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Taxonomic Studies of Cardiochilinae (Hymenoptera: Braconidae) Focused on Specific Genera from Both the Old World and the New World

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TAXONOMIC STUDIES OF CARDIOCHILINAE (HYMENOPTERA: BRACONIDAE) FOCUSED ON SPECIFIC GENERA FROM BOTH THE OLD WORLD AND NEW WORLD

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ABSTRACT

Taxonomy is a fundamental scientific study in biology, which defines, classifies, and names biological organisms. Braconidae Latreille, 1829 (Hymenoptera) is a megadiverse insect family in need of continuing taxonomic research. Among 45 braconid subfamilies, Cardiochilinae Ashmead, 1900 has had little attention by braconid taxonomists during the previous twenty years. In this dissertation, seven cardiochiline genera, *Bohayella* Belokobylskij, 1987, *Heteropteron* Brullé, 1846, *Neocardiochiles* Szépligeti, 1908, *Orientocardiochiles* Kang & Long, 2020, *Retusigaster* Dangerfield, Austin, & Whitfield, 1999, *Schoenlandella* Cameron, 1905 and *Wesmaelella* Spinola, 1851 are taxonomically reviewed and investigated. *Orientocardiochiles* was described as a new genus, the first new genus in the last twenty-three years. *Neocardiochiles* has been resurrected, and the relationships among *Heteropteron*, *Neocardiochiles,* and *Wesmaelella* were re-evaluated using a phylogeny based on morphological data. In the *Neocardiochiles* project, five new species of *Neocardiochiles* were described and five new combinations proposed. New distribution records of *Bohayella* from Costa Rica and Ecuador were reported, and three new species of the genus have been described. In addition, six species of *Retusigaster* and *Schoenlandella* have been newly described with information about potential food sources for *R. arugosus* (Mao, 1949) and *R. pushi* Kang, 2022 and potential host insect species of *S. montserratensis* Kang, 2021. Molecular data of some species have been obtained and deposited in GenBank, which can be utilized in future research. Traditional and interactive identification keys have been constructed and high-quality key images are provided. Eighteen genera and 237 species of Cardiochilinae have now been recorded. Taxonomic data obtained in the dissertation will be fundamental for future basic and applied agricultural and biological research.

CHAPTER 1. INTRODUCTION

1.1. Introduction to the Family Braconidae

Braconidae Latreille, 1829 is the second largest subfamily in Hymenoptera, which includes 45 subfamilies, ~1,060 genera, ~20,000 species (Yu et al. 2016). As far as is known, all the members are parasitoids. These braconid parasitoids oviposit a single egg or multiple eggs in their hosts. All the known hosts of braconids are insects, mostly in the orders Lepidoptera Coleoptera, Diptera, and Hemiptera. On the other hand, some members of the adelphotaxon, Ichneumonidae Latreille, 1802 (Hymenoptera), also use spiders as their host. Recently, the taxonomic status of the two subfamilies Trachypetinae Schulz, 1911 and Masoninae van Achterberg, 1995 fluctuated. Based on molecular and morphological data, Trachypetinae was elevated as a family Trachypetidae by Quicke et al. (2020b), and Masoninae was transferred to Ichneumonidae (Quicke et al. 2020a). Recently, Jasso-Martínez et al. (2022) returned Trachypetidae as Trachypetinae and placed Masoninae into Braconidae based on ultraconserved elements (UCEs) data. Traditionally, braconid species are informally separated into two groups, cyclostomes (including the aphidioid complex) and non-cyclostomes, based on exposure of labrum caused by clypeal margin structure (Sharkey 1993). In the previous studies based on molecular data-based phylogenies, these two informal groups were resolved as a monophyletic group (Sharanowski et al. 2011, Sharanowski et al. 2021, Jasso-Martínez et al. 2022). Ancestral characteristics of Braconidae were mapped on genomic data-based phylogenies by Sharanowski et al. (2021) and Jasso-Martínez et al. (2022), and the most plesiotypic character of the non-cyclostome braconids was recovered as koinobiont braconids that allow hosts to continue to grow after parasitism. However, there were no consistent results of the two studies regarding the ancestral characteristics of the cyclostomes. In Sharanowski et al. (2021), the most plesiotypic

character of the cyclostomes was confirmed as idiobionts that do not allow host to continue to grow after parasitism. In Jasso-Martínez et al. (2022), koinonbiosis was recovered as the most plesiotypic character of the cyclostomes. Among non-cyclostome braconid subfamilies, there is a microgastroid complex comprised of Adeliinae Viereck, 1918, Cardiochilinae Ashmead, 1900, Cheloninae Förster, 1862, Khoikhoiinae, Mason, 1983 Medesellinae Whitfield & Mason, 1994, Microgastrinae Latreille, 1804, and Miracinae Viereck, 1918. The largest subfamily of the complex is Microgastrinae, which includes 81 genera and ~3000 described species (Ferenandez-Triana et al. 2020), and Cheloninae is the second largest subfamily in the complex with 16 genera and 1375 species (Yu et al. 2016). Cardiochilinae is the third largest subfamily on which the current dissertation is focused. Still, relationships among subfamilies of the microgastroid complex are uncertain due to close relationships among the members of the complex (Murphy et al. 2008). During the near future, with deposited molecular data from the 2000s and newly obtained molecular data, it is probable that the relationships of the complex will be resolved.

1.2. Introduction to the Subfamily Cardiochilinae

Cardiochilinae is the third largest subfamily in the microgastroid complex as mentioned in 1.1. Before this dissertation research, 16 genera and ~220 species were recorded (Yu et al. 2016). Cardiochiline members can be easily distinguished from other braconids by the combination of the following characters: labrum concealed (non-cyclostome); 3RSb vein curved or angled; Y-shaped suture present on T1. Biology of most members is inadequately known. Those whose biology is known are solitary koinobiont endoparasitoids of lepidopteran larvae (Huddlestone and Walker 1988; Yu et al. 2016). Some cardiochiline species were tested and utilized as biological control agents (Bhatnagar 1988; Coaker 1959; Lewis and Vinson 1971; Barrion et al. 1979; Marsh 1986) against some important lepidopteran pests such as *Chloridea virescens*

(Fabricius, 1777) (Nocutidae), *Cnaphalocrocis medinalis* (Guenée, 1854) (Crambidae), *Diaphania hyalinata* (Linnaeus, 1767) (Crambidae) *Heliothis armigera* (Hübner, 1808) (Noctuidae). Another biological feature is the presence of bracoviruses (polydnaviruses of braconids). These polydnaviruses are produced in the cells of the calyx glands. This gives the immatures of members of the micarogastroid complex protection from the immune systems of the host insects. These polydnaviruses were first discovered from *Toxoneuron nigriceps* (Viereck, 1912) (Vinson and Scott 1975) and the species has been actively used as model insects for these bracovirus studies (Vinson and Scott 1975; Tanaka and Vinson 1991; Pennacchio et al. 1998; Provost et al. 2004; Cônsoli et al. 2007; Salvia et al. 2021).

Despite the size of the subfamily, the generic taxonomic status of Cardiochilinae has often fluctuated based on morphological characters (Whitfield and Dangerfield 1997; Dangerfield et al. 1999; Mercado and Wharton 2003). The two largest genera, *Cardiochiles* Nees, 1819 and *Schoenlandella* Cameron, 1905 account for about ~55% of the described species in the World. The other fifteen genera account for an average of ~ 3% each of the recorded species in the world (Dangerfield et al. 1999).

To re-evaluate the relationships of the cardiochiline genera with newly collected specimens, the research projects in this dissertation were designed and conducted. The main project was the revision of the *Heteropetron* Brullé, 1846 genus group based on phylogenetic data. The relationships among genera of *Heteropteron, Neocardiochiles* Szépligeti, 1908, and *Wesmaelella* Spinola,1851 were compared, and *Neocaridiochiles*, which was a junior synonym of *Heteropteron,* was resurrected. In addition, five new species of *Neocardiochiles* were described based on morphological and molecular data. In other projects, *Bohayella* Belokobylskij, 1987, *Orientocardiochiles*, *Retusigaster* Dangerfield, Austin, & Whitfield, 1999,

Schoenlandella were investigated, and ten new species with a new genus from the Old World were discovered and described. All projects include identification keys with detailed images. As part of the main project, a web-based interactive key was constructed. Potential food sources and a potential host insect were also discovered and reported to science.

1.3. Objectives

The primary objective of the current dissertation research is to conduct taxonomic research of Cardiochilinae based on morphological and molecular data. This includes secondary objectives: describing new taxa, construction of identification keys, obtaining molecular data, updating biological and taxonomic information, and generating phylogenetic trees.

Chapter 3 consists of two subchapters. The main goal of subchapter 3.1. is to describe the new genus, *Orientocardiochiles* Kang & Long, 2020 and its type species, *Orientocardiochiles joeburrowi* Kang, 2020 from the Oriental region based on morphological data. The primary goal of subchapter 3.2. was to describe two new species of *Schoenlandella* Cameron, 1905 based on morphological data and to provide the first identification key to species of *Schoenlandella* in Iran. Chapter 4 contains four subchapters. The major aims of subchapter 4.1. were to report the first distribution records of *Bohayella* Belokobylskij, 1987 from Costa Rica and Ecuador, to describe three new species based on morphological characters, and to construct the first key to species of *Bohayella* in the New World. The goal of subchapter 4.2. was to describe three new species of *Retusigaster* Dangerfield, Austin & Whitfield, 1999 based on morphological data, to provide updated taxonomic and biological information of *Retusigaster*, and to provide an identification key with detailed images. The objective of subchapter 4.3 was to describe a new species of *Schoenlandella* from Montserrat and discuss a potential host insect of the new cardiochiline species. The goals of subchapter 4.4. were to examine relationships between genera

of *Heteropteron*, *Neocardiochiles,* and *Wesmaelella* based on a morphological data-based phylogeny, to describe five new species of *Neocardiochiles*, to propose new combinations, to obtain molecular data of new species, and to construct both traditional and interactive identification keys.

