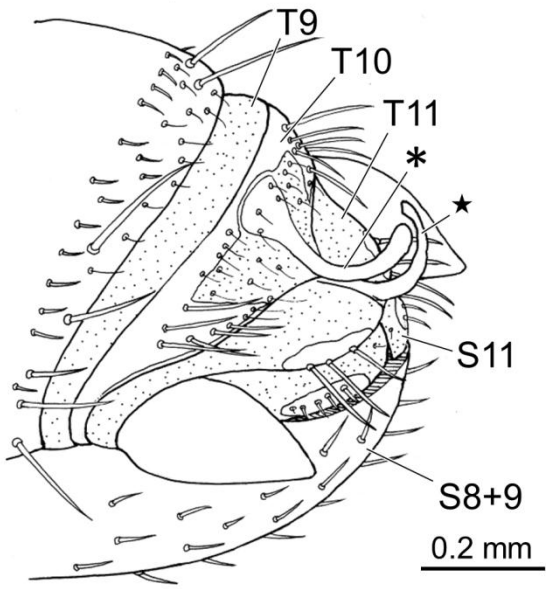
4A

0.2 mm



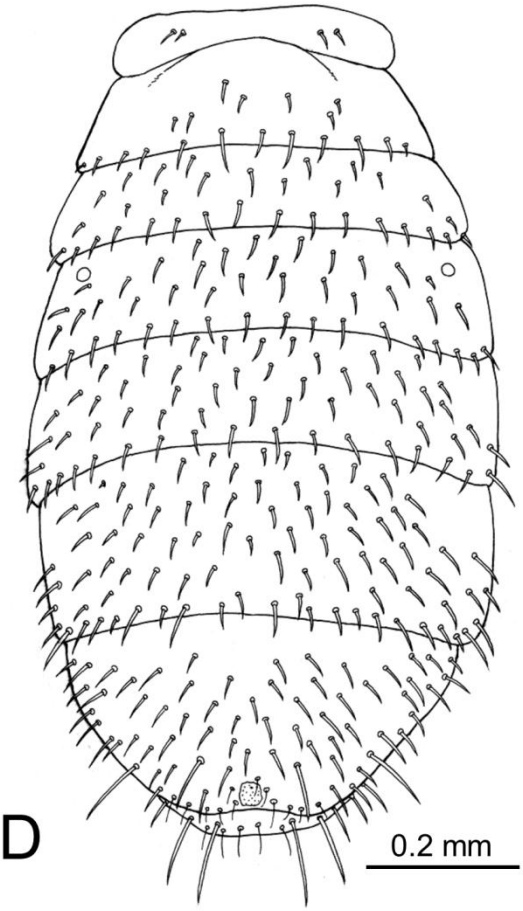
B

0.2 mm



