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A revision of the genus *Chlorocryptus* Cameron (Hymenoptera, Ichneumonidae), with the first record of the genus from Japan

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Abstract

The genus *Chlorocryptus* is revised and two species are recognized: *Chlorocryptus purpuratus* (Smith, 1852) and *C. coreanus* (Szépligeti, 1916). *Cryptaulax metallicus* Szépligeti, 1916, which has been hitherto listed in catalogs as *Chlorocryptus fuscipennis* Townes et al., 1961, is shown as a new synonym of *Chlorocryptus purpuratus*. *Chlorocryptus purpuratus* and *C. coreanus* are redescribed and illustrated in detail and a key is provided. *Chlorocryptus purpuratus* is recorded from Japan and Vietnam for the first time and is considered to have recently been introduced into Japan.

Key Words

Alien species
intraspecific variation
Limacodidae
natural enemy
new synonymy
taxonomy

Introduction

Chlorocryptus Cameron, 1903 is a small genus presently comprising three species: *C. purpuratus* (Smith, 1852), *C. coreanus* (Szépligeti, 1916), and *C. fuscipennis* Townes et al., 1961. They are easily sighted because of their large body size (10–15 mm) and metallic blue, purple, or green luster throughout the body. *Chlorocryptus purpuratus* is widely distributed in the Oriental Region to northern China and is well known as a common parasitoid of limacodid moths, which are injurious to leaves of various trees, especially oil palms (Gauld 1987, Mariau 1999). *Chlorocryptus purpuratus* and *C. coreanus* are well recognized, particularly in China (Chu et al. 1978, He and Chen 2006, He et al. 1996, 2004, Sheng et al. 2013, Wang and Li 1987). However, difficulties in identification or taxonomic confusion still exist in other countries (Gauld 1987, Jonathan 2006). In contrast, *Cryptaulax metallicus* Szépligeti, 1916, for which Townes et al. (1961) proposed a new name *Chlorocryptus fuscipennis*, is known only from the type series collected on Sulawesi and has not been studied in detail ever since its original description (Szépligeti 1916, Townes et al. 1961).

In 2010, one of us (RM) collected several specimens of *Chlorocryptus purpuratus* (Smith) at Isoshima in Osaka Prefecture. This finding was a surprise because *Chlorocryptus* species have never before been recorded from Japan, nor are any specimens collected in Japan known from older collections. However, specimens from other Southeast Asian countries are not rare in museum collections. Given the present known distribution of this species, it is presumed that it has recently been introduced into Japan.

Since this first discovery, we have collected additional specimens in Japan. Because its potential hosts, limacodid moths, are abundant in Japan (27 species from 19 genera are presently found; Owada et al. 2011), it is expected that the species can expand its distribution range into Japan.

Here, we study all three currently recognized species of the genus and revise their taxonomic status. We record

Chlorocryptus purpuratus from Japan as an alien species to provide the basis for monitoring the future expansion of the distribution range of this species.

Material and methods

Collection and field survey of *Chlorocryptus purpuratus* in Osaka and adjacent area were conducted by the second author (RM). Two immature specimens were collected from a cocoon of *Parasa consocia* Walker (Lepidoptera, Limacodidae). Cocoons of the moth are easily found clustered on the ground at the base of certain trees such as *Cerasus* × *yedoensis* (Matsum.) A.N.Vassiljeva, *Celtis sinensis* Pers., and *Salix* spp. in the study area. RM also conducted successful rearing experiments by supplying *C. purpuratus* females with *Parasa consocia* cocoon.

Morphological observations of *Chlorocryptus* specimens collected by RM and other colleagues and those from museum collections were conducted by the first author (TY). Specimen depositories are abbreviated as follows: Natural History Museum, London (BMNH), Hungarian Natural History Museum, Budapest (HNHM); Muséum national d'Histoire naturelle, Paris (MNHN); Osaka Museum of Natural History, Osaka (OMNH); Systematic Entomology, Graduate School of Agriculture, Hokkaido University, Sapporo (SEHU), Taiwan Agricultural Research Institute in Taichung (TARI).

A part of the specimens were dissected for detailed observations. Genitalia and other body parts were detached from the specimens that were previously macerated in hot water, and the detached body parts were further dissected in 80% ethanol. The dissected body parts were heated in 10% KOH solution at 60 °C for a sufficient period of time depending on the condition of the material to remove muscles from the exoskeleton. Cleaned parts were then washed in diluted acetic acid and distilled water and observed in 80% ethanol or pure glycerol.

Larval exuviae of the parasitoid were extracted from the host cocoon and their cephalic structures and spiracles were observed. They were macerated and stretched in 10% KOH solution and processed as body parts of adult specimens. One 5th instar larva collected in the field was killed to obtain DNA barcode sequences and subsequently treated as the exuviae in morphological observations.

Stereomicroscopes (Nikon SMZ-10 and Olympus SZ40), a light-microscope (Olympus BX40), and a field emission scanning electron microscope (SEM) (JEOL JSM-6301F, Tokyo, Japan) were used for morphological observations. Dissections and observations were carried out under the Olympus stereomicroscope, line drawings were made with a drawing tube attached to the Nikon stereomicroscope, and images of the wings and genitalia were taken using a Nikon Coolpix 4500 digital camera attached to the Olympus stereomicroscope. Images of larval exuviae were taken using the same digital camera attached to the light-microscope. Specimens for SEM analysis were not coated and were observed with an accelerating voltage of 1.0 kV. Digital images were edited using Adobe Photoshop Elements® 6.0.

Terminology used for adult morphology follows Gauld (1991) and Harris (1979), whereas descriptions of immature stages follow Short (1978). OOL and POL refer to ocello-ocular line and postocellar line, respectively. Nervellar index is defined as in Gauld and Mitchell (1981), i.e., the relative length of the first abscissa of Cu1 to the length of cu-a of the hind wing (Fig. 22).

DNA barcoding was carried out by RM. The DNA barcode sequences of cytochrome *c* oxidase I (COI) were obtained from an adult and a larva collected in Japan. Amplification of COI was carried out using the primer set LCO1490 and HC02198 designed by Folmer et al. (1994). The PCR protocol consisted of an initial 5-min denaturation at 94 °C, followed by 40 cycles at 94 °C for 15 s, 46 °C for 15 s, and 72 °C for 15 s, and ending with a 10-min extension step at 72 °C. Gene regions were sequenced using the same primer set and a BigDye® Terminator ver. 3.1 Cycle Sequencing Kit (Applied Biosystems, Foster City, CA, USA). Cycle sequencing reactions were run on an ABI Prism 310 Genetic Analyzer (Applied Biosystems, USA).

Taxonomy

Genus *Chlorocryptus* Cameron

Chlorocryptus Cameron, 1903: 34. Type species: *Chlorocryptus metallicus* Cameron. Designated by Viereck (1914: 32).

Cochlidionostenus Uchida, 1936: 115. Type species: *Cryptaulax coreanus* Szépligeti. Original designation. Synonymized by Townes et al. (1961: 141).

Cryptaulaxoides Uchida, 1940: 121. Type species: *Cryptus purpuratus* Smith. Original designation. Synonymized under *Cochlidionostenus* by Townes (1957: 104).

Description. Large and stout species, fore wing length about 10–15 mm, with metallic blue, purple or greenish luster (Fig. 1). Frons deeply concave, with longitudinal ridge below median ocellus and laterally with transverse rugae and punctures (Figs 2, 13). Antennal scrobe glabrous and polished. Face distinctly convex medially, densely sculptured (Figs 2, 5, 13, 16). Clypeus large, 1.2–1.9 times as wide as high, flat to weakly convex (Figs 2, 13). Mandible short and stout, upper tooth longer than lower tooth (Figs 6, 17). Occipital carina joining hypostomal carina above mandibular base. Female flagellum with apical third flattened ventrally (Fig. 7), there densely covered with mixture of one type of sensilla chaetica and one type of sensilla basiconica (Figs 41, 42); apex round, not truncated, possessing a bundle of thick sensilla, which are widened apically, and whose sockets interrupted on one side (Figs 39, 40). Male flagellum not flattened ventrally; with 5 or 6 tyloids which can be on 13th–20th flagellomeres; apex of flagellum with thick sensilla as in female but fewer.

Epomia strong (Figs 9, 19). Notaulus absent (Figs 8, 18). Sternaulus distinct, about 0.7 as long as mesopleuron. Median part of postpectal carina represented by tubercle. Submetapleural carina distinct and complete. Metasternum with distinct flange immediately anterior to hind coxa (Fig. 10).

Legs slender, hind femur about 6–8 times as long as median width, and hind tibia about 9–11 times as long as apical width. Male hind tarsal claws sharply bent, apical part covered with scale-like sculpture (Fig. 45). Female hind tarsal claws not specialized unlike male (Fig. 43). Orbicula slender, flask-shaped in female (Fig. 44), parallel-sided in male (Fig. 46).

Wings infumate in various degrees (Figs 22–27). Fore wing with areolet small, quadrangular, 0.3–0.4 times as long as 2m-cu; 2m-cu joining behind middle of areola; cu-a a little distad of Rs&M. M+Cu of hind wing straight on apical 0.6; nervellar index less than 2.8; 2A curving toward anal margin.

First metasomal tergite with baso-lateral tooth (Figs 12, 21); petiole dorsally flat (Figs 11, 20), sparsely punctate; postpetiole (Figs 11, 12, 20, 21) parallel-sided in dorsal view, dorsal face weakly to moderately convex, densely with shallow, large punctures; median longitudinal carina weak, usually almost absent; lateral and ventral longitudinal carinae distinct. Second and 3rd tergites distinctly punctate, with narrow glabrous band on posterior rim. Fourth and following tergites with smaller, minute punctures. Female sterna heavily sclerotized; 2nd sternum posteriorly embraced by 3rd (Fig. 28). Ovipositor sheath 0.8–1.0 times as long as hind tibia, with terminal point (Fig. 47). Upper valve of ovipositor bearing apical ridges. Lower valve of ovipositor with distinct oblique teeth. Male sterna not evenly sclerotized; median part weakly sclerotized (Fig. 29). Gonosquama weakly tapered toward apex and apex rounded (Fig. 30). Apex of aedeagus round, gently curved in lateral view (Fig. 31), tapered in ventral view (Fig. 32).

Biology. Both *Chlorocryptus purpuratus* and *C. coreanus* are parasitoids of limacodid moths and are often reported in the context of biological control (Table 1). They are solitary ectoparasitoids that oviposit into the host cocoon. The possession of ridges on the upper valve of the ovipositor is considered to be an adaptation to penetrate the hard cocoons of limacodid moths because this character state is found in some other cryptine species such as *Lithochila nohirai* (Uchida, 1930) and *Paragambrus sapporoensis* (Uchida, 1930) that also attack the limacodid cocoons (Townes 1969).

Chlorocryptus purpuratus (Smith)

Figs 1–12, 22–25, 28–35, 39–58.