CHAPTER 2. MATERIALS AND METHODS

2.1. Specimens

Approximately 700 cardiochiline specimens were borrowed from the following institutions:

- California Academy of Sciences (CAS; San Francisco, California, USA)
- Fera Sciences Ltd (London, UK)
- Hungarian Natural History Museum (HMNH; Budapest, Hungary)
- Hymenoptera Institute (HIC: 116 Franklin Ave., Redlands, California, USA)
- Illinois Natural History Survey (INHS: Champaign, Illinois, USA)
- Insect Taxonomy Research Department, Iranian Research Institute of Plant Protection, Agricultural Research Education and Extension Organization (IRIPP: Tehran, Islamic Republic of Iran)
- Institute of Ecology and Biological Resources (IEBR: Ha Noi, Vietnam)
- Louisiana State Arthropod Museum (LSAM: Baton Rouge, Louisiana, USA)
- Museo de Insectos, University of Costa Rica (MICR: San José, Costa Rica)
- Museum of Comparative Zoology (MCZ; Cambridge, Massachusetts, USA)
- Museums Victoria (MVMA: Melbourne, Victoria, Australia)
- Texas A&M University Insect Collection (TAMU: College Station, Texas, USA)
- University of Wyoming Insect Museum (UWIM; 1000 East University Avenue, University of Wyoming, Laramie, Wyoming 82071-3354, USA)

Holotypes of species described will be deposited in the following institutions:

Sections 2.5−2.7 of this chapter were previously published as a part of Kang I, Whitfield JB, Owens BE, Chen J (2022c), "Resurrection of *Neocardiochiles* Szépligeti, 1908 (Hymenoptera: Braconidae: Cardiochilinae) with descriptions of five new species from the Neotropical region," Journal of Hymenoptera Research 91: 41−68. Copyright © Ilgoo Kang et al. [https://doi.org/10.3897/jhr.91.84937]

- CAS
- Canadian National Collection of Insects (CNC: Ottawa, Ontario, Canada)
- National Museum of Natural History (NMNH; the Smithsonian Institution, Washington D.C., USA)
- Natural History Museum in London (NHML: London, UK)
- Royal Belgian Institute of Natural Sciences (RBINS; Brussels, Belgium)
- TAMU
- UWIM

2.2. Terminology, Acronyms, and Morphometric Characters

External morphological examinations were performed using a Leica MZ75 stereomicroscope. Morphological terminology mostly follows Dangerfield et al. (1999), Sharkey and Wharton (1997). For subchapter 3.1., morphological terms are based on van Achterberg (1993). Terms for sculpture are based on Harris (1979). Wing vein terminology mostly follows Sharkey and Wharton (1997), and the modified Comstock-Needham system (van Achterberg 1993) was used for subchapter 3.1. The following acronyms are used for morphological terms: OOL: distance between posterior ocelli and eye; OD: diameter of posterior ocellus; POL: distance between posterior ocelli, T1: first metasomal tergite, T2: second metasomal tergite, T3: third metasomal tergite, T4: forth metasomal tergite, T5: fifth metasomal tergite, T6: sixth metasomal tergite, T7: seventh metasomal tergite, and T8: eight metasomal tergite. Body parts were measured using the Adobe Photoshop CS 6 and Photoshop CC 2022 v. 23.0 (Adobe Systems, Inc). Numbers in parentheses in species descriptions indicate the actual size of each body character. The unit of length is mm. Definitions of the morphological measurements used in the subchapter 3.1. are mostly based on van Achterberg (1988).

2.3. Distribution Maps

Distribution maps were produced using QGIS 3.10.0 (QGIS Development Team 2019). Google satellite or terrain maps were downloaded via the QuickMapServices plugin.

2.4. Genus and Species Concepts

Generic boundaries and species concepts were initially based on morphological characters, and molecular or phylogenetic data were compared with morphology-based genus or species concepts when molecular or phylogenetic data were available.

2.5. Morphological Phylogenetic Analysis

The morphological phylogenetic analysis was conducted in subchapter 4.4. to examine relationships of *Heteropteron* Brullé, 1846, *Neocardiochiles* Szépligeti, 1908 and *Wesmaelella* Spinola, 1851. *Protomicroplitis calliptera* (Say, 1836) (Braconidae: Microgastrinae) was used as an outgroup. Thirty-nine morphological characters were included in the analysis (Table 1); 29 were included as new informative characters, and ten characters were modified or based on the characters used by Dangerfield et al. (1999) in their phylogenetic analysis. Characters of each species were coded from female specimens. A male specimen of *N. whitfieldi* (Mercado, 2003), comb. nov., was used to code characters because the only known specimen of the species is male. Thirty-two characters were coded as binary states and the remaining seven characters were coded as multistate characters. Continuous characters were coded as discrete characters. The character matrix (Appendix A) for the phylogenetic analysis was prepared using Mesquite version 3.70 (Maddison and Maddison 2021). In the matrix (Appendix A), '?' indicates character states that were not coded because those characters were absent on specimens. Using this matrix (Appendix A), a maximum parsimony (MP) analysis was conducted using PAUP* (Swofford 2021). Heuristic searches were conducted via multiple TBR + TBR hold. All character states

were unweighted and unordered. A list of apomorphic characters was produced using PAUP* and mapped on the MP phylogeny using Adobe Acrobat Pro DC (Adobe Systems, Inc).

Table 1. List of characters and character states used in the data matrix

Number	Characters	Character states
1	Y-shaped suture on frons	absent = 1; present = 2
2	POD	broad = 1; narrow = 2
3	Malar space width	as long as basal width of mandible = 1; shorter than basal width of mandible = 2
4*	Mouthparts length	short = 1; elongate = 2
5	3rd maxillary palpi shape	moderately swollen apically in lateral view = 1; strongly swollen apically in lateral view= 2
6	Scutellar sulcus shape	transversely straight = 1; transversely curved = 2
7	Scutellar sulcus depth	shallow and evenly impressed = 1; medially shallow, laterally deep = 2
8	Scutellum length	longer than basal width of scutellum = 1; shorter than basal width of scutellum = 2
9	Metascutellum length	long = 1; short = 2
10	Posterior margin of axilla	meeting lateral margin of scutellum with narrow angle = 1; meeting lateral margin of scutellum with broad angle = 2
11	Pronotal carina	absent = 1; present = 2
12	Episternal scrobe	apparent = 1; weakly impressed = 2

(table cont'd.)

Number	Characters	Character states
13	Ventral margin of metapleuron	without carinate margin = 1; anteriorly carinate = 2; entirely carinate = 3
14*	Median longitudinal furrow on propodeum	absent=1; present=2
15	Curved submedial carina on propodeum	absent=1; present posteriorly=2
16	Lateral margin of propodeum	absent=1; carinate=2
17*	Fore wing 1r	present = 1; absent=2
18	Fore wing 2RS shape	angled = 1; basally weakly curved = 2; straight= 3
19*	Fore wing 3RSb	broken basally = 1; evenly present = 2
20	Fore wing (RS+M)b length	shorter than m-cu = 1; longer than m-cu = 2
21	Fore wing (RS+M)b angle	meeting 2M with ~140˚ = 1; meeting 2M with 180˚ = 2
22	Fore wing RS2	present as basal stump = 1; absent = 2
23	Fore wing r-m length	0.5 × longer than height of second submarginal cell = 1; 0.3 × longer than height of second submarginal cell = 2; as long as height of second submarginal cell = 3
24	Fore wing 1cu-a origin	arising from middle of 1CU = 1; arising from basal fourth of 1CU = 2

(table cont'd)

Number	Characters	Character states
25*	Fore wing 1a	absent = 1; present = 2
26	Hind wing M+CU length	slightly longer than 1M = 1; shorter than 1M = 2; as long as 1M = 3
27	Hind wing cu-a length	as long as 1M = 1; shorter than 1M = 2
28*	Hind wing 2-1A length	reaching at basal half = 1; not reaching at basal half = 2
29	Second tarsomere of fore leg length	shorter than fifth tarsomere = 1; as long as fifth tarsomere = 2
30	Second tarsomere of middle leg length	shorter than combined length of third and fourth tarsomeres = 1; longer than combined length of third and fourth tarsomeres = 2
31	Basal spur on hind tibia length	~0.33 × longer than hind basitarsus = 1; ≥ 0.40 × longer than hind basitarsus = 2
32*	Tarsal claws	Simple = 1; pectinate = 2
33*	T1 ratio	≤ 1.70 × = 1; ≥ 2.0 × = 2
34	First laterotergite	weakly curved posteriorly = 1 strongly curved posteriorly = 2
35	Spiracle of first laterotergite	touching dorsal margin of first laterotergite = 1; located near median = 2
36	Spiracle of second laterotergite	close to anterior margin, but not touching = 1; located near median = 2

(table cont’d)

Number	Characters	Character states
37*	Ovipositor sheath length	longer than hind femur = 1; shorter than hind femur; unknown = ?
38	Ovipositor sheath shape	ventro-apically round=1; ventro-apically pointed=2; unknown=?
39*	Median longitudinal fold on hypopygium	absent = 1; present = 2; unknown = ?

***** Characters are based on or modified from Dangerfield et al. (1999)

2.6. Molecular Analyses

DNA was extracted from one to two legs of each specimen using the DNeasy Blood and Tissue Kit (QIAGEN, Hilden, Germany). Mitochondrial 16S rRNA (16S), and nuclear 28S rRNA (28S) genes were targeted and amplified using the primers listed in Table 2. PCR reaction volumes were 25ul containing 12.5ul of DreamTaq Green PCR Master Mix (2X) (Thermo Scientific), 1–2ul of template genomic DNA, 9.5ul of ddH_2O, and 1.0ul of each primer at 5–10uM. PCR conditions were 95°C for 3 min; 40 cycles of 95°C for 30 s, 50°C for 30 s and 72°C for 1 min; and a final extension at 72°C for 7 min for 16S. For 28S, we followed Smith et al. (2008), but reduced the cycle number from 35 to 30. PCR products were visualized on a 1.8–2.0 % agarose gel to confirm the success of amplification. PCR products were initially cleaned by a EtOH clean-up method and sequenced on the 3130xl Genetic Analyzers (Applied Biosystems) using BigDye Terminator v3.1 chemistry (Applied Biosystems) at the LSU Genomics Facility. DNA assembly and sequence editing were conducted using Geneious Prime 2021.2 (https://www.geneious.com). Edited sequences of 16S and 28S were aligned using MUltiple Sequence Comparison (MUSCLE) (Edgar 2004) on the website of EMBL's European

Bioinformatics Institute (https://www.ebi.ac.uk/Tools/msa/muscle/) (Madeira et al. 2019) with a default setting. Genetic distances were estimated using MEGA11 (Tamura et al. 2021). The estimates were performed with a Kimura-2-parameter model (K2P) with pairwise deletion for the gaps/missing data treatment.