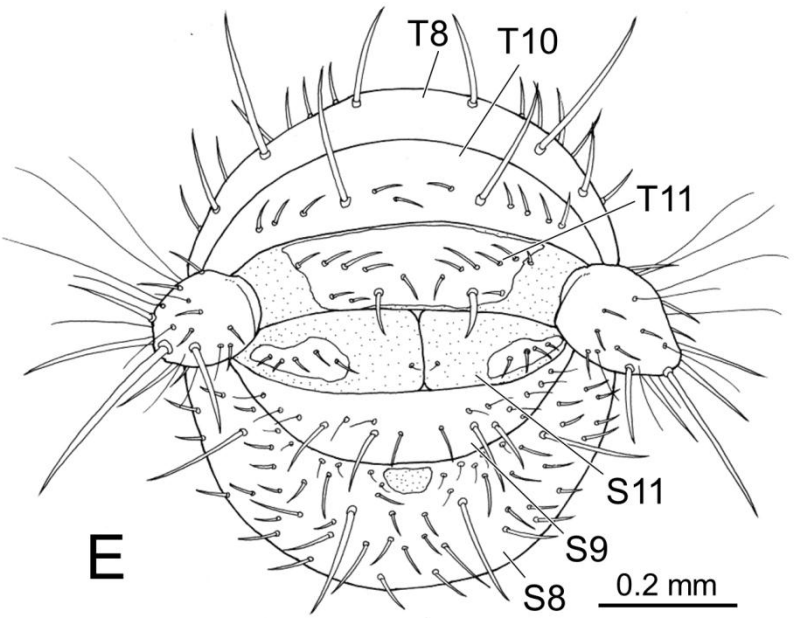
C

0.2 mm



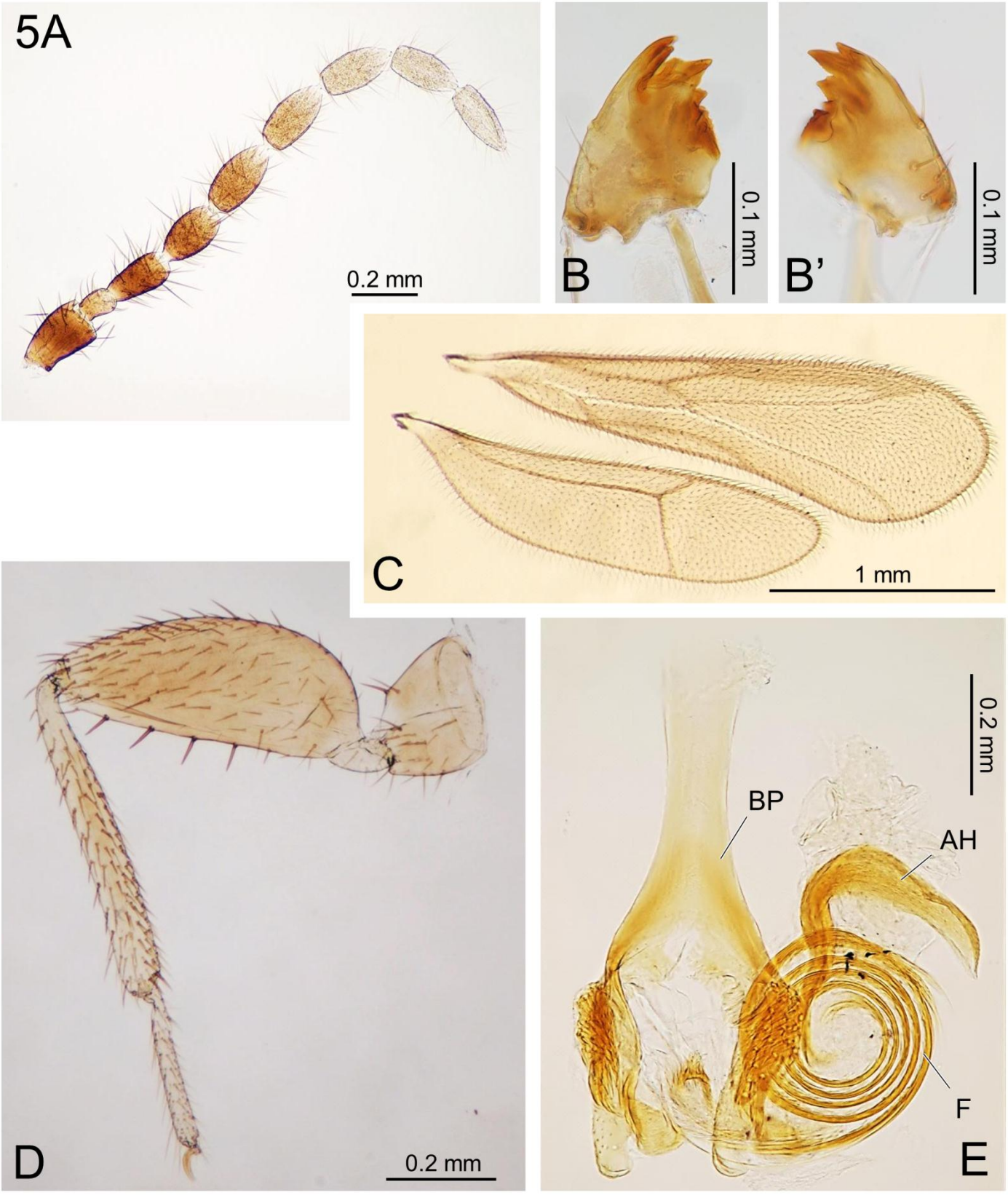
D

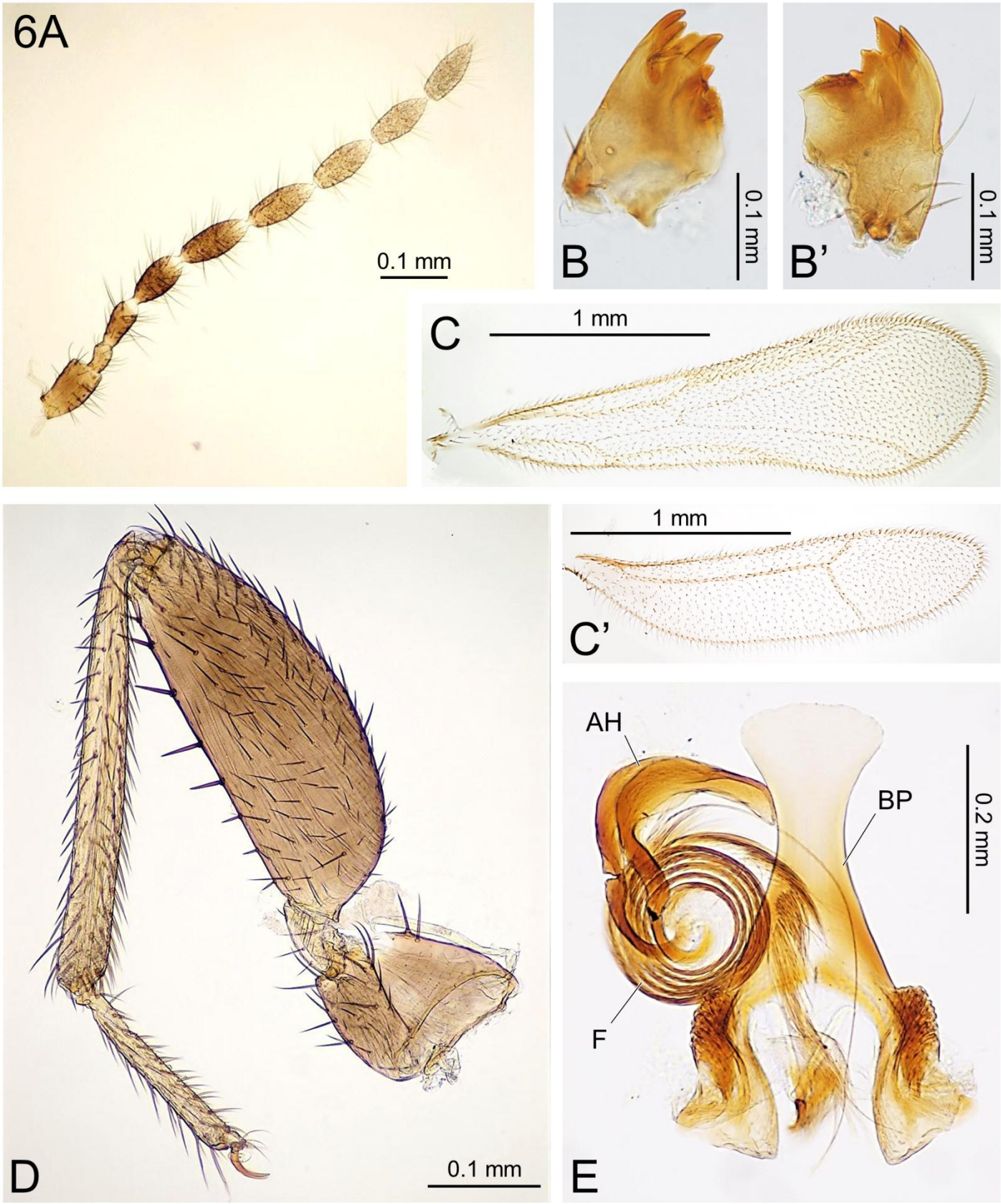