Cryptus purpuratus Smith, 1852: 33. Holotype: ♀, China, Hong-Kong (BMNH), mentioned "Ning-po-foo" in original description [examined].

Chlorocryptus metallicus Cameron, 1903: 35. Holotype: ♀, India, Khasia Hill (BMNH) [examined]. Synonymized by Gauld (1987).

Chlorocryptus coeruleus Cameron, 1903: 36. Holotype: ♀, India, Khasia Hill (Oxford University Museum, UK). Synonymized by Gauld (1987).

Chlorocryptus reticulatus Cameron, 1907: 84. Holotype: ♂, India, Sikkim (BMNH) [examined]. Synonymized with *coeruleus* by Townes et al. (1961).

Cryptaulax cyaneus Szépligeti, 1916: 286. Lectotype: ♀, India, Sikkim (HNHM) designated by Townes et al. (1961) [examined]. Synonymized with *coeruleus* by Townes et al. (1961).

Cryptaulax metallicus Szépligeti, 1916: 287. Lectotype: ♀, designated by Townes et al. (1961), Celebes, Patunuang (HNHM) [examined]. **New synonym**.

Cryptaulaxoides purpuratus (Smith): Uchida 1940: 121.

Cryptaulaxoides metallicus (Cameron): Uchida 1940: 121.

Cochlidionostenus purpuratus (Smith): Townes 1957: 104.

Chlorocryptus fuscipennis Townes et al., 1961: 142. Replacement name for *Cryptaulax metallicus* Szépligeti, 1916.

Chlorocryptus purpuratus (Smith): Townes et al. 1961: 142.

Neodontocryptus hyalina Saxena, 1978: 216. Holotype: ♀, India, Manipur, Kanchipur (depository unknown; see "Remarks"). Synonymized with *coeruleus* by Gupta (1987).

References. Gonggrijp 1931: 8 (noted as parasitoid of *Thosea asigna*, photo); Kellogg 1938: 123 (*reticulatus*, listed); Uchida 1940: 121 (*Chryptaulaxoides purpuratus*, record), 122 (*Cryptaulaxoides metallicus*, in key); Wu 1941: 59 (*Cryptus purpuratus*, listed); Uchida 1952: 48 (*Cryptaulaxoides purpuratus*, record); Narayanan and Lal 1961: 257 (*coeruleus*, listed), 257 (*metallicus*, listed) 258 (*reticulatus*, listed); Townes et al. 1961: 141 (*coeruleus*, catalogued), 142 (*fuscipennis*, catalogued), 142 (*metallicus,* catalogued), 142 (*purpuratus*, catalogued); Townes et al. 1965: 167 (*coeruleus*, catalogued), 168 (*purpuratus*, catalogued); Chao 1976: 266 (*coeruleus*, listed, distribution), 267 (*purpuratus*, listed, distribution); Chu et al. 1978: 40 (description, figure, host, parasitism, distribution); Tiong 1979: 282 (*Chlorocryptus* sp. nr. *coeruleus*, noted as parasitoid of *Thosea asigna*); Yang and Wu 1981: 303 (listed); Tiong 1982: 535 (*Chlorocryptus* sp. nr. *coeruleus*, noted); Zhang 1983: 21 (diagnosis, host, biology); Xiao 1985: 25 (biological notes); He and Wang 1987: 379 (description, host, distribution); Wang and Li 1987: 1326 (in key, host, distribution, records); Gauld 1987: 130 (diagnosis, figure of fore wing, distribution, hosts, biology); Dang et al. 1990: 12 (description, figure, hosts, distribution); He et al. 1992: 1224 (description, figure, hosts, distribution); He and Tian 1993: 536 (description, figure, hosts, distribution); Wang and Yao 1993: 645 (records); Chen 1993: 138 (noted, figure); He et al. 1996: 511 (description, figure, hosts, distribution); Mariau 1999: 150 (table 1), 153 (listed and noted as a parasitoid of Limacodidae on palms); He et al. 2001: 721 (records); Lin 2003: 939 (catalogued); Wang 2003: 274 (*coeruleus*, description, distribution); He et al. 2004: 514

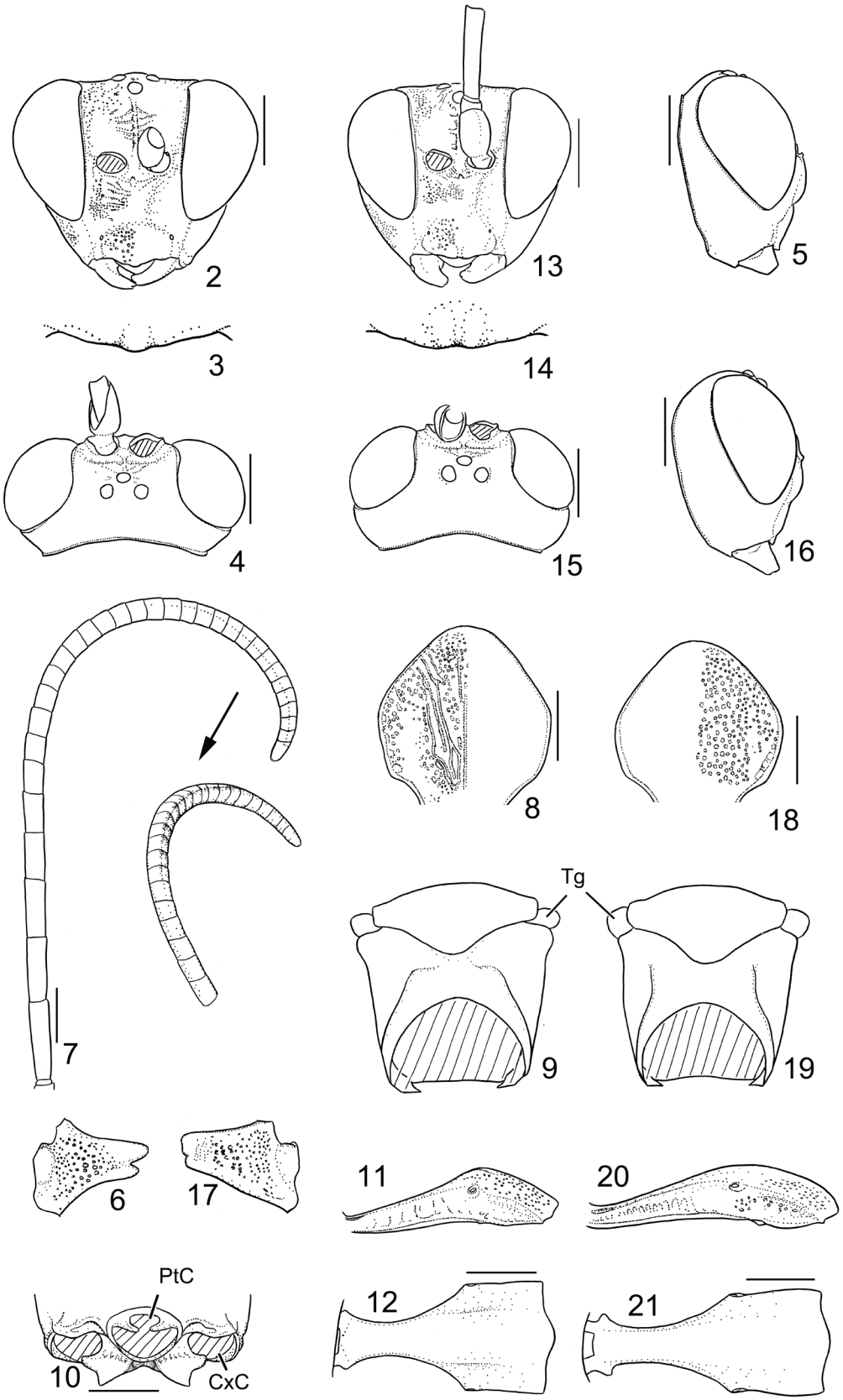
Figure 1. *Chlorocryptus purpuratus* female, ovipositing into a cocoon of *Parasa consocia* Walker.

(description, figure, hosts, records, distribution); Jonathan 2006: 191 (*coeruleus*, description, figures, records, distribution), 192 (*metallicus*, diagnosis, distribution); He and Chen 2006: 111 (description, figures, biology, hosts, distribution); Ding et al. 2009: 27 (record, hosts); Sheng and Sun 2009: 70 (description, photo, hosts, records, distribution); Sheng et al. 2013: 139 (description, photo, hosts, records, distribution).

Type specimens examined. Holotype of *Cryptus purpuratus* Smith: ♀, "56 113, Hong Kong", BMNH (ID 3b-572). Holotype of *Chlorocryptus reticulatus* Cameron: ♂, "Sikkim", BMNH (ID 3b-2013). Lectotype of *Cryptaulax cyaneus* Szépligeti: ♂, "India, Sikkim, ex coll. Fruhstorfer", HNHM (ID 115215). Lectotype of *Cryptaulax metallicus* Szépligeti: ♀, "S.-Celebes, Patunuang, Jan. 1896, H. Fruhstorfer", HNHM (ID 115222). One of the paralectotypes of *Cryptaulax metallicus* Szépligeti: ♀ same data as the lectotype, SEHU (Uchida collection).