Table 2. Information for genes and primers used in the current study.

Target genes	Primer sequences (5′→3′)	References
16S rRNA	cacctgtttatcaaaaacat (F)	Dowton and Austin (1994)
	cttaattcaacatcgaggtc (R)	Chen et al. (2006)
28S rRNA	agagagagttcaagagtacgtg (F)	Belshaw and Quicke (1997)
	ttggtccgtgtttcaagacgg (R)	Campbell et al. (2000)
	tagttcaccatctttcgggtc (R)	Belshaw et al. (2001)

2.7. Molecular Phylogenetic Analyses

Maximum likelihood analysis (ML) was conducted using MEGA11 (Tamura et al. 2021). For 16S, the analysis was conducted using the General Time Reversible (GTR) model (Nei and Kumar 2000). Bootstrapping was not conducted because only three species were included in the analysis. For 28S, the ML was performed using the Hasegawa-Kishino-Yano model (HKY) with 1,000 bootstrap replicates (Hasegawa et al. 1985). The substitution models were selected using ModelTest-NG (Darriba et al. 2020) on raxmlGUI 2.0 (Edler et al. 2021). All phylogenetic trees were rooted with *Protomicroplitis calliptera* as outgroup (GenBank Accesion Numbers:

ON023818.1 (16S) and ON040756.1 (28S)) and edited via MEGA11 and Adobe Acrobat Pro DC (Adobe Systems, Inc).

2.8. Interactive Key Construction

To construct interactive key, the Atlas of Living Australia (ALA) version of DELTA Editor (Open DELTA 1.02 beta) (Dallwitz et al. 1999) was used. Morphological characters of the members of *Neocardiochiles* were recorded in a DELTA matrix, and an interactive key was generated using the function in the software. The constructed interactive key was tested using Intkey (Dallwitz et al. 2000).

CHAPTER 3. NEW TAXA OF CARDIOCHILINAE (HYMENOPTERA: BRACONIDAE) FROM THE OLD WORLD

3.1. A New Genus from the Oriental Region (Hymenoptera: Braconidae: Cardiochilinae)

Introduction. The Oriental region exhibits the highest genus-level and the second highest species-level diversity of the braconid subfamily Cardiochilinae Ashmead, 1900 among the world biogeographic regions (Yu et al. 2016). Prior to this work, eight genera among sixteen world genera were recorded from the Oriental region: *Asiacardiochiles* Telenga, 1955, *Austerocardiochiles* Dangerfield, Austin & Whitfield, 1999, *Bohayella* Belokobylskij, 1987, *Cardiochiles* Nees, 1819, *Eurycardiochiles* Dangerfield, Austin & Whitfield, 1999, *Hartemita* Cameron, 1910, *Psilommiscus* Enderlein, 1912, *Toxoneuron* (Say, 1836) (introduced genus from the Nearctic region), and fifty-one species were recorded among 221 described world species (Yu et al. 2016). A type specimen of the new genus *Orientocardiochiles* Kang & Long gen. nov. (Type species: *Orientocardiochiles joebuurowi* Kang sp. nov.) was collected near the Thailand−Malaysia border and confirmed as a member of *Orientocardiochiles* based on morphological characters. The new discovery increases the number of the recorded cardiochiline genera in Malaysia from four to five and globally from sixteen to seventeen (Kang et al. 2020a). In this subchapter, diagnostic characters of *Orientocardiochiles* (Figs. 1−3) are provided and compared with characters of the most easily confused genus, *Austerocardiochiles* (Figure 6). In

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Section 3.1 was partially published as Kang I, Long KD, Sharkey MJ, Whitfield JB, Lord NP (2020a) "*Orientocardiochiles*, a new genus of Cardiochilinae (Hymenoptera, Braconidae), with descriptions of two new species from Malaysia and Vietnam," *ZooKeys* 971: 1−15. Copyright © Ilgoo Kang et al. [https://doi.org/10.3897/zookeys.971.56571]

Section 3.2 was previously published as Kang I, Ameri A, Sharkey MJ (2021a) "Revision of Iranian *Schoenlandella* Cameron, 1905 (Hymenoptera, Braconidae, Cardiochilinae) with descriptions of two new species from Hormozgan province," *Deutsche Entomologische Zeitschrift* 68(2): 261−268. Copyright © Ilgoo Kang et al. [https://doi.org/10.3897/dez.68.69090]

addition, a description of the type species *Orientocardiochiles joebuurowi* Kang sp. nov. is given with diagnostic characters and a distribution map.

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters: 2.1., 2.2., 2.3., and 2.4. Specimens were borrowed from HIC and MVMA.

Taxonomy. Descriptions of the new genus and type species with detailed information are included in the following:

***Orientocardiochiles* Kang & Long, gen. nov.**

(See Figs. 1−3)

Type species. *Orientocardiochiles joebuurowi* Kang, sp. nov.

Diagnosis (based on all the members of the genus). Body large and stout, finely sculptured, whitish to pale yellow in color with black spots and stripes. Head in dorsal view transverse. Antenna 41−43-segmented. Eyes sparsely pilose (Figure 2A). Clypeus with distinct suture and two clypeal tubercles present apically. Malar suture present. Mandible bidentate and angularly bent ventrally. Mouthparts (the length of galea and glossa) short (Figure 2A). Maxillary palpus five- or six-segmented. Labial palpi 4-segmented. Notauli deep, crenulate, meeting posteriorly in deep smooth area (Figs 1B, 2B). Scutellar sulcus curved, with 5+ crenulae. Scutellum more or less elevated medially, without carina laterally and apically. Propodeal areola completely developed and kite-shaped or elongated pentagonal. Epicnemial carina absent. Mesopleuron mostly smooth; precoxal sulcus well-defined and crenulate, not reaching posterior margin. Metapleuron rugulose. Mesosternal sulcus finely crenulate. Hind tibia without apical projection; inner tibial spur distinctly longer than outside spur, subequal to half of hind basitarsus. Tarsal claws pectinate (Figure 3A). Fore wing with elongated pterostigma; vein r

reaching at apical fourth of pterostigma; SR1 sharply angled at basal fourth; basal fourth of vein SR1 almost perpendicular to apical vein 3−SR. Vein 1a present as a spectral short trace; 1st discal cell in fore wing rather short compared to first submarginal cell. Second submarginal cell elongated. First subdiscal (brachial) cell broad. M+CU in hind wing distinctly shorter than 1−M. Hind wing with 6 hamuli. T1 widened apically, with lateral suture clearly defined throughout. T2 mostly rugose except for plateau-like projection; plateau-like projection of T2 present at anteromedial base (Figure 2C). T3 entirely smooth. Hypopygium sharply pointed at apex (Figure 3B), median longitudinal area evenly sclerotized or largely desclerotized medially throughout; median enfold of hypopygium present or absent. Ovipositor sheath longer than metasoma, pointed at apex, and with short setae throughout.

Distribution. Oriental region (Malaysia and Vietnam).

Biology. Unknown.

Etymology. The name for the genus refers to *Cardiochiles* from the Oriental region. From “orientum” (Latin for the eastern region) and the generic name “*Cardiochiles* Nees, 1819.” The gender of the genus name is masculine.

Orientocardiochiles joeburrowi Kang, sp. nov.

(See Figs. 1−3)

Material examined. Holotype Malaysia • ♀; female, Perlis, Wang Kelian; 6°40'40.94"N, 100°11'23.94"E; xi.2008; Sharkey & Norliyana.

Description. Body large and stout, 9.1 mm. Antenna 6.4 mm. Length of fore wing 9.6 mm. Ovipositor sheath 4.4 mm. Head. Antenna 41-segmented; length of scape ~ 1.3 × longer than its width (0.30:0.23); third segment (basal flagellomere) ~ 2.2 × longer than second segment (pedicel) (0.29:0.13); apical segment ~ 1.9 × longer than subapical segment (0.15:0.08). Clypeal

suture distinct; with two well-developed tubercles; width of clypeus ~ 1.9 × its height (0.72:0.44); face width ~ 0.9 × length of face and clypeus combined (0.11:0.12); distance between tentorial pits ~ 1.9 × distance between a pit and eye margin (0.60:0.32). Mandible bidentate; basal width of mandible ~ 0.7 × longer than the distance from mandible to eye margin (0.22:0.31). Maxillary palpus 5-segmented. Labial palpus four-segmented. Galea short with dense setae. Glossa short. Head transverse, median length 0.35 × longer than the maximum width of head in dorsal view (0.75:2.17). Eye length ~ 2.0 × length of temple as viewed dorsally (0.72:0.36). Ocellar triangle marginated with shallow suture; POL:OD:OOL= 0.10:0.18:0.42. Mesosoma. Length of mesosoma ~ 1.4 × its height (0.37:0.26). Notauli present. Mesoscutum with shallow submarginal furrows. Scutellar sulcus curved with five crenulae, ~ 0.33 × longer than median length of scutellum (0.19:0.57). Postscutellar depression absent. Propodeum rugulose; propodeal areola kite-shaped, length of median areola ~ 1.8 × longer than its maximum width (0.60:0.34); median transverse carina on the propodeum reaching lateral margin. Pronotum mostly smooth and carinate posteriorly. Mesopleuron mostly smooth; precoxal sulcus well-defined and crenulate, not reaching posterior margin. Metapleuron rugulose. Mesosternal sulcus with few barely perceptible crenulae. Legs. Fore tibial spur ~ 0.57 × basitarsus (0.44:0.77). Length of hind femur, tibia and basitarsus ~ 3.8 × (2.10:0.55), ~ 7.1 × (3.20:0.45) and ~ 6.0 × (0.18:0.03) longer than maximum width of each. Basal spur of mid tibia ~ 0.58 × longer than length of mid-basitarsus (0.67:1.15). Basal spur of hind tibia ~ 1.8 × longer than length of apical spur (0.88:0.49), and ~ 0.49 × longer than length of hind basitarsus (0.88:1.78). Hind basitarsus ~ 0.56 × longer than length of hind tibia (0.18:0.32), and ~ 0.96 × longer than length of remaining hind tarsi 2–5 (1.78:1.85). Hind tarsal claws pectinate with ten teeth. Wings. Length of fore wing ~ 3.2 × longer than its maximum width (0.96:0.32). Length of pterostigma ~ 4.4 × longer than its