0.2 mm

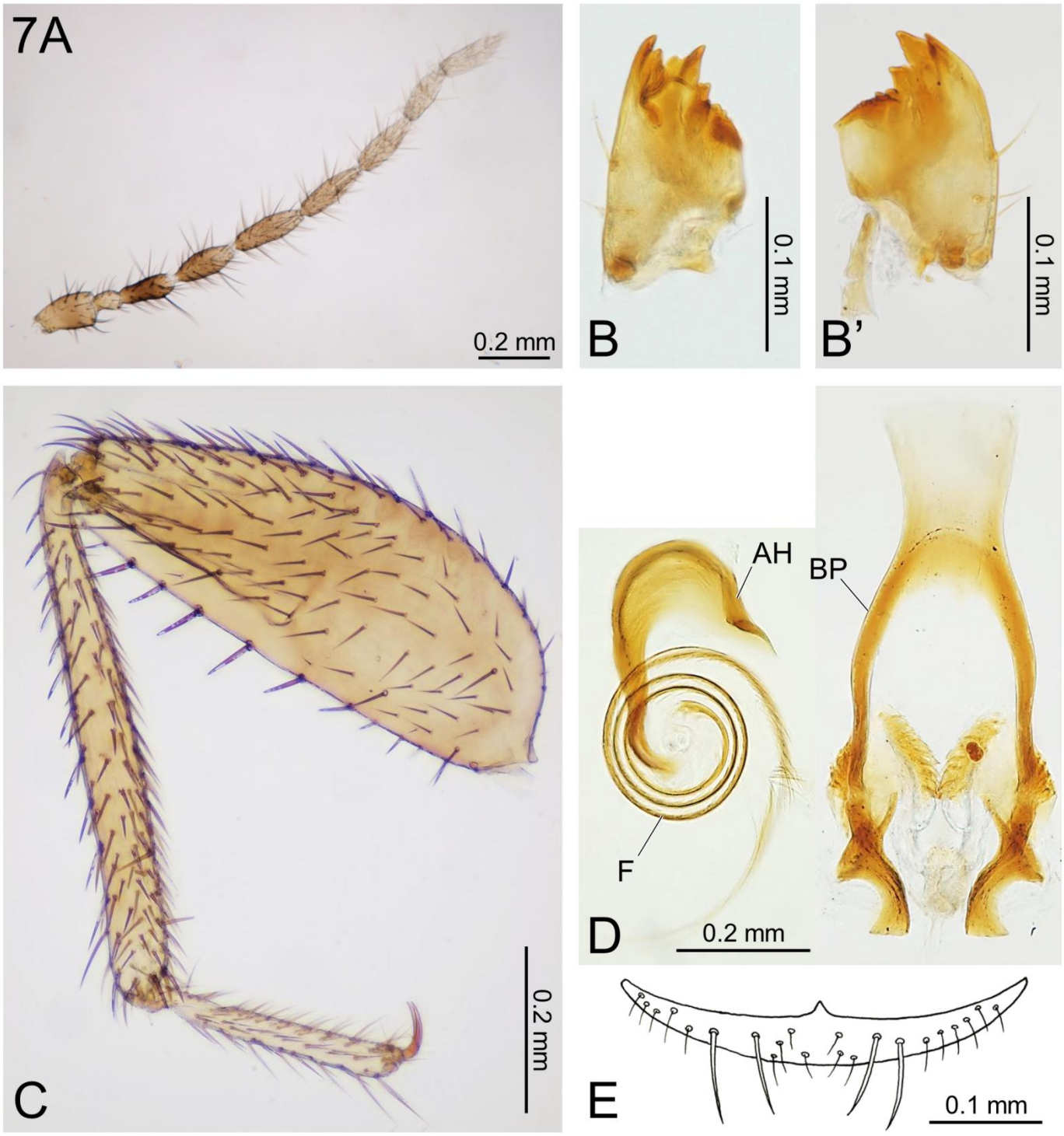


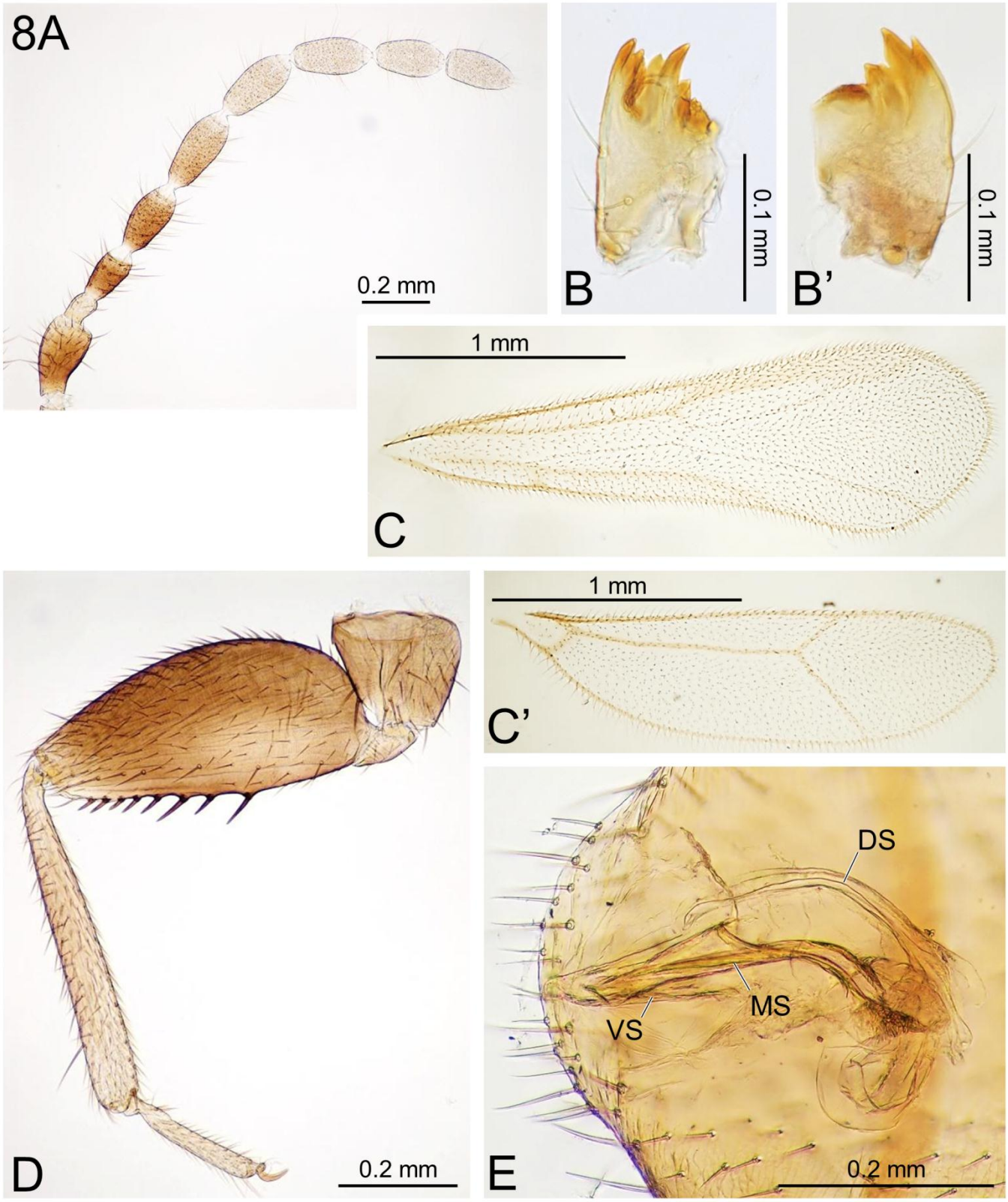
E

0.2 mm


5A
0.2 mm
B
0.1 mm
B'
0.1 mm
C
1 mm
D
0.2 mm
E
0.2 mm
BP
AH
F


6A
0.1 mm
B
0.1 mm
B'
0.1 mm
C
1 mm
C'
1 mm
D
0.1 mm
E
AH
BP
F
0.2 mm


7A
0.2 mm
B
0.1 mm
B'
0.1 mm
C
0.2 mm
AH
BP
F
D
0.2 mm
E
0.1 mm


8A
0.2 mm
B
0.1 mm
B'
0.1 mm
1 mm
C
1 mm
C'
D
0.2 mm
DS
MS
VS
E
0.2 mm