Additional specimens. Japan. Yamadaike Park, Hirakata, Osaka Pref., 1 ♀, 6.viii.2011, Y. Mori, OMNH. Isoshima, Hirakata, Osaka Pref., 34.82683°N/ 135.6450°E, R. Matsumoto, OMNH: 1 ♂, 18.x.2010; 1 ♀, 29.x.2010; 1 ♀, 8.xi.2010; 1 ♀, 3.x.2010; 3 ♀, 2 ♂, 24.ix.2011; 1 ♀, emerged from a cocoon of *Parasa consocia* Walker collected on 15.i.2013, emerged in iii.2013. Offspring of females collected at Isoshima, bred on *Parasa consocia* Walker, OMNH: 1 ♂, laid on 1.xi.2010, emerged on 20.xii.2010; 1 ♂, laid on 4.xi.2010, emerged on 22.xii.2010; 1 ♂, laid on 10.xi.2010, emerged on 24.xii.2010; 1 ♂, laid on 9.xi.2010, emerged on 28.xii.2010; 1 ♂, laid on 4.xi.2010, emerged on 6.i.2011. Oka, Hirakata, Osaka Pref., 34.8178°N/135.6415°E, R. Matsumoto, OMNH: 1 ♂, 28.ix.2011; 1 ♀, 16 ♂, 24.ix.2011 [1 ♂ for DNA extraction: DNA-ICH-002]. Tawaraguchicho, Ikoma, Nara Pref., 34.7027°N/135.6795°E, 1 ♀, 19.viii.2012, R. Matsumoto, OMNH. Hitakatsu, Tsusima Is., Nagasaki Pref., 1 ♂, emerged from a cocoon of *Monema flavescens* Walker collected on 28.iii.2013, emerged in iv.2013, K. Sasaki, OMNH. **China**. Wutaihsien, Shanxi Prov., 1 ♀, 12.viii. SEHU. Chinkiang, Kiangsu [= Jiangsu Prov.], 1 ♀, 12.xi.1918, O. Piel, SEHU. Tchefou [= Yantai] Shandong Prov., 1 ♀, MNHN (coll. de Gaulle). Ningpo, Zhejiang Prov.: 3 ♀, P. Buch, 1924, MHNM; 2 ♀, MNHN (coll. de Gaulle). Moupin, Sichuan Prov., 1 ♀, 1899, Chasseurs indigènes, MNHN (coll. Oberthür). **Nepal.** Balaju, Kathmandu, 1 ♀, 11.ix.1987, H. Takizawa, SEHU. **Vietnam**. Chu Yang Sin National Park, 12°27′13.74″N/108°20′21.75″E, Krong Bong District, Dak Lak Province, 1 ♂, 12.iii.2013, K. Konishi. Cuc Phuong, Ha Son Binh Prov. (SEHU): 1 ♂, 28.iv.1996, Y. Okushima, OMNH; 1 ♂, 200–300m alt., 24.iv.1998, R. Matsumoto, OMNH. Ba Be National Park, Ba Be, 200m alt., 22.23°N/ 105.37°E, R. Matsumoto, OMNH: 1 ♂, 4.v.2006; 1 ♂, 1.v.2006. **Malaysia**. Klapa Bali, 3 ♀, 3 ♂, 10.vi.1949, MNHN. Klapa Bali, "ds cage de Setora nitens", "VI–VII 1949", P. Vayssuère: 11 ♀, 5 ♂, 10.vi.1949; 2 ♀, 1 ♂, 11.vi.1949. **Indonesia**. Semarang, Java, 1 ♀, E. Jacobson, 1906, MNHN. Malang, Java, 1 ♀, MNHN. Gunung Lompobattang, 1250–1350m, South Sulawesi, 1 ♀, 16.xii.2010, K. Takasuka, OMNH. **Unknown locality**. 2 ♂, "Sina", MNHN (coll. Sichel).

Immature stage. Fifth instar larva. 1 ex. Isoshima, Hirakata, Osaka Pref., in cocoon of *Parasa consocia* Walker, 24.ii.2012, R. Matsumoto [OMNH; DNA extraction: DNA-ICH-001].



Figures 2–21. 2–12. *Chlorocryptus purpuratus*; **13–21.** *C. coreanus*. **2 & 13.** Head, frontal view (surfacial sculpture partly shown on right half); **3 & 14.** Apical margin of clypeus; **4 & 15.** Head, dorsal view; **5 & 16.** Head, lateral view; **6 & 17.** Mandible; **7.** Flagellum; **8 & 18.** Mesoscutum; **9 & 19.** Pronotum, anterior view, showing epomia; **10.** Metasternum, posterior view; **11 & 20.** First metasomal segment, lateral view; **12 & 21.** First lateral segment, dorsal view. **CxC** – coxal cavity; **PtC** – petiolar cavity; **Tg** – tegula. Scale lines: 1 mm.

Diagnosis. Punctation on head finer than *C. coreanus*. Temple flat and narrower, occupying 0.2–0.3 of length of head in dorsal view (Fig. 4). Face with transverse rugae in addition to punctures (Figs 2, 5). Clypeus with median obtuse tubercle on apical margin (Fig. 3). Mandibular teeth acute (Fig. 6). Female flagellum without white annulus and with apical third of flagellum ventrally distinctly flattened and widened (Fig. 7). Epomia turned abruptly horizontally toward mesal line of pronotum at midway to upper edge of pronotum (Fig. 9). Prepectus with a short vertical carina opposite lower corner of pronotum. Mesoscutum with longitudinal rugae in addition to punctures, and with moderate-sized glabrous area on lateral lobe (Fig. 8). Propodeum with posterior transverse carina. Nervellar index 1.9–2.8 (Figs 22–25). Postpetiole usually shorter, 0.7–0.9 times as long as wide in female (Fig. 12), 0.6–0.8 in male. Area between median longitudinal carinae of 1st metasomal tergite distinctly raised at beginning of postpetiole (Fig. 11). Subgenital plate (Figs 33–35) with postero-lateral corner gently curved, with posterior margin simply convex medially, and without white spot at base of its apodeme.

Description. Adult. ♀. Head 2.0–2.1 times as wide as long in dorsal view (Fig. 4). Temple flat and narrow, occupying only 0.2–0.3 of length of head in dorsal view (Fig. 4). POL/OOL=0.4–0.8. Vertex and gena densely punctate with shallow and small punctures; punctures smaller on gena than on vertex. Face 1.4–1.5 times as wide as high, distinctly convex medially, densely punctate with fine punctures and with some sublateral transverse rugae (Figs 2, 5). Clypeus with median obtuse protuberance on apical margin (Fig. 3); punctures sparser than on face and irregular with mixture of different sized punctures. Malar space 0.9–1.2 times as wide as mandible width. Mandible with acute teeth, its lower tooth about half length of upper one (Fig. 6). Antenna with 31–32 flagellomeres; apical third of flagellum weakly thickened and weakly flattened ventrally, weakly tapered to apex; first flagellomere 3.4–4.3 times as long as apical width, a little longer than 2nd flagellomere; fifth flagellomere 1.5–2.1 times as long as apical width (Fig. 7).

Epomia turns horizontally toward mesal line of pronotum at midway to upper edge of pronotum (Fig. 9). Prepectus with a short vertical carina opposite lower corner of pronotum. Mesoscutum densely punctate, with longitudinal to oblique rugae on median lobe, and with moderate-sized glabrous area on lateral lobe (Fig. 8). Scutellum with large punctures. Mesopleuron punctate to areolate-rugose on lower part to strigate on upper frontal part. Mesosternum punctate-reticulate. Metapleuron areolate-rugose. Upper division of metapleuron punctulate. Propodeum areolate rugose; posterior transverse carina distinct laterally, forming weak crest, with median portion merged in rugae and indistinct; anterior transverse carina and basal section of lateromedian longitudinal carina weakly marked; other carinae absent.

Legs slender. Hind femur 6.0–7.3 times as long as maximum width. Hind tibia 9.3–10.7 times as long as apical width.

Fore wing about 10–15 mm long. Nervellar index 1.8–2.8 (Figs 22–25).

First metasomal tergite 1.8–2.1 times as long as apical width, with postpetiole 0.6–0.9 times as long as apical width; area between median longitudinal carinae distinctly raised at proximal margin of postpetiole (Figs 11, 12). Ovipositor sheath 0.8–1.0 times as long as hind tibia.

Body with metallic luster in blue, purple or green. Flagellum entirely black, without white band. Fore and middle tibiae and all tarsi dark brown to black. Ovipositor sheath and ovipositor black. Wings infumate in variable degrees (Figs 22–25). Veins dark brown to black, strongly pigmented all over.

♂. Similar to female except as follows: face 1.2–1.3 times as wide as long; malar space 0.8–1.0 times as long as basal width of mandible; flagellum with 35–37 flagellomeres, with 5 or 6 tyloids which can be on 13th–20th flagellomeres; 1st flagellomere 2.7–3.3 times as long as apical width; 1st metasomal segment 1.6–2.1 times as long as apical width; hind femur 7.3–8.0 times as long as median depth; hind tibia 10.3–12.7 times as long as apical width; anterior side of fore femur, fore tibia and dorsal stripe of middle tibia light brown. Subgenital plate with posterior margin evenly convex and with postero-lateral corner gently rounded (Figs 33–35).

Immature stages. Mandible, labral sclerite, epistoma, hypostoma, and labial sclerite well sclerotized through larval development (Figs 48, 50). Pleurostoma less strongly sclerotized (Figs 48, 50). Mandible with minute teeth both on dorsal and ventral sides (ventral teeth difficult to discern under light microscope) (Figs 55, 56), except for 1st instar (Fig. 54). Labrum with five to seven conspicuous setae in a row on each side along labral sclerite. Clypeus with three pairs of setae on lower margin. Antenna of moderate size, conical, without papilla or obvious seta or sensilla (Fig. 51).

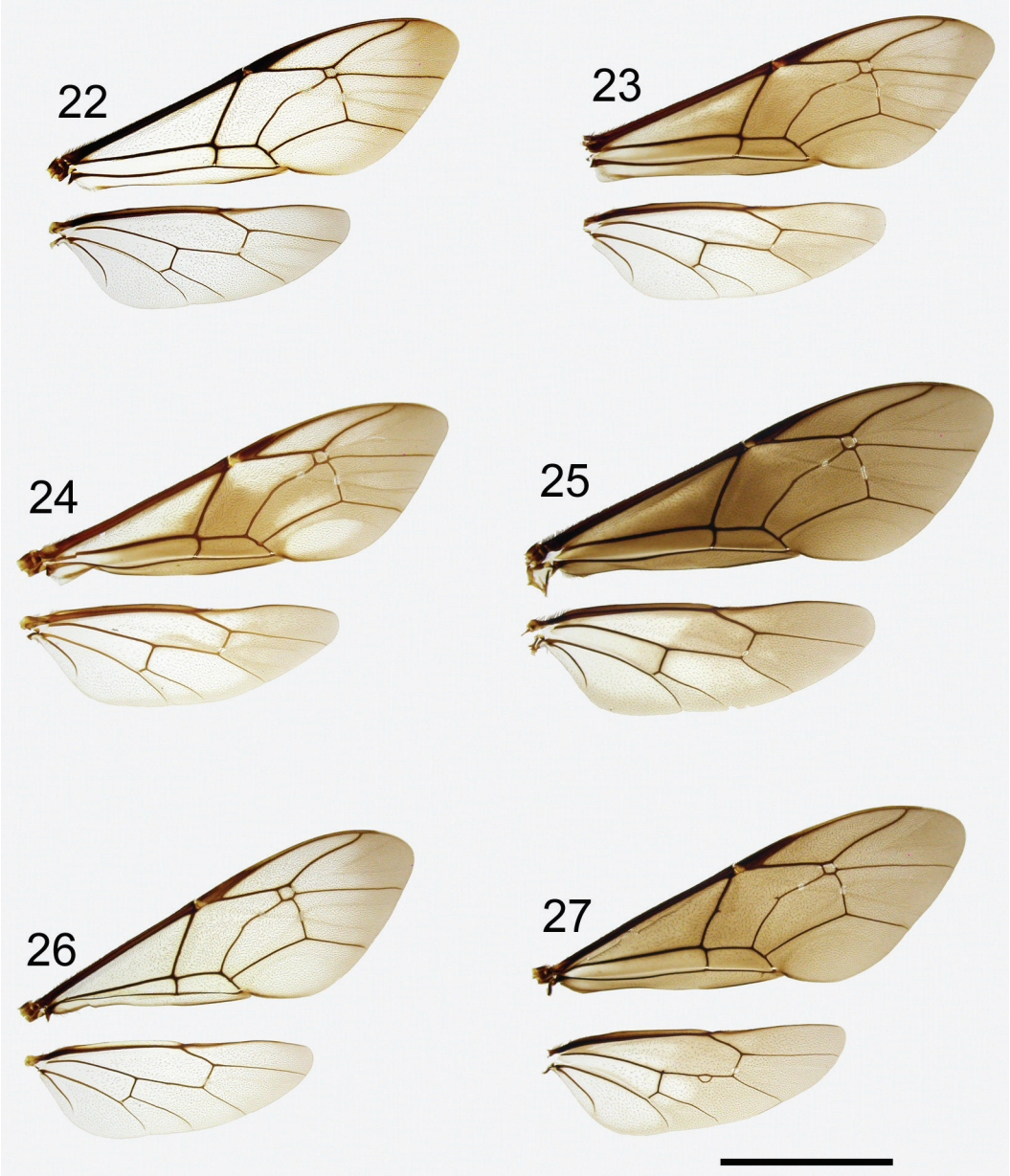
First instar larva (Fig. 48). Hypognathus. Hypostomal spur very weakly sclerotized. Stipital sclerite not developed. Mandible without teeth on blade (Fig. 54). Labrum with three setae on each side. Atrium of spiracle and closing apparatus not differentiated (Fig. 49).