width (1.91:0.44). Fore wing r:3−SR:2−SR= 33:165:99; 1-M ~ 2.4 × longer than m-cu (0.88:0.36); 2−SR+M ~ 1.63 × longer than m-cu (0.59:0.36); 1−CU1 0.23 × longer than 2−CU1 (0.22:0.96) and ~ 0.37 × longer than cu-a (0.22:0.59). Length of hind wing ~ 5.2 × longer than its maximum width (0.78:0.15); second submarginal cell trapezoid, maximum length of the cell ~ 3.15× longer than its maximum height (2.62:0.83). Hind wing M+CU distinctly shorter than 1-M, and ~ 0.63 × longer than 1−M (0.75:1.19); 1−M ~ 3.6 × longer than length of 1r-m (1.19:0.33); 2−SC+R horizontal to the longitudinal axis of hind wing; 2−1A absent. Metasoma. T1 punctate medially, about ~ 1.1× longer than its apical width (1.33:1.25). T2 dorsally rectangular; median length of T2 ~ 0.34 × longer than its apical width (0.50:1.46), and ~ 0.74 × as long as median length of T3 (0.50:0.67). T3 entirely smooth. Hypopygium acute apically, fully sclerotized without median suture. Ovipositor length about ~ 1.23× longer than length of metasoma (0.57:0.46). Ovipositor sheath densely setose throughout; setose part of ovipositor sheath ~ 0.95 × longer than length of metasoma (0.44:0.46), ~ 1.38 × longer than length of hind tibia (0.44:0.32), and ~ 0.46 × longer than length of fore wing (0.44:0.96).

Color. Body mostly whitish pale and appearing striped; the following areas melanic: antenna, vertex, median mesonotal lobe (mostly melanic except for posterior area), lateral mesonotal lobe (pale basally), scutellum, anterior propodeum, fore trochantellus, basal fore femur, mid trochanter (mostly) and trochantellus, hind coxa with a large melanic spot posterolaterally, entire hind trochanter and trochantellus, hind femur (except for anteromedial area), mid and hind tarsi, median T1, entire T2, anterior T3–T6, posterior T7, ovipositor and external ovipositor sheath. Wings entirely lightly infuscate, stigma dark brown but centrally pale.

Male. Unknown.

Etymology. Named in honor of Mr. Joseph Lee Burrow, the world-class football quarterback for the LSU Tigers and the 2019 Heisman Trophy winner.

Host. Unknown.

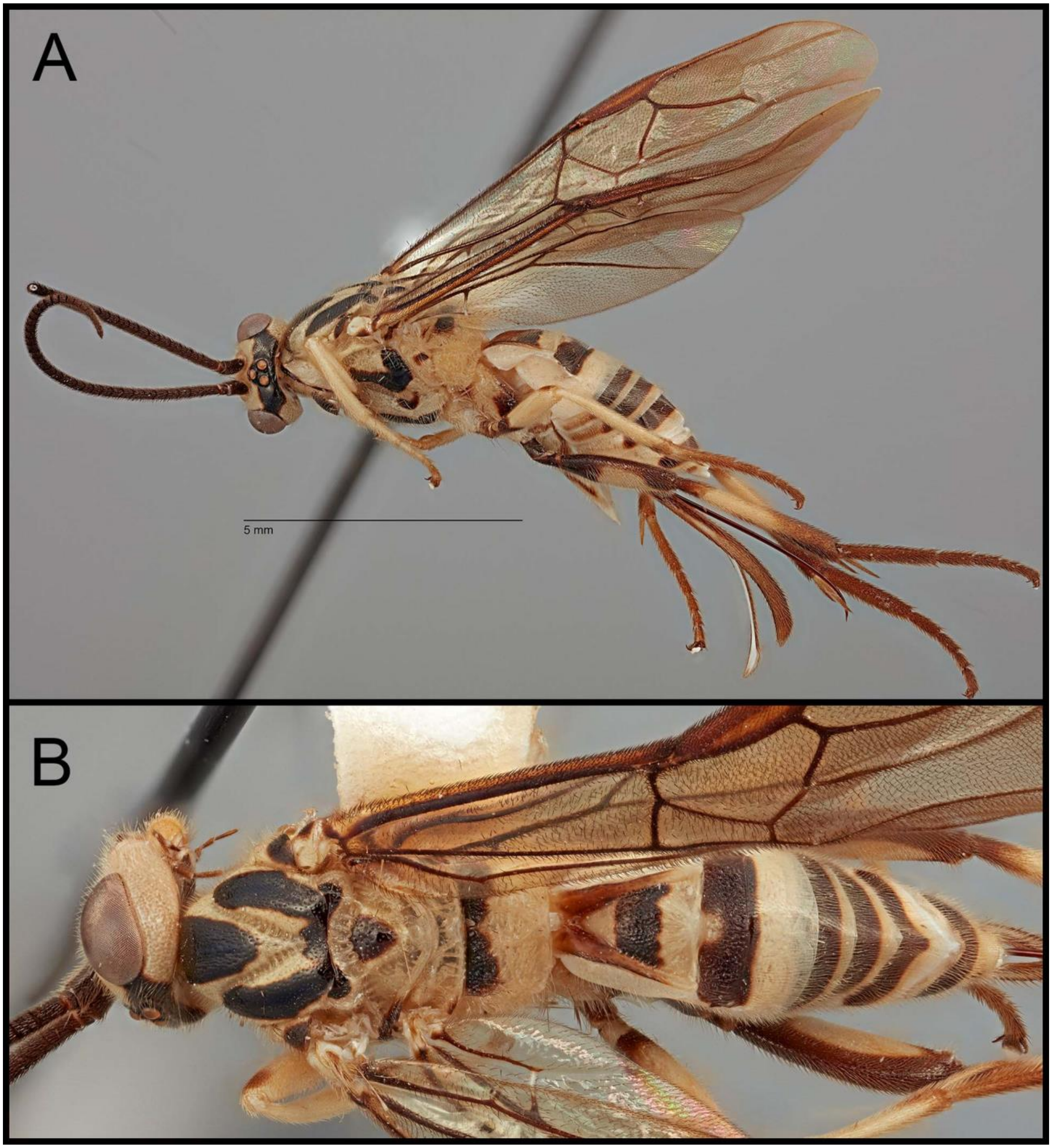

Figure 1. First image plate of *Orientocardiochiles joeburrowi* sp. nov. A) Lateral habitus; B) Dorsal habitus.

Distribution. The species is known from only one female specimen collected from Wang Kelian, Malaysia, which is near the Thailand–Malaysia border (Figs. 4, 5).

Comments. *Orientocardiochiles joeburrowi* Kang sp. nov., can be distinguished from another member of the genus *O. nigrofasciatus* Long, sp. nov. recorded in Vietnam by the following diagnostic characters: i) fore wing entirely lightly infuscate; ii) propodeum without short longitudinal carina anteriorly; iii) propodeal areola quadrate (kite-shaped); iv) hind tarsal claw pectinate with ten teeth; v) hypopygium entirely sclerotized and without median enfold; vi) scapus entirely brown.

Discussion. In the early stage of this work, *Orientocardiochiles joeburrowi* sp. nov. was confirmed as the only member of the genus and the initial diagnosis was composed based on this information. In the conversation between the author of the dissertation and braconid specialist, Dr. Cornelis van Achterberg, Dr. van Achterberg informed the author that a similar specimen was collected and held by Dr. Khuat Dang Long in the Institute of Ecology and Biological Resources, Ha Noi, Vietnam. Because specimens of each species are rare, we decided to virtually confirm the shared characters using species descriptions and detailed images. We both agreed that *Orientocardiochiles* is a new genus of Cardiochilinae, and shared characters between *Orientocardiochiles joeburrowi* sp. nov. and *O. nigrofasciatus* Long, sp. nov. and distinct characters were confirmed. The final diagnosis of the genus was written based on two species and included above. Members of the *Orientocardiochiles* are close to the members of *Austerocardiochiles* (Figure 6), and the members of both genera share the following morphological characters: eyes setose (Figs. 2A, 6C); ovipositor elongate and slightly downcurved (Figs. 1A, 6A); metatibia without expanded apex (Figs. 1A, 6A); T1 entirely separated from laterotergite by suture and ≤ 3.0 × longer than its posterior width (Figs 2C, 6D).

However, the members of *Orientocardiochiles* can be distinguished from the members of *Austerocardiochiles* by the following characters: interommatidial setae short and sparse (Figure 2A); mandible angularly bent ventrally (Figure 2A); epicnemial carina absent (Figure 1A); hind wing M+CU apparently longer than 1−M (Figure 1A); plateau-like projection on T2 (Figure 2C); hypopygium elongated and with pointed apex (Figure 3B); ovipositor sheath not widened apically and longer than metasoma (Figure 1A). Even though members of *Orientocardiochiles* are rarely collected, additional species of the genus are likely to be discovered from adjacent countries in the Oriental region.

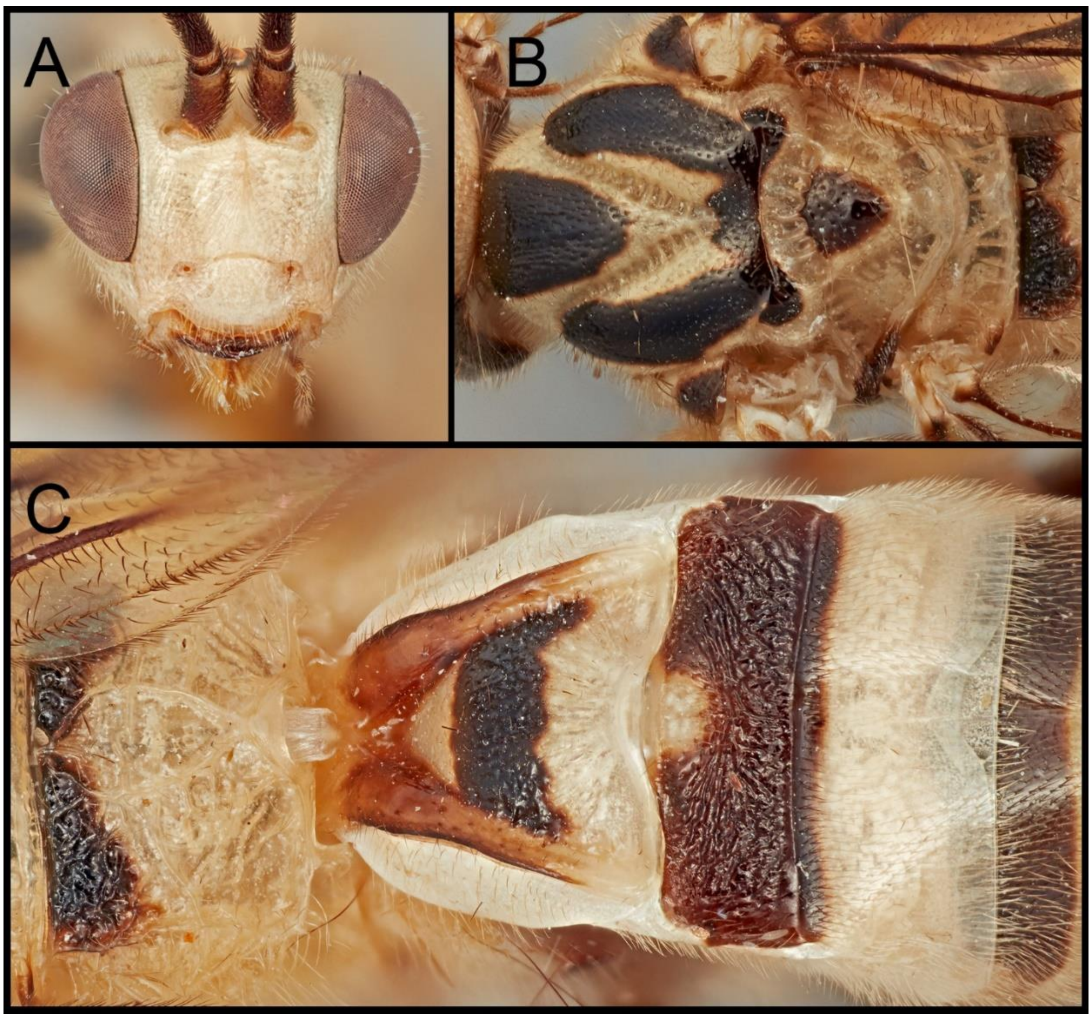

Figure 2. Second image plate of *Orientocardiochiles joeburrowi* sp. nov. A) Anterior head; B) dorsal mesoscutum; C) dorsal propodeum and T1−T3.

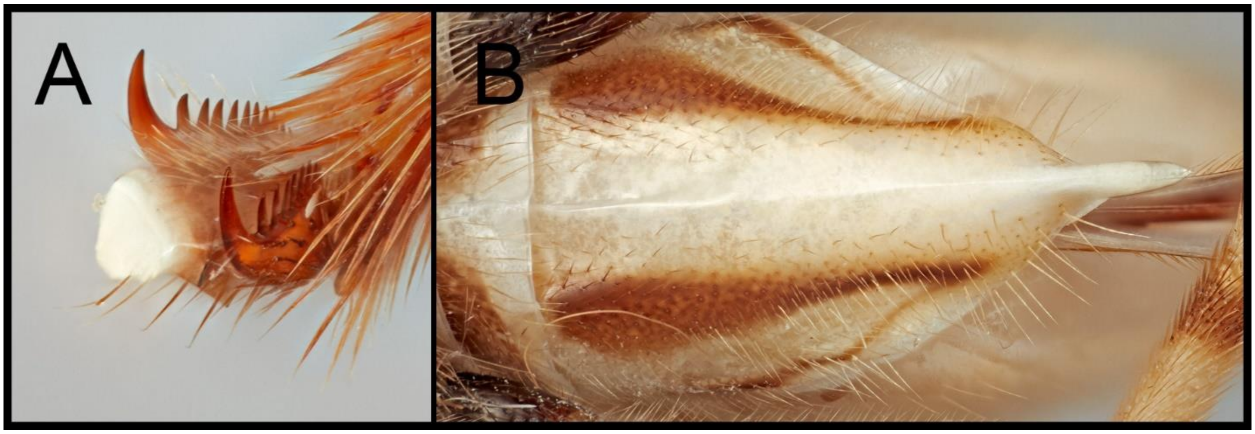

Figure 3. Third image plate of *Orientocardiochiles joeburrowi* sp. nov. A) Hind claws; B) ventral hypopygium

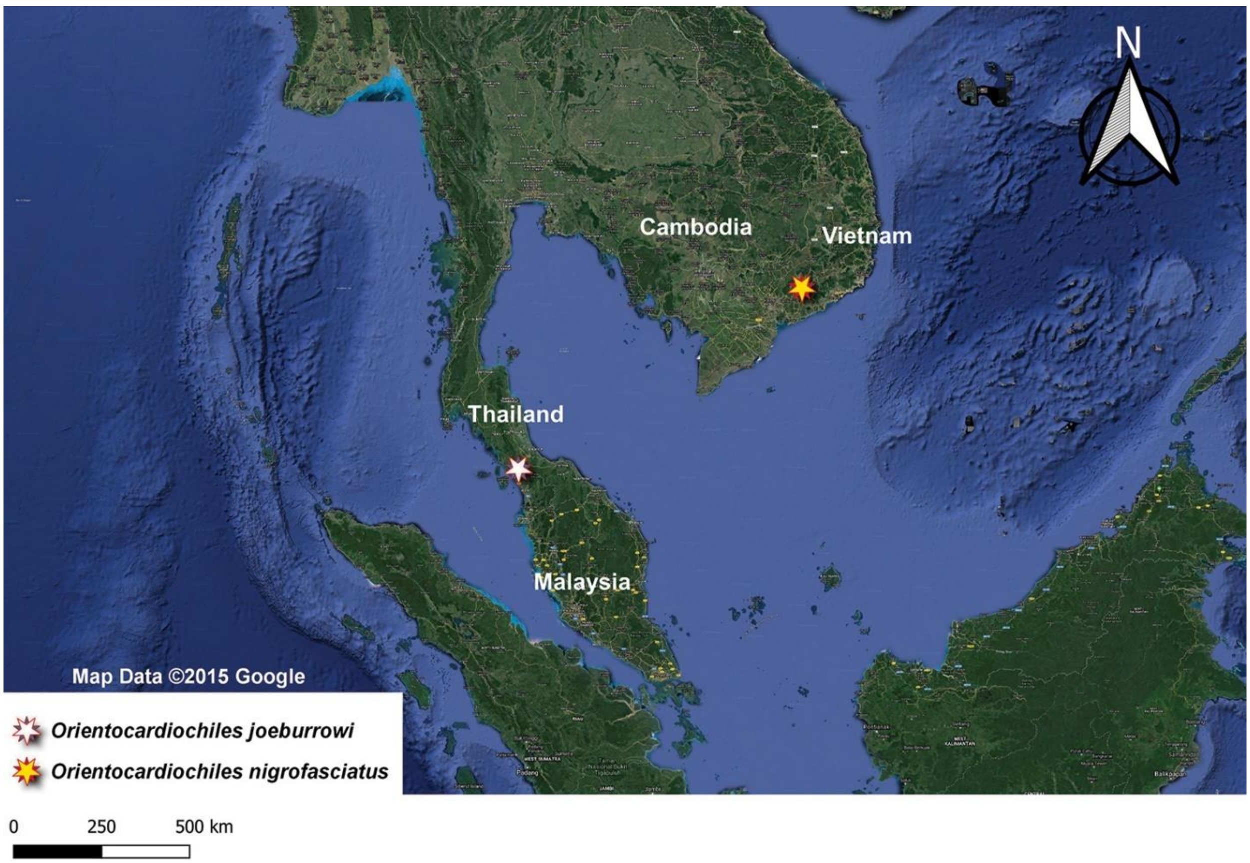

Figure 4. Distribution map of *Orientocardiochiles joeburrowi* sp. nov. and *O. nigrofasciatus* sp. nov.