Second instar larva. Prognathus. Narrow epistomal spur present. Two pairs of setae on labium of 1st instar remaining but upper most one situated just below salivary orifice present only as a hole. Spiracle with atrium differentiated.

Third and fourth instar larvae. Epistomal spur more developed than in 2nd instar and stipital sclerite present.

Final instar larva (Fig. 50). Dorsal part of epistoma not distinctly sclerotized and transparent, gradually evanescent. Clypeus slightly sclerotized but well delimited from surrounding area, without setae. Mid-dorsal part of labral sclerite weakly expanded and oval in form. Cardo very slightly sclerotized. Maxillary palp with two sensilla. Labial palp with two sensilla. Salivary orifice U-shaped. Closing apparatus of spiracle adjoining atrium (Figs 52, 53).

Biology. Several limacodid moths have been recorded as hosts. Some of the moths are serious pests of palm trees



Figures 22–27. Wings. **22–25.** *Chlorocryptus purpuratus*; **26 & 27.** *C. coreanus*. **22.** ♂, Isoshima, Japan; **23.** ♀, Chinkiang, Jiangsu, China; **24.** ♀, Klapa Bali, Malaysia; **25.** ♀, Gunung Lompobattang, South Sulawesi, Indonesia; **26.** ♀, Keumsan, South Korea; **27.** ♀, Chulin, Taiwan, China. Scale line, 5 mm.

in the Oriental Region (Gauld 1987, Mariau 1999); hence, *C. purpuratus* is of economic importance as their natural enemy. The host records are summarized in Table 1.

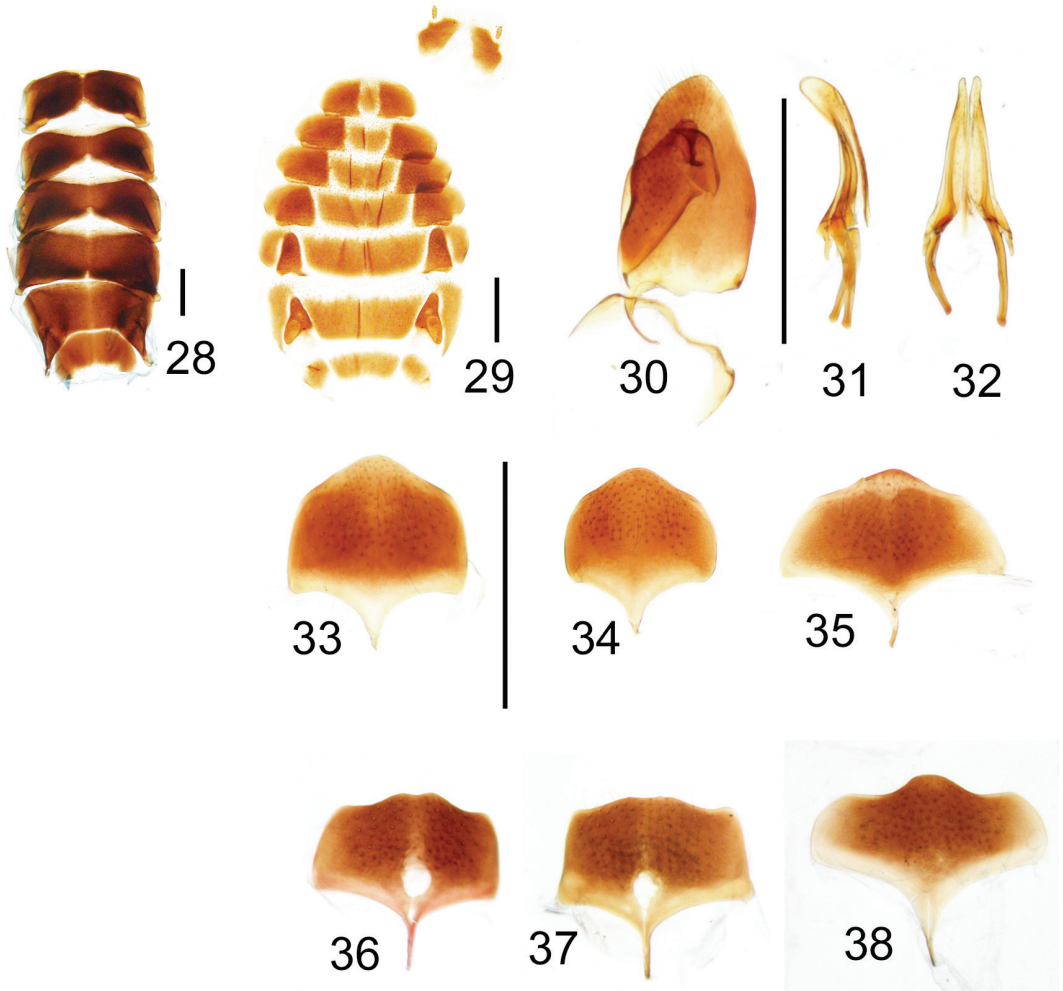
In this study, we observed females collected in Osaka ovipositing into cocoons of *Parasa consocia* Walker (Fig. 1). They spent more than 30 min to penetrate the moth cocoons and to accomplish the oviposition.

Distribution (Figs 57, 58). Japan (new record): Honshu, Tsushima Is. China: Beijing (He and Wang 1987), Fujian (Chao 1976, Kellog 1938, Wang 2003), Guangxi (He et al. 1992), Guizhou (He et al. 1992, Wang and Yao 1993), Hebei (Wang and Yao 1993), Henan (Dang et al. 1991, Sheng and Sun 2009), Hong Kong (Smith 1852), Hubei (He and Chen 2006), Hunan (Dang et al. 1991), Jiangsu (Uchida 1940), Jiangxi (Chu et al. 1978, Ding et al. 2009, Sheng et al. 2013), Shaanxi (Dang et al. 1991), Shandong (Chao 1976, He and Tian 1993), Shanghai (Chao 1976, Xiao 1985), Shanxi (Uchida 1952), Sichuan (He et al. 1992), Yunnan (Wang and Li 1987), Zhejiang (Chao 1976, He et al. 2001, 2004). Vietnam (new record). Malaysia: Sabah (Gauld 1987). Indonesia: Java (Gauld 1987, Saxena 1978), Sumatra (Gauld 1987), Sulawesi (Szépligeti 1916). India (Cameron 1903, Jonathan 2006, Saxena 1978, Szépligeti 1916). Nepal (Saxena 1978).

Remarks. Although this species shows a wide range of variation in density of the surface sculpture and setae, wing color (Figs 22–25), and shape of the subgenital plate (Figs 33–35), these variations are continuous. The specimens from Sulawesi, including the lectotype of *Cryptaulax metallicus* Szépligeti, have extensively dark

Table 1. Host records of *Chlorocryptus* spp. (modified from Gauld 1987). All hosts belong to Limacodidae.

Chlorocryptus	Host	Locality	References
C. coreanus	*Miresa inornata*	not mentioned	Uchida 1930a
	Monema flavescens	Taiwan	Uchida 1930b; Sun et al. 1982; Pan 1983; Yin and Zou 1987; Wang et al. 1991, 1993
C. purpuratus	*Birthamula chara*	Sumatra	Gauld 1987
	Birthosea bisura	Sumatra	Gauld 1987
	Darna sp.	Java	Gauld 1987
	Monema flavescens	Tsushima	Present study
	Parasa consocia	China, Osaka	Zhang 1983; Xiao 1985; present study
	Parasa lepida	China	Zhang 1983; Xiao 1985
	Setora nitens	Sumatra, Java	Gauld 1987
	Setothosea asigna	Indonesia, Sabah	Gonggrijp 1931; Tiong 1979, 1982; Gauld 1987
	Susica malayana	Indonesia	Gauld 1987
	Thosea lutea	Sumatra	Gauld 1987
	Thosea postornata	China	Zhang 1983; Xiao 1985
	Thosea sinensis	China	Zhang 1983; Xiao 1985
	Thosea vetusta	Indonesia	Gauld 1987
	Trichogyia semifascia	Sumatra	Gauld 1987



Figures 28–38. 28–35. *Chlorocryptus purpuratus*. **36–38.** *C. coreanus*. **28.** Second to seventh sterna (♀, Isoshima, Japan); **29.** Second to eight sterna and ninth tergites (♂, Isoshima); **30.** Gonosquama and basal ring (Isoshima); **31.** Aedeagus, lateral view (Isoshima); **32.** Aedeagus, ventral view (Isoshima); **33–38.** Subgenital plate (**33**. Isoshima; **34.** Cuc Phuong, Vietnam; **35.** Klapa Bali, Malaysia; **36.** Seonunsan, South Korea; **37.** Tieling, Liaoning, China; **38.** Keumsan, South Korea.).

wings (Fig. 25); however, we considered this an extreme end of the variation.

Jonathan (2006) treated *Chlorocryptus coeruleus* Cameron and *Chlorocryptus metallicus* Cameron as distinct species. However, given his descriptions, they fall within the variation of *Chlorocryptus purpuratus*.

Despite these large intraspecific variations, this species is clearly distinct from *Chlorocryptus coreanus* with the above given diagnostic characters.

The distribution of *Chlorocryptus purpuratus* extends further south than that of *C. coreanus* although the distributions of both species largely overlap in China (Figs 58, 59). We do not know what determines such a difference in the distribution and whether the species compete or segregate where they co-exist. The host and habitat preferences might be different between the species, which may also be of practical interest in the biological control of the notorious limacodids on various trees.