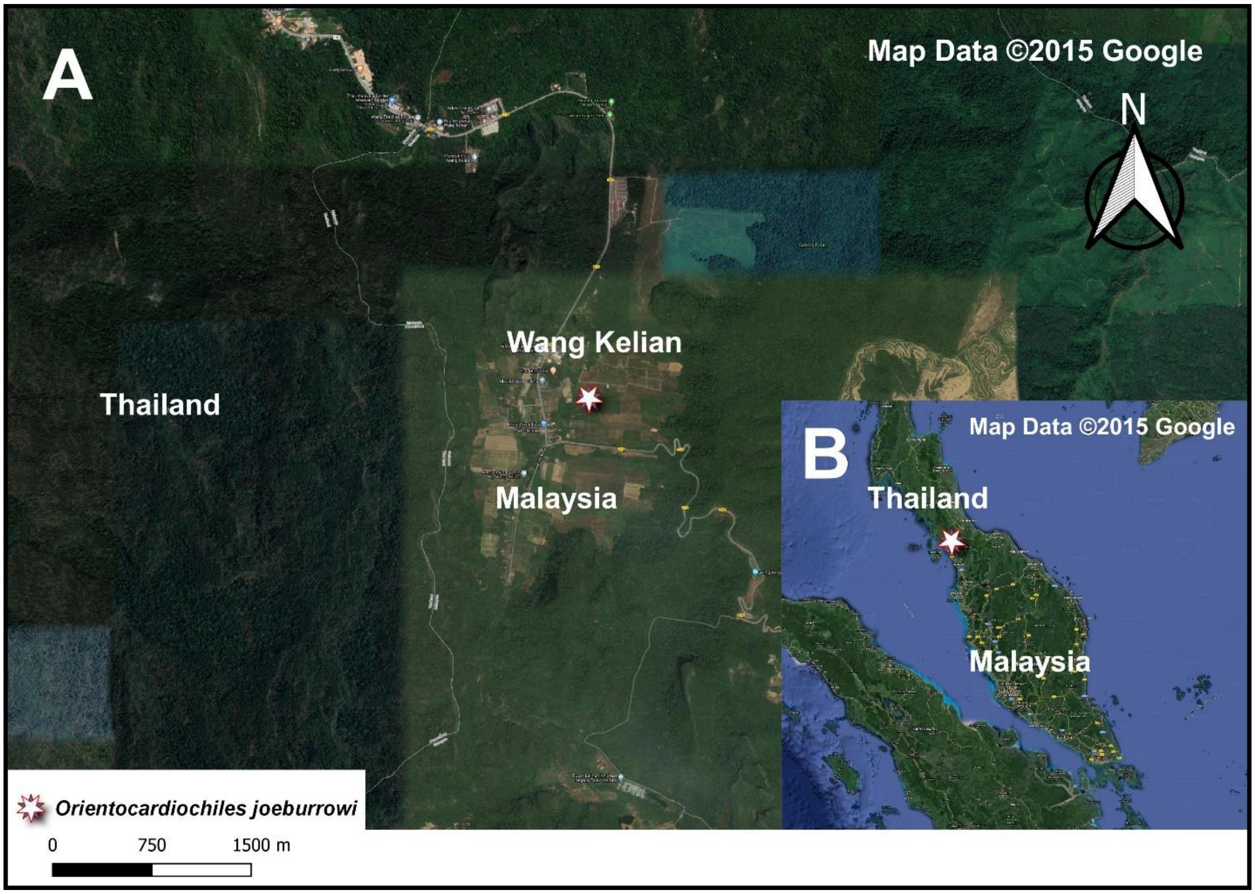

Figure 5. Distribution map of *Orientocardiochiles joeburrowi* sp. nov. A) Map of the locality where a specimen was collected in Wang Kelian; B) map of the locality where a specimen was collected in Malaysia.

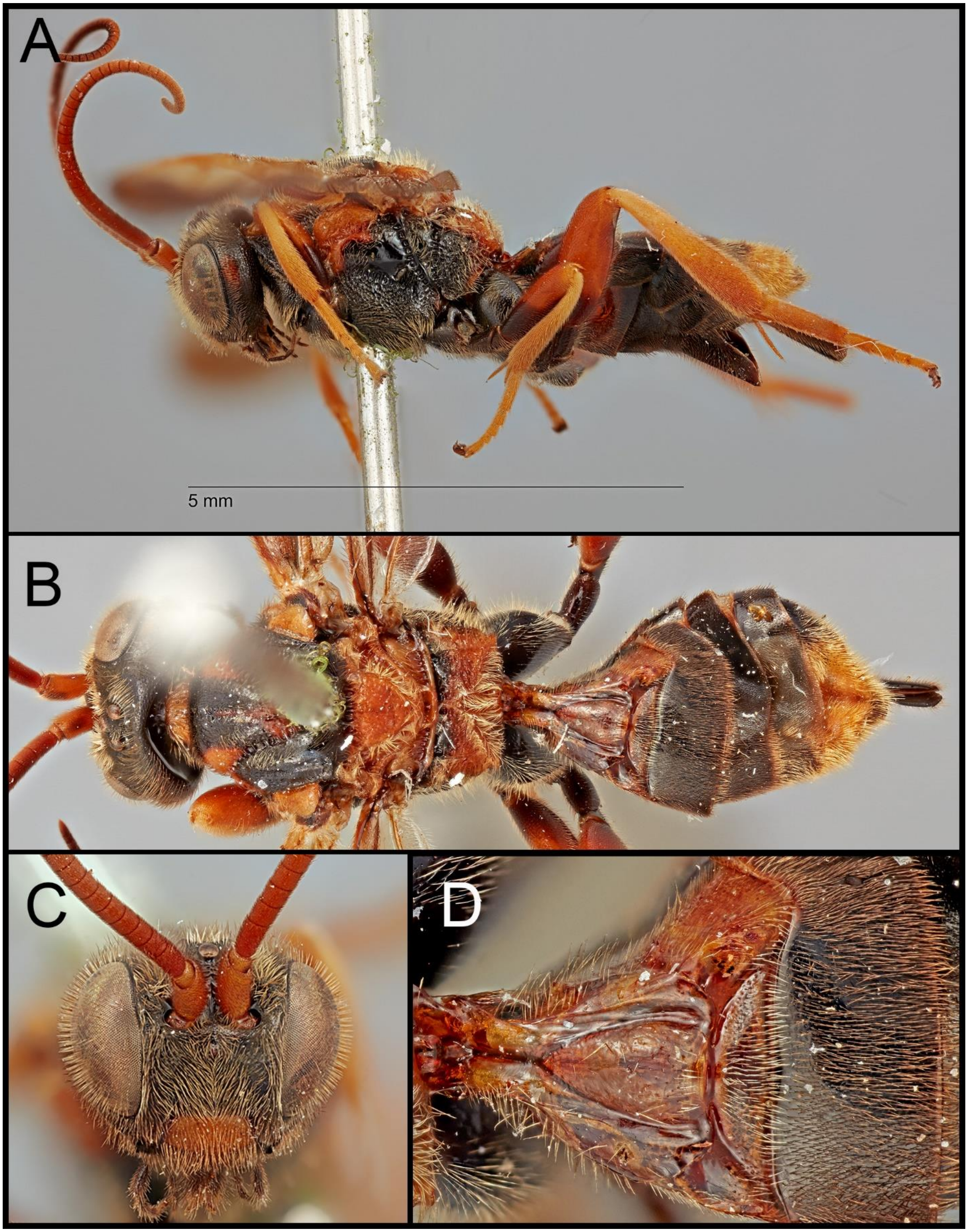

Figure 6. *Austerocardiochiles pollinator*, paratype. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) dorsal T1−T3.

3.2. Two New Species of *Schoenlandella* (Hymenoptera: Braconidae: Cardiochilinae) from Iran

Introduction. Beginning in 2010, braconid taxonomic projects have been actively conducted in one country in the Middle East, the Islamic Republic of Iran (Iran). Until 2012, only four species in two genera of Cardiochilinae were recorded from the country (Yu et al. 2012). According to Gadallah and Ghahari (2019), four more species and one additional genus were newly recorded from 2012 to 2019, so a total of eight cardiochiline species in three genera, *Cardiochiles* Nees, 1819, *Pseudcardiochilus* Hedwig, 1957, and *Schoenlandella* Cameron, 1905 were recorded from Iran before this dissertation research. Among the three genera, *Schoenladella* exhibits the highest species diversity in arid areas in the Old World, especially from the Afrotropical and Australian regions (Kang et al. 2021b). Because ~80% of Iran consists of arid areas (Sanjerehei 2014) and the country is adjacent to the northern Afrotropical region, discovering new members of *Schoenlandella* was likely. However, after confirming the first distribution record of *Schoenlandella* by Gadallah and Ghahari (2019), no new species of *Schoenlandella* were recorded.

In 2020, there was an opportunity to examine Iranian cardiochiline specimens collected by Dr. Ali Ameri, who is a faculty member at the Agricultural Research Education and Extension Organization in Tehran. Fifteen specimens collected in the Hormozgan province from 2016 to 2017 were confirmed as two new species of *Schoenlandella* based on morphological characters. Based on this discovery, these new species were described with detailed images, distribution maps, and an illustrated key to species of Iranian *Schoenlandella* was generated. Diagnosis of each new species was composed after examining specimens of two similar appearing Afrotropical species, *S. testacea* (Kriechbaumer, 1894) and *S. variegata* (Szépligeti, 1913).

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters: 2.1., 2.2., 2.3., and 2.4. Specimens were borrowed from IRIPP and TAMU.

Taxonomy. Descriptions of two new species with detailed information are included in the following:

Schoenlandella Cameron, 1905

Schoenlandella Cameron, 1905 (Cameron 1905a). Type Species: *Schoenlandella nigromaculata* Cameron, 1905 (Cameron 1905a) by subsequent designation by Viereck, 1914 (synonymized with *Cardiochiles* Nees, 1819 by Szépligeti, 1911). Removed from synonymy by Whitfield and Dangerfield (1997).

Ernestiella Cameron, 1905 (Cameron 1905b) synonymized with *Schoenlandella* Viereck, 1914. Type species: *Ernestiella nigromaculata* Cameron 1905 (Cameron 1905b).

Key to species of Iranian *Schoenlandella*

1. A. Notauli smooth; fore wing stigma entirely pale; metapleuron mostly smooth (Telenga 1955) .... *S. deserta* (Telenga)

   B. Notauli crenulate; BB. Fore wing stigma mostly melanic, basally pale; BBB. metapleuron posteriorly strongly sculptured 2

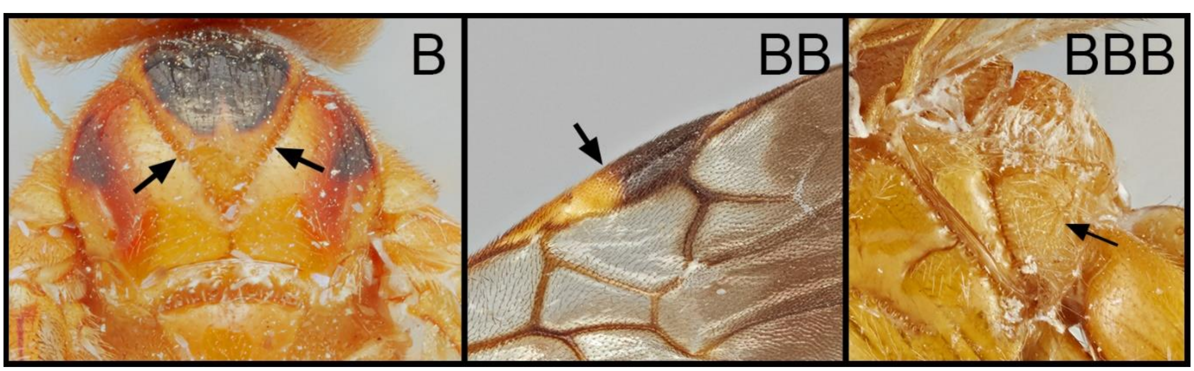

Figure 7. Key image of couplet 1 of the key to species of Iranian *Schoenlandella*.

2 (1). A. Length of gena longer than eye length in lateral view; AA. hind basitarsus shorter than combined length 2nd–4th tarsomeres ....*S. latigena* sp. nov.

B. Length of gena shorter than eye length in lateral view; BB. hind basitarsus longer than combined length 2nd–4th tarsomeres ....*S. angustigena* sp. nov.

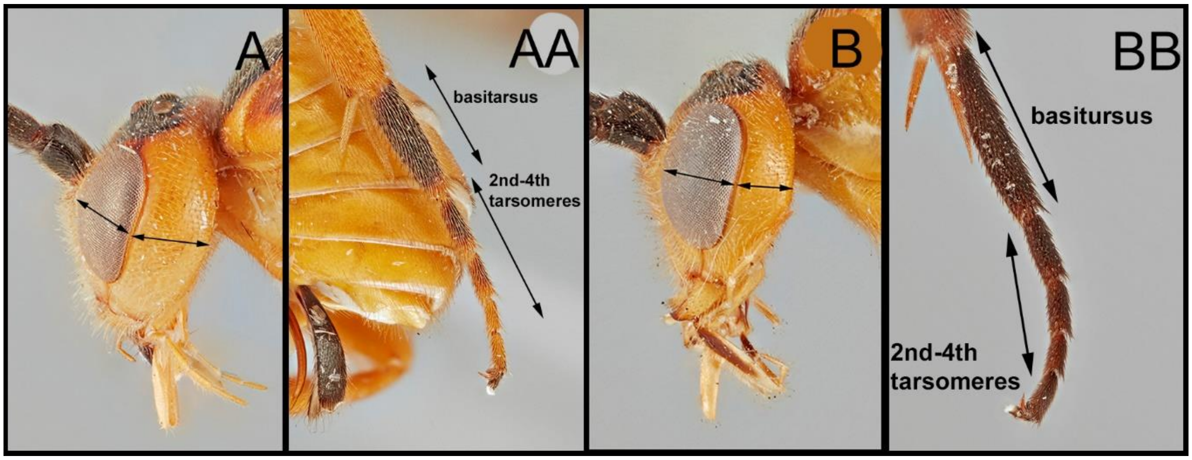

Figure 8. Key image of couplet 2 of the key to species of Iranian *Schoenlandella*.

Schoenlandella angustigena Kang sp. nov.

(See Figure 9)

Material examined. Holotype: Iran • ♀, Fayrab, Roodan (Rudan), Hormozgan; 27°8´29.39´´N, 54°12´20.89´´E; 377 m; 23.II.2017; Col. Ameri. Paratypes: Iran • 2♀, 1♂, same as holotype. 2♀, female, Bazyarai, Minab, Hormozgan; 27°10´36.83´´N, 57°2´12.44´´E.; 34 m; 06.V.2016; Col. Ameri. 1♀, Boo moosa (Abu Musa), Hormozgan; 25°52´52.37´´N, 55°1´13.84´´E; 9 m; 15.IV.2016; Col. Ameri. 1♀, Chelo, Minab, Hormozgan; 27°8´3.62´´N, 56°58´49.71´´E; 16 m; 05.IV.2016; Col. Ameri. 1♀, female, Zakin, Bandar Abbas, Hormozgan; 27°50´25.33´´N, 56°18´12.33´´E; 1176m; 09.IV.2016; Col. Ameri.

Diagnosis. *Schoenlandella angustigena* sp. nov. can be distinguished from other Iranian *Schoenlandella* species by having the following combination of characters: gena apparently shorter than eye length in lateral view (Figure 9C); hind basitarsus longer than combined length

of 2nd–4th tarsomere (Figure 9E). Hind wing mostly infuscate, hyaline at basal fourth, apically gradually darkened. *S. angustigena* sp. nov. is similar to the Egyptian species, *S. acrenulata* (Fischer, 1958), but *S. angustigena* sp. nov. differ from *S. acrenulata* by possessing more number of antennomeres, pale upper face and glossa, pale scutellum and propodeum, relatively short hind tibial spur and long ovipositor sheath,

Description. Body 4.90–6.25 mm. Head. Eye densely setaceous with short interommatidial setae. Flagellum 33–36-segemented. Length of gena ~ 0.79 × longer than eye length in lateral view (0.37:0.47) (Figure 9C). POL ~ 0.69 × longer than diameter of anterior ocellus (0.09:0.13). Face mostly smooth, ~1.01× longer than its width (0.84:0.83). Clypeus with two weakly developed tubercles; width of clypeus ~ 2.06 × longer than its length (0.70:0.34). Galea elongate ~ 1.97 × longer than clypeus height (0.67:0.34) (Figs 9C, 9D). Mandible bidentate. 5th maxillary palpomere ~ 0.89 × longer than apical palpomere (0.17:0.19). Mesosoma. Notauli entirely crenulate and acutely meeting at base (Figure 9B). Scutellar sulcus broad, with five or six crenulae. Length of scutellum ~ 0.97 × longer than basal width of scutellum (0.68:0.70). Postscutellar depression crenulate, as long as anterior width of dorsellum. Dorsellum without median carina. Pronotum medially sculptured, carinate-rugose. Mesopleuron mostly smooth. Precoxal sulcus medially crenulate not reaching anterior and posterior margins of mesopleuron. Episternal scrobe shallow and wavy. Posterior mesopleural furrow entirely crenulate. Metapleuron anteriorly smooth, posteriorly rugose, groove between metepimeron and metepisternum crenulate. Propodeum mostly confused-rugulose; propodeal spiracle ovoid; median areola of propodeum well defined with carinate margin, carinate margin narrowly meeting at both anterior margin of propodeum and nucha, its median width as long as its median

length; transverse carina of propodeum medially strongly developed and reaching lateral margin of propodeum. Legs. Fore basitarsus ~ 1.13 × longer than combined length 2nd–4th tarsomeres (0.63:0.56). Mid-basitarsus as long as combined length of 2nd–4th tarsomeres (0.70:0.70). Maximum width of hind femur ~ 1.72 × longer than apical width of hind tibia (0.50:0.29); cup-like projection of hind tibia absent; basal spur on hind tibia ~ 0.66 × longer than basitarsus (0.71:1.07). Hind basitarsus laterally slightly expanded, but not expanded as in *Hartemita* Cameron, 1910, ~ 1.13 × longer than combined length 2nd–4th tarsomeres (1.07:0.94) (Figure 9E). Claws pectinate with obtuse apical tooth. Wings. Fore wing wing length: ~ 5.71 mm. Hind wing length: ~ 4.66 mm. Fore wing apically infuscate; 1r absent; 3r basally spectrally present (7♀, 1♂) or absent (1♀); 3RSb broken basally, angled at basal third; second submarginal cell elongate; 1a absent. Hind wing infuscate mostly, hyaline at basal fourth; apically gradually darkened. r entirely nebulous and pigmented; RS tubular at base, apically nebulous and pigmented; M+CU apparently shorter than 1M; M tubular at base, apically nebulous and entirely pigmented, gradually fading apically; 2–1A present as basal stump. Metasoma. T1 ~ 1.14 × longer than its apical width (0.83:0.73). T2 with a pair of curved submedian grooves, anteriorly deeply impressed, posteriorly gradually weakened (Figure 9F), median length of T2 ~ 0.53 × longer than median length of T3 (0.31:0.59). Fourth and fifth metasomal sterna membranous posteriorly, medially unfolded. Hypopygium slightly impressed medially but unfolded, acute apically, its surface entirely sclerotized (Figure 9G), its length ~ 1.26 × longer than its height in lateral view (0.88:0.70). Ovipositor sheath slightly downcurved and gradually expanding from base to apex, anteriorly bare posteriorly densely setose with long setae, length of protruded ovipositor sheath ~ 0.53 × longer than hind tibia (1.09:2.07). Ovipositor downcurved.

Male. Same as female except for body length and coloration. The body length of male is slightly shorter than females. The medial mesonotal lobe and ventral mesopleuron are pale in the male specimen.

Color. All specimens are mostly pale, and the following areas are melanic: antenna, vertex, frons, apical mandible, galea, median mesonotal lobe (mostly), ventral mesopleuron, inner hind tibia apically, apical hind tarsus, and ovipositor sheath. Wings apically infuscate, stigma mostly melanic except for base. Five specimens have a melanic mesonotal lobe and a pale ventral mesopleuron, however they share all other morphological characters with other members of *S. angustigena*.

Host. Unknown.

Distribution. Members of *S. angustigena* sp. nov. are known from Bandar Abbas, Minab and Rudan, as well as Abu Musa Island, Hormozgan, Iran (Figure 10).

Etymology. From the Latin, *angusti*-, meaning “narrow” and *gena*, meaning “cheek”.