This is the first record of *Chlorocryptus purpuratus* from Japan and Vietnam. Considering that *C. purpuratus* has never before been collected in Japan, most probably the Japanese populations have been introduced recently. Its potential hosts, limacodid moths, are abundant and some of them have been well studied as pests in Japan, including their natural enemies (Kaji 1979, Koike 1985, 1998, Komeda and Hisamatsu 2006, Minamikawa 1962, Oda and Uezumi 1978, Togashi 1981, Togashi and Ishikawa 1994, 1995, 1996, Toyomura 1970, Yuasa 1934).

In 2012 and 2013, alongside the adults, we also collected two larvae in *Parasa consocia* cocoons in Osaka. This indicates that *C. purpuratus* has already been established in this area for two or three years.

One of the limacodid moths, *Parasa lepida* (Cramer), which had been originally distributed in South Asia, Southeast Asia, and southern China, invaded western Japan and became established in the late 1970's (Oda and Hattori 1981, Higa and Kishimoto 1984). It is probable that cocoons of *Parasa lepida* or other Limacodidae containing *C. purpuratus* were introduced accidentally in Japan with imported nursery trees.

The holotype of *Neodontocryptus hyalina* Saxena could not be located during the course of this study.

The holotype of the species was deposited in the V. K. Gupta collection, which was originally housed at the University of Delhi. Later, his collection was transferred to Florida, first to the University of Florida (Yu et al. 2012) and finally to FSCA (Virendra K. Gupta, personal communication). Therefore, we expected that the holotype of *N. hyalina* would be at FSCA; however, only one paratype was located, whereas the holotype was not found (Jim Wily, personal communication).

The lectotypes of *Cryptaulax cyaneus* Szépligeti and *C. metallicus* Szépligeti were designated by Townes et al. (1961). Five paralectotypes (two females and three males) of *C. cyaneus* and one paralectotype (female) of *C. metallicus* are preserved at HNHM together with their lectotypes (Gellért Puskás, personal communication). One female paralectotype of *C. metallicus*is is preserved in the Uchida collection at SEHU, which he obtained probably after visiting HNHM during his study trip to Europe and the United States from 1937 to 1939 (Uchida 1940).

DNA barcodes. INSD accession number: AB851419 for DNA-ICH-001 and AB851420 for DNA-ICH-002. Both have identical sequences.

Chlorocryptus coreanus (Szépligeti)

Figs 13–21, 26–27, 36–38, 59

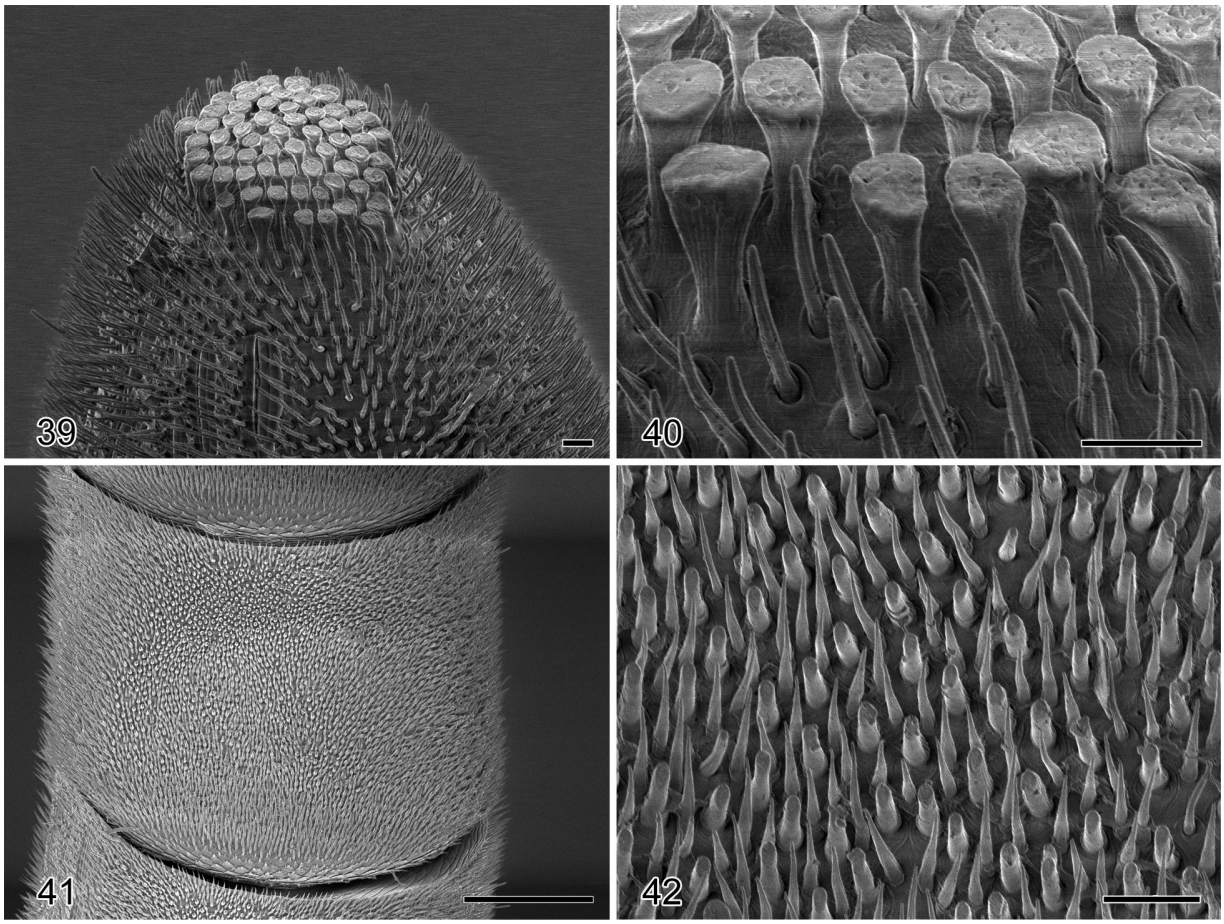
Cryptaulax coreanus Szépligeti, 1916: 287. Holotype: ♀, Korea, Seoul (HNHM) [examined].

Cryptus trirrhogmaniformis Sonan, 1929: 424. Lectotype: ♂, Formosa, Chikurin (TARI). Synonymized by Uchida (1930b).

Cochlidionostenus coreanus (Szépligeti): Uchida 1936: 116.

Chlorocryptus coreanus (Szépligeti): Townes et al. 1961: 141.

References. Uchida 1930a: 317 (*Cryptaulax*, records, host); Uchida 1930b: 360 (*Cryptaulax*, hosts); Uchida 1931: 177 (*Cryptaulax*, record, host); Matsumura 1931: 41 (*Cryptaulax*, diagnosis, figure, distribution); Uchida 1940: 122 (*Cochlidionostenus*, in key); Uchida 1942: 113 (*Cochlidionostenus*, records); Sonan 1944: 14 (*Cryptus trirrhogmaniformis*, listed); Uchida 1955: 114 (*Cochlidionostenus*, records); Kim 1955: 40 (*Cochleonosterus* (lapsus), record); Townes et al. 1961: 141 (catalogued); Chu et al. 1963: 750 (*Cryptaulax coteanus* (lapsus), as parasitoid of Limacodidae); Townes et al. 1965: 167 (catalogued); Yen 1973: 86 (*Cryptus trirrhogmaniformis*, listed, host); Chao 1976: 266 (listed, distribution, hosts); Chu et al. 1978: 40 (diagnosis, distribution, host); Yang and Wu 1981: 303 (listed, distribution, host); Sun et al. 1982: 46 (description, immature stages, host, biology); Pan 1983: 50 (*coevanus* (lapsus), description, figures, host, biology); Chiu et al. 1984: 17 (listed, distribution, hosts); Yin and Zou 1987: 11 (diagnosis, immature stages, biology, biological control effect on *Cnidocampa flavescens*); He and Wang 1987: 379 (diagnosis, host, distribution); Wang and Li 1987: 1326 (in key, record, host, distribution); Gauld 1987: 130 (taxonomic remarks); Wang et al. 1991: 30 (percentage of parasitism, biological control effect on *Cnidocampa flavescens*); Niu and Wang 1992: 1206 (description, figure, distribution, host, biology); Wang et al. 1993: 467 (rate of parasitism, life history, biological control effect); Wang and Huang 1993: 732 (description, figure, host, records, distribution); He et al. 1996: 510 (description, figure, host, distribution); Sheng et al. 1999: 374 (listed, records, distribution); He et al. 2001: 721 (listed, hosts, records, distribution); Lin 2003: 939 (listed, host, distribution); Wang 2003: 274 (description, figure, host, records, distribution); He et al. 2004: 514 (description, figures, host, records, distribution); He and Chen 2006: 110 (description, figures, biology, distribution); Chen et al. 2009: 70 (listed, distribution, records); Sheng and Sun 2009: 69 (description, photo, hosts, records, distribution); Sheng et al. 2013: 138 (description, photo, hosts, records, distribution).



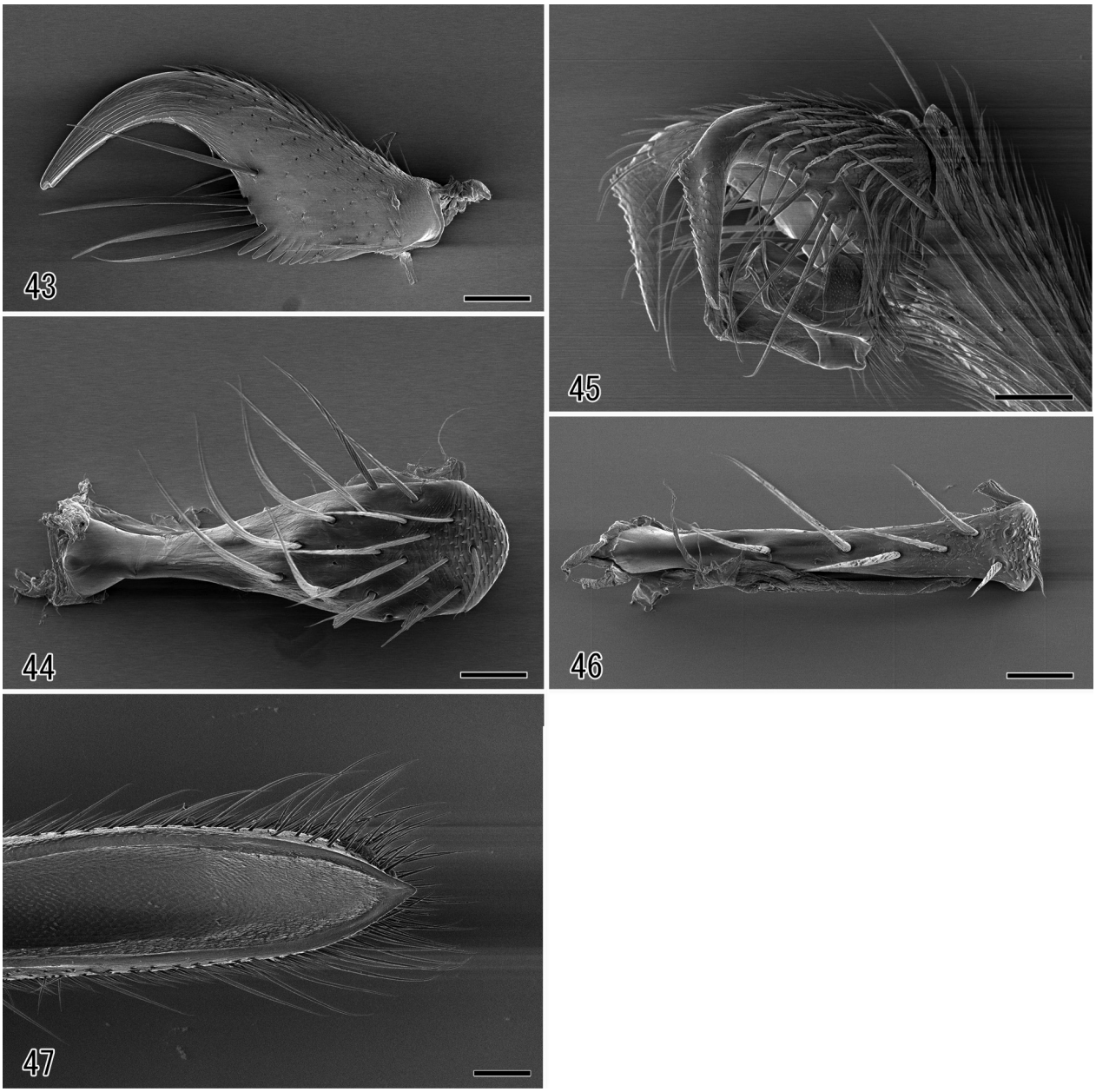
Figures 39–42. *Chlorocryptus purpuratus*. **39.** Apex of the female flagellum; **40.** Sensilla on the apex of the female flagellum; **41.** Ventral (flattened) face of the female flagellum (27th segment); **42.** Ditto, enlarged. Scale lines, 0.01 mm (Figs **39, 40, & 42**); 0.1 mm (Fig. **41**).

Type specimens examined. Holotype of *Cryptaulax coreanus* Szépligeti: ♀, "Korea, Sebul" ["Soeul" in the original description], HNHM (ID 115220). Paralectotype of *Cryptus trirrhogmaniformis* Sonan: ♂, "Shinchiku, Chikurin, ft. 3000" [= Chulin, Hsinchu], 10.ix.1928, J. Sonan, reared from a cocoon of *Monema* sp. on a cherry tree, SEHU.

Other specimens. South Korea. Poseoksa (N36°03.073'/E127°28.688'), Keumsan, Chungcheong-namdo, P. Tripotin, SEHU: 1 ♂, viii.1998; 1 ♀, 21.ix.2001. Seonunsan (N36°27'50″/E126°34'28″), Geochang, Jeollabuku-do, 1 ♂, 5.vi.2004, C. L. Young, SEHU. Suigen [= Suwon], Gyeonggi-do, K. Sato, SEHU: 1 ♂, 1925; 1 ♀, 4 ♂, 1.vi.1928; 1 ♀, 14.vi.1928. Shôyo-san, Keikido [= Soyosan, Gyeonggi-do], SEHU: 1 ♀, 15.vi.1941; 2 ♂, 10.ix.1943; 2 ♂, 17.ix.1943. Homyeongsan, Cheongpyeong, 1 ♂, 4.v, SEHU. Godaesan, Gyeonggi-do, 1 ♂, 21.vi.1942, SEHU. **China**. Tetsurei, Manchoukuo, [= Tieling, Liaoning Prov.], 1 ♀, 1 ♂, 11.vi.1938, I. Okada, SEHU. Domonrei, Manchoukuo [= Tumenling, Jiutai, Jilin Prov.], 1 ♀, 1 ♂, 19.viii.1939, H. Kôno, SEHU. Kaigen, Manchoukuo, [= Kaiyuan, Liaoning Prov.], I. Okada, SEHU: 1 ♀, 15.ix.1935; 1 ♀, 1.vi.1938. Ryôsuiji, Dalian, 1 ♀, 23.vi.1929, SEHU. "Nord Pekin", 1 ♂, A. David, 1865, MNHN.

Diagnosis. Punctation on head coarser than *C. purpuratus*. Temple swollen and wide, occupying 0.3–0.4 of length of head in dorsal view (Fig. 15). Face without transverse rugae (Fig. 13). Clypeus usually with pair of weak tubercles on apical margin (Fig. 14). Mandibular teeth blunt (Fig. 17). Female flagellum with white annulus around mid-length and with apical third ventrally weakly flattened but not widened. Epomia not turned toward mesal line of pronotum (Fig. 19). Prepectus without a short vertical carina opposite lower corner of pronotum. Mesoscutum punctate, without rugae, and glabrous area on lateral lobe narrow (Fig. 18). Propodeum without posterior transverse carina. Nervellar index 1.3–1.8 (Figs 26, 27). Postpetiole long, 0.8–1.0 as long as wide in female, 0.7–1.0 in male (Fig. 21). Median longitudinal carina of 1st tergite not raised at all at beginning of postpetiole (Fig. 20). Subgenital plate (Figs 36, 37) with postero-lateral corner more angulated, with posterior margin weakly notched on median convexity, and with white spot at base of its apodeme.

Description. Adult. ♀. Head (Fig. 15) 1.7–1.8 times as wide as long in dorsal view. Temple swollen, occupying 0.3–0.4 of length of head in dorsal view (Fig. 15). POL/OOL=0.6–0.8. Vertex and gena densely with coarse punctures; punctures smaller and shallower on gena than



Figures 43–47. *Chlorocryptus purpuratus*. **43.** Female hind tarsal claw; **44.** Orbicular of female hind tarsus; **45.** Male hind tarsal claw; **46.** Orbicula of male hind tarsus; **47.** Apex of ovipositor sheath. Scale lines, 0.1 mm (Figs **43, 45, & 47**); 0.05 mm (Figs **44 & 46**).

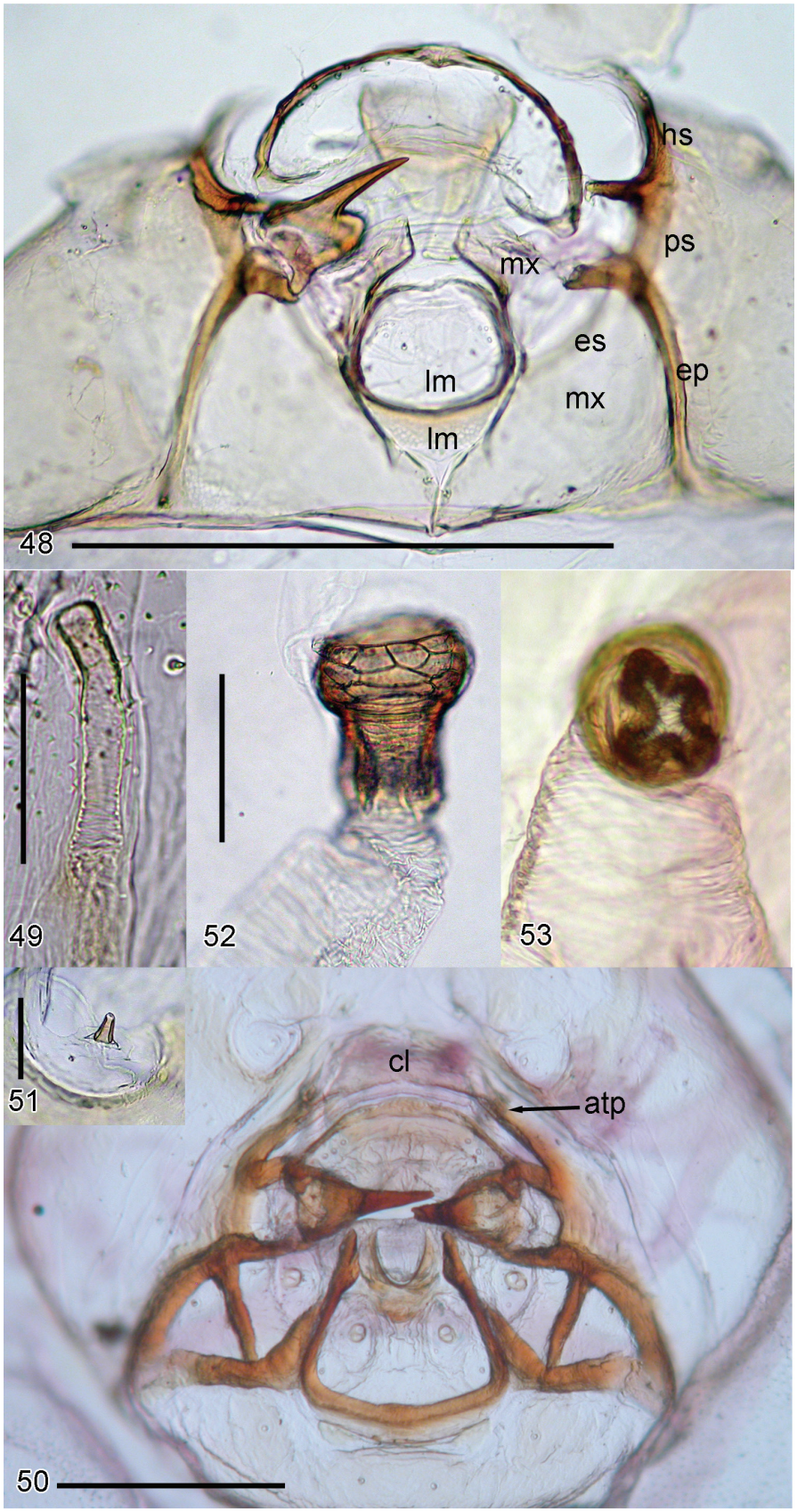
on vertex. Face 1.4–1.5 times as wide as high, distinctly convex medially, punctate-reticulate (Figs 5, 13). Clypeus with pair of weak tubercles on apical margin, punctate-reticulate, punctures larger than on face (Fig. 14). Malar space 0.8–1.0 times as wide as mandible width. Mandible stout, with short and blunt teeth; upper tooth broad, a little longer than lower one (Fig. 17). Antenna with 32–34 flagellomeres. Apical third of flagellum weakly flattened ventrally but not thickened, weakly tapered to apex. First flagellomere 4.9–5.8 times as long as apical width, a little longer than 2nd flagellomere. Fifth flagellomere 2.3–2.5 times as long as apical width.

Epomia ends at midway to upper edge of pronotum without turning toward mesal line of pronotum (Fig. 19). Prepectus without a short vertical carina opposite lower corner of pronotum. Mesoscutum and scutellum lacunose, without rugae, and with only narrow glabrous stripe on lateral lobe (Fig. 18). Mesopleuron punctate to areolate-rugose on lower part to transversely strigate on upper frontal part. Mesosternum densely punctate. Metapleuron areolate-rugose. Upper division of metapleuron punctulate. Propodeum areolate rugose; only anterior transverse carina present, other carinae absent.

Legs slender. Hind femur 6.0–7.7 times as long as maximum width. Hind tibia 8.5–9.5 times as long as apical width.

Fore wing about 11–14 mm long. Nervellar index 1.3–1.8 (Figs 26, 27).

First metasomal tergite 1.9–2.3 times as long as apical width, with postpetiole 0.7–1.0 times as long as apical



Figures 48–53. Larval morphology of *Chlorocryptus purpuratus*. **48.** Head capsule of 1st instar larva (left mandible is detached); **49.** Spiracle of 1st instar larva; **50.** Head capsule of 5th instar larva, antennae broken off; **51.** Antenna of 5th instar larva; **52 & 53.** Spiracle of 5th instar larva. **Atp** – anterior tentorial pit; **cl** – clypeus; **ep** – epistoma; **es** – epistomal spur; **hs** – hypostoma; **lm** – labrum; **mx** – maxilla; **ps** – pleurostoma. Scale lines, 0.5 mm (Fig. **48**); 0.05 mm (Fig. **49**); 0.5 mm (Fig. **50**); 0.1 mm (Fig. **51**); 0.2 mm (Figs **52 & 53**).

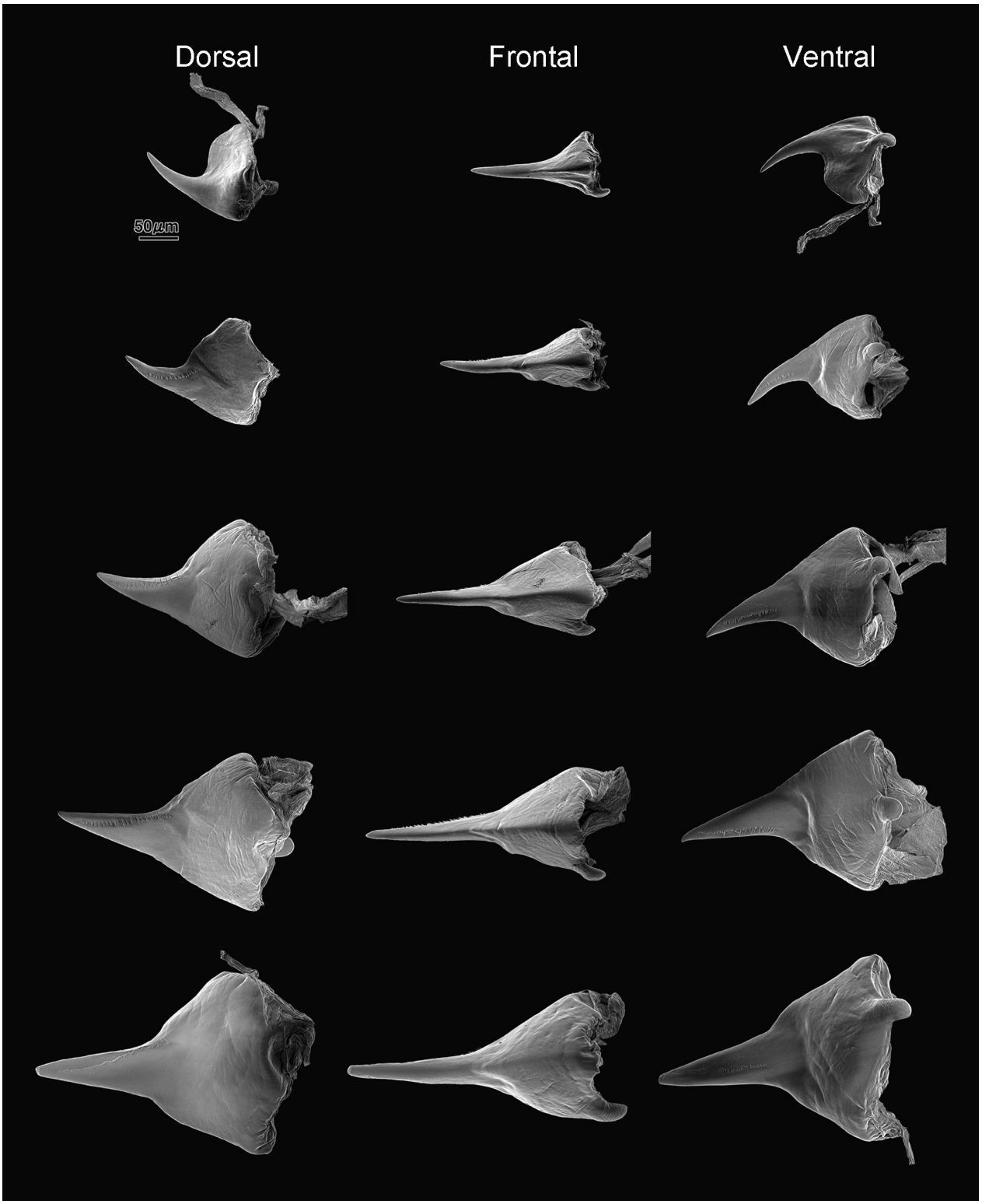
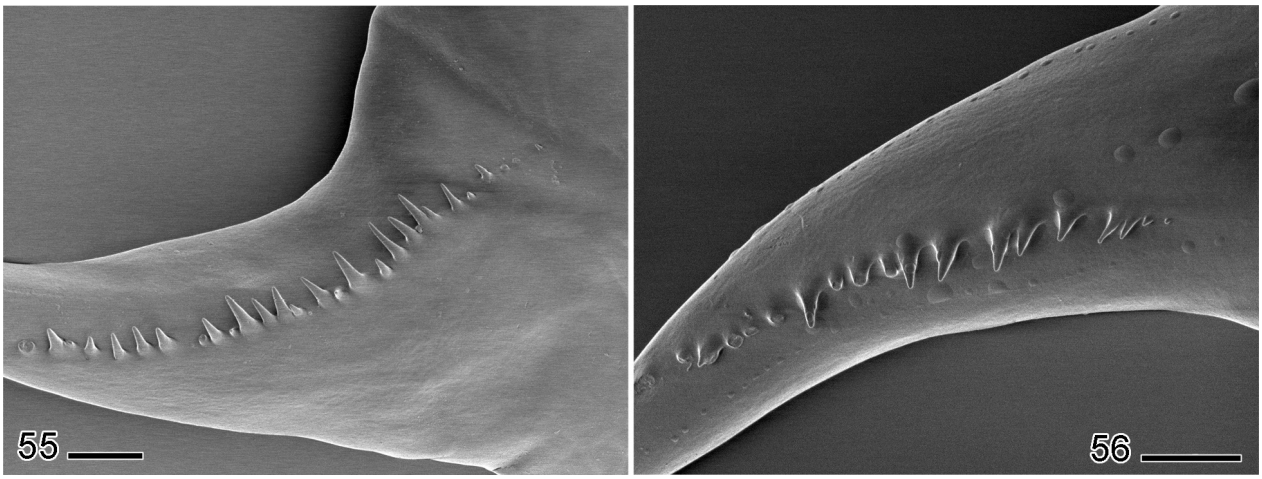


Figure 54. *Chlorocryptus purpuratus*, left mandibles of larva. The mandibular parts isolated from 1st to 5th larval exuviae of the same individual extracted from a host cocoon. From above to bottom, 1st to 5th instars.

width; dorsal face not distinctly raised; median longitudinal carina absent or very weak on its entire length (Figs 20, 21). Ovipositor sheath 0.9–1.0 times as long as hind tibia.

Body with metallic luster in blue, purple or green. Flagellum black with white band on 6th–9th flagellomeres. Fore and middle tibiae and all tarsi are dark brown to black. Ovipositor sheath and ovipositor black. Wings narrowly infumate apically (Fig. 26).

♂. Similar to female except as follows: face 1.0–1.2 times as wide as long; flagellum with 37–39 flagellomeres, with 5 or 6 tyloids which can be on 14th–20th flagellomeres; 1st flagellomere 2.8–3.3 times as long as



Figures 55, 56. Left mandible of 2nd larva of *Chlorocryptus purpuratus*. **55.** Dorsal side; **56.** Ventral side. Scale lines, 0.01 mm.

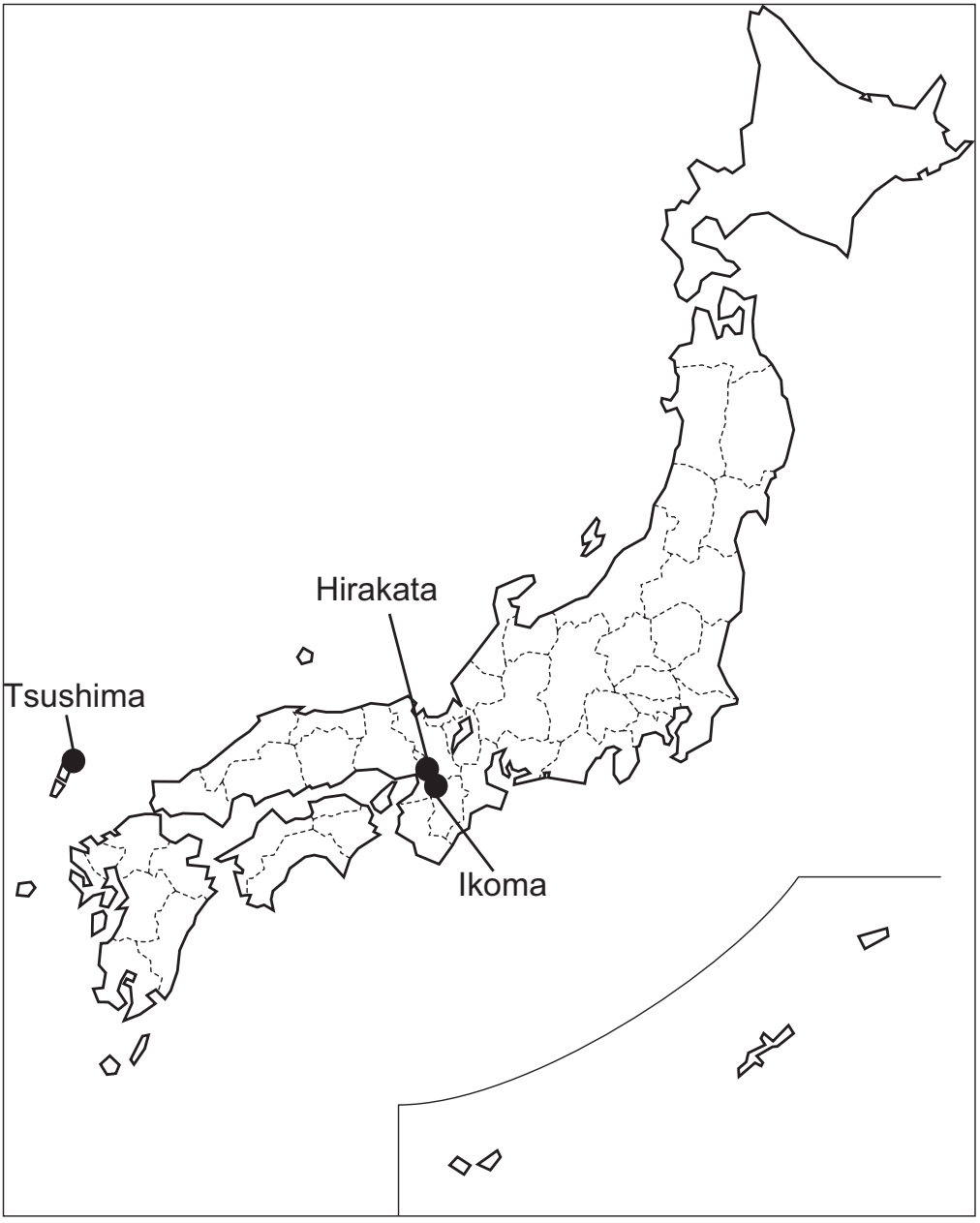
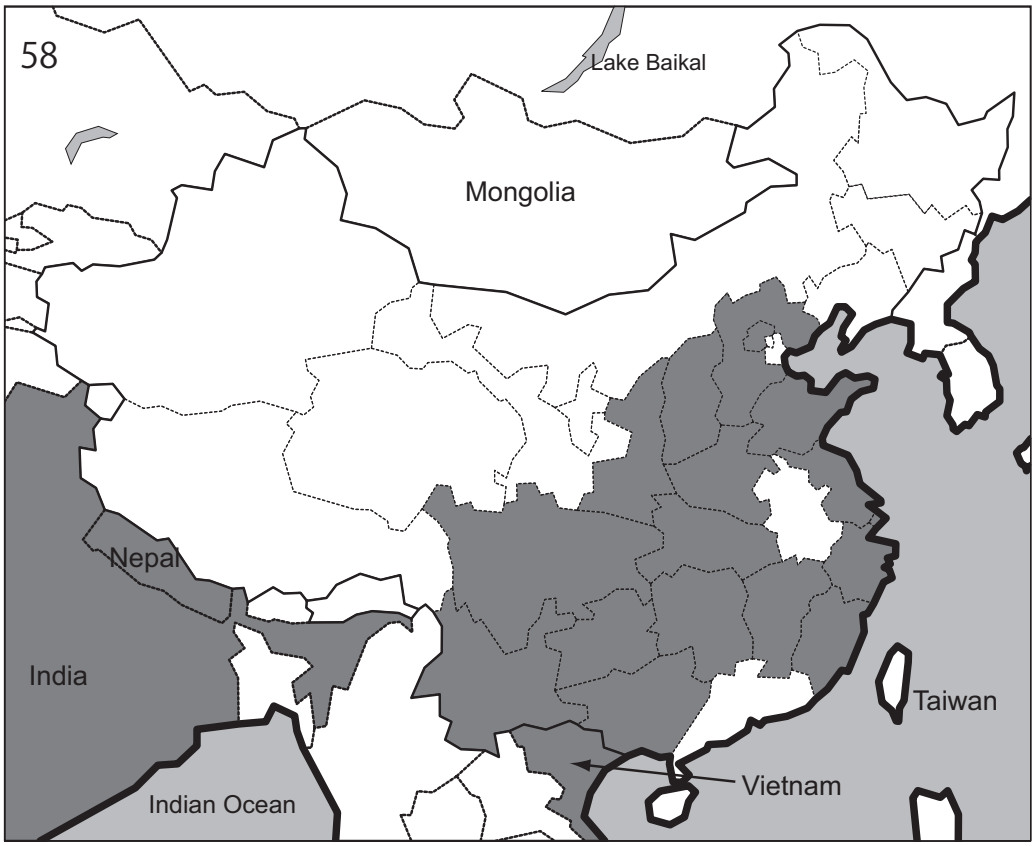
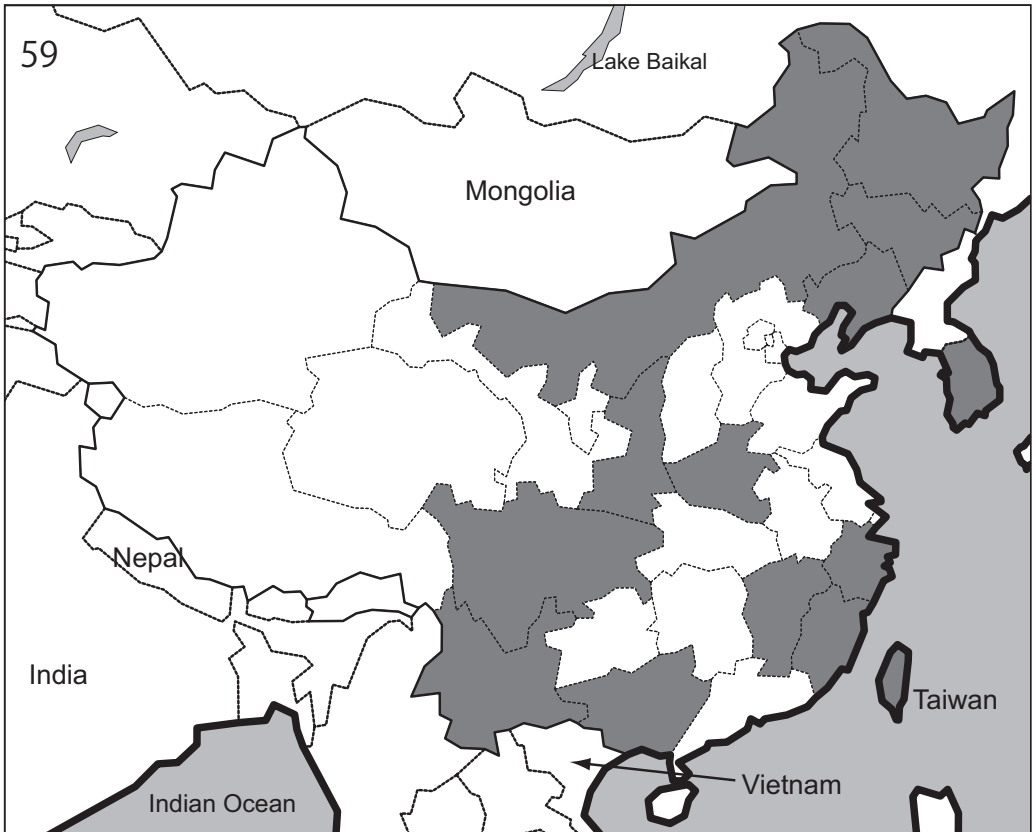


Figure 57. Distribution of *Chlorocryptus purpuratus* in Japan.





Figures 58, 59. Distributions of *Chlorocryptus purpuratus* and *C. coreanus* in China (by province) and in adjacent countries.

apical width; 1st metasomal segment 2.0–2.4 times as long as apical width; hind femur 7.0–8.5 times as long as median depth; hind tibia 9.3–10.0 times as long as apical width; stripe on anterior face of fore femur, fore tibia and dorsal stripe of middle tibia light brown. Subgenital plate with postero-lateral corner more angulated than in *C. purpuratus*, with posterior margin convex, with small concavity on middle of convexity (Figs 36, 37), but one aberrant specimen from Korea without concavity (Fig. 38); usually with white spot near base of apodeme. Wings narrowly infumate in specimens from Korea and North China, but Taiwanese specimens with extensively brown wings (Fig. 27).

Biology. *Monema flavescens* Walker (Uchida 1930b, Sun et al. 1982, Pan 1983, Yin and Zou 1987, Wang et al. 1991, 1993) and *Miresa inornata* Walker (Limacodidae) (Uchida 1930a) have been recorded as hosts.

Distribution. (Fig. 58). Korea (Szépligeti 1916, Uchida 1930a, 1955, Kim 1955). China: Fujian (Wang 2003, Wang and Huang 1993), Guangxi (Niu and Wang 1992), Heilongjiang (Niu and Wang 1992), Henan (Sheng et al. 1999, Sheng and Sun 2009), Jiangxi (Sheng et al. 2013), Jilin (Yin and Zou 1987), Liaoning (Uchida 1942, Sun et al. 1982, Pan 1983), Neimenggu (Niu and Wang 1992), Shaanxi (He and Chen 2006), Sichuan (Wang and Huang 1993), Yunnan (Wang and Li 1987), Zhejiang (He and Wang 1987, He et al. 2001). Taiwan (Sonan 1929, Uchida 1931).

Remarks. Similar to the preceding species, this species shows considerable intraspecific morphological variation. Only the Taiwanese specimens, namely the type series of *Cryptus trirrhogmaniformis*, have the fore wings entirely tinged with brown (Fig. 27) (according to the original description of *C. trirrhogmaniformis*, the lectotype has also brown wings), and all the other specimens examined have the fore wings darkened only apically (Fig. 26). One specimen from Korea (Fig. 38) has a differently shaped subgenital plate, which we considered to be aberrant.

In the description of *Cryptaulax coreanus*, Szépligeti (1916) did not originally designate the holotype nor mentioned the number of specimens he examined. The Szépligeti's collection at HNHM contains only one specimen of the species, which Townes et al. (1961) treated as the holotype fixed by monotypy.

Cryptus trirrhogmaniformis Sonan was described based on two male syntypes. One was deposited at TARI and the other was probably donated to Uchida at that time and now is located at SEHU. The TARI specimen was treated as "type" by Townes et al. (1961), which is considered a lectotype designation as it is evident that the authors cited the specimen to serve as the name-bearing type (ICZN 74.5).

Key to species

1 Temple swollen and wide, occupying 0.3–0.4 of length of head in dorsal view (Fig. 15). Face without transverse rugae (Fig. 13). Female flagellum with white annulus around mid-length and with apical third ventrally weakly flattened but not widened. Mesoscutum punctate, without rugae, and glabrous area on lateral lobe narrow (Fig. 18). Propodeum without posterior transverse carina ..... *C. coreanus* (Szépligeti).

– Temple flat and narrower, occupying 0.2–0.3 of length of head in dorsal view (Fig. 4). Face with transverse rugae in addition to punctures (Fig. 2). Female flagellum without white annulus and with apical third of flagellum ventrally distinctly flattened and widened (Fig. 7). Mesoscutum with longitudinal rugae in addition to punctures, and with moderate-sized glabrous area on lateral lobe (Fig. 8). Propodeum with posterior transverse carina.....*C. purpuratus* (Smith).

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