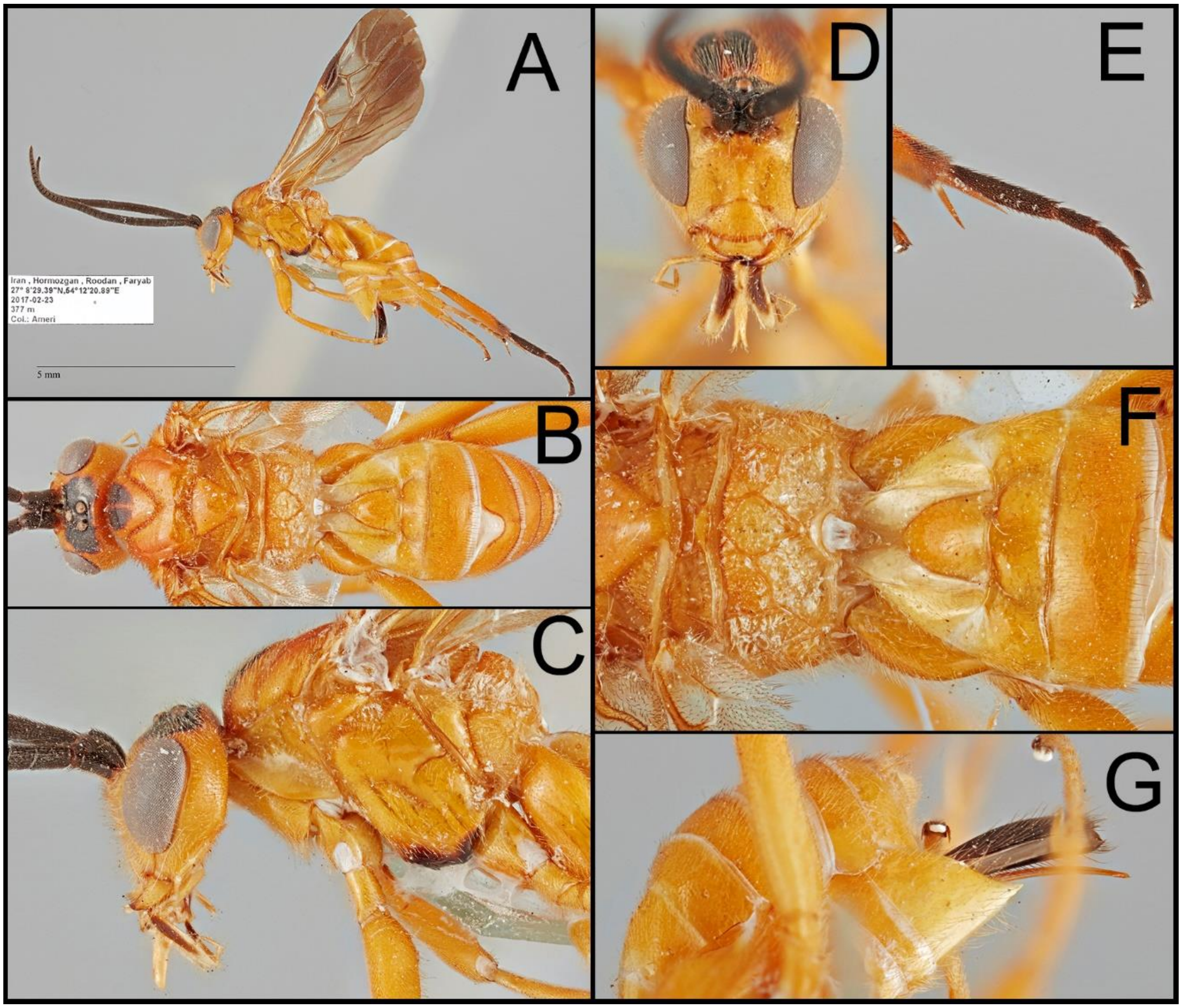

Figure 9. *S. angustigena* sp. nov. A) Lateral habitus; B) dorsal habitus; C) lateral head and mesosoma; D) anterior head; E) hind tarsus; F) dorsal scutellum to T3; H) ventro-lateral metanotum.

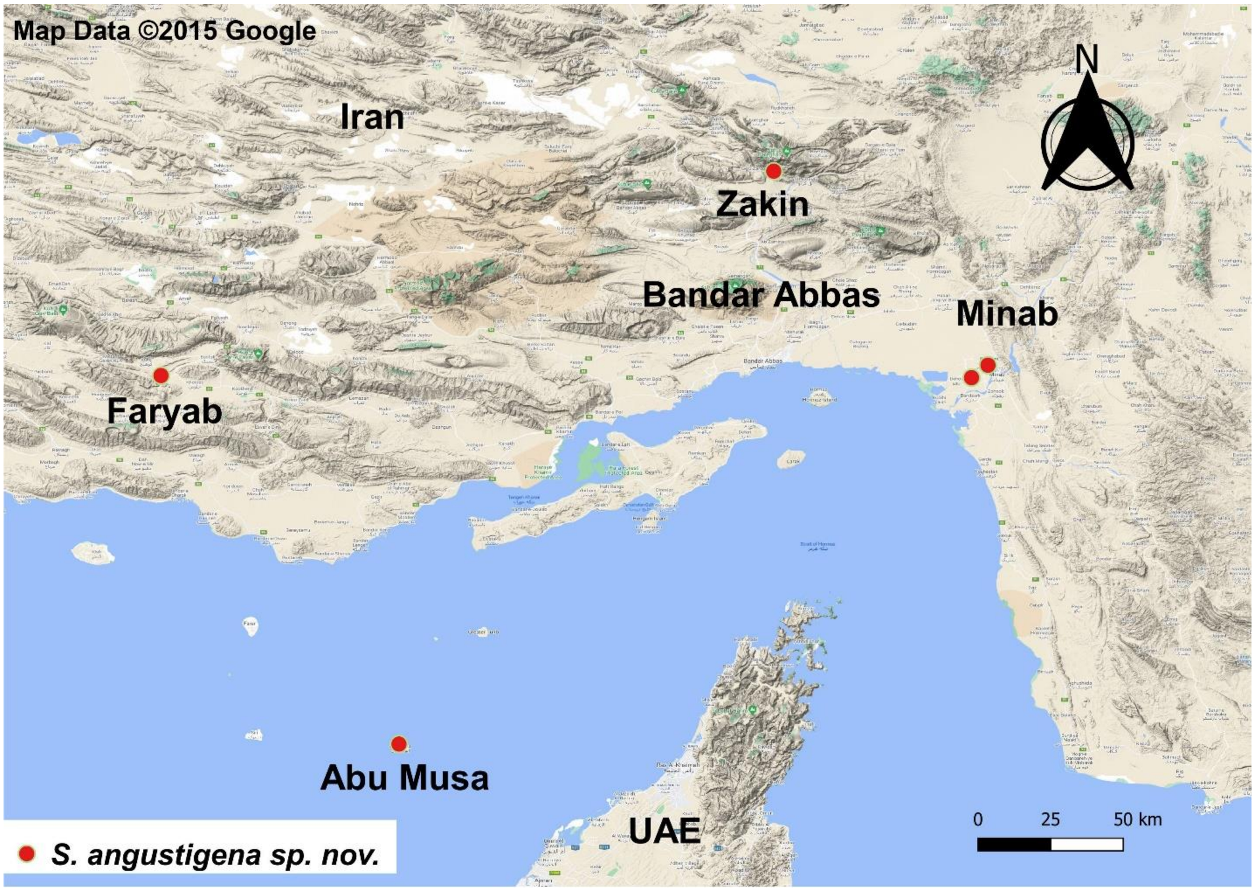

Figure 10. Distribution map of the members of *S. angustigena* sp. nov. in Iran.

***Schoenlandella deserta* (Telenga, 1955)**

Cardiochiles desertus Telenga, 1955 (Telenga 1955).

Schoenlandella deserta (Telenga, 1955) (Dangerfield et al. 1999).

Description. See Telenga (1955), Oltra and Falco (1997), and Edmardash et al. (2018).

Host. Unknown.

Distribution. Members of *Schoenlandella deserta* (Telenga, 1955) are known from Azerbaijan, Egypt, Iran, Morocco, Spain, Turkmenistan, and Uzebekistan (Edmardash et al. 2018, Oltra and Falco 1997, Telenga 1955, Yu et al. 2016).

***Schoenlandella latigena* Kang sp. nov.**

(See Figure 11)

Material examined. Holotype Iran • ♀; female, Bazyarai, Minab, Hormozgan; 27°10´36.83´´N, 57°2´12.44´´E.; 34m; 06.V.2016; Col. Ameri. Paratypes 1♀; same as holotype except for the colleting date; 21.IV.2016. 1♂; Boo moosa (Abu Musa), Hormozgan; 25°52´52.37´´N, 55°1´13.84´´E; 9m; 15.IV.2016; Col. Ameri. 2♀; female, Zakin, Bandar Abbas, Hormozgan; 27°50´25.33´´N, 56°18´12.33´´E; 1176m; 09. IV.2016; Col. Ameri. 1♀; female, Mosaferabad, Roodan (Rudan), Hormozgan; 27°44´50.62´´N, 57°13´36.08´´E; 459m; 06.V.2016; Col. Ameri.

Diagnosis. Members of *Schoenlandella latigena* sp. nov. are most similar to members of *S. deserta* (Telenga, 1955). Compared to members of *S. deserta*, members of *S. latigena* sp. nov. possess a more elongate gena (Figure 11A) and a melanic stigma (Figure 11F). In addition, they share crenulate notauli (Figure 11B) and a sculptured metapleuron (Figure 11A). Members of *S. latigena* sp. nov. are also similar to members of an Afrotropical species, *S. variegata* (Szepligeti, 1913). Members of these two species share densely setose eyes, broad face and clypeus, ventrally melanic mesopleuron, apically infuscate wings, and short and slightly expanded hind basitarsus. However, members of *S. latigena* sp. nov. can be distinguished from *S. variegata* by having relatively shorter interommatidial setae (Figure 11C), narrower face, longer gena, longer hind basitarsus, and longer and unfolded hypopygium (Notes: Female members of *S. variegata* have a medially folded hypopygium.) (Figure 11D).

Description. Body 6.25–6.45 mm. Head. Eye densely setaceous with short interommatidial setae. Antennomeres 32–33-segmented. Length of gena ~ 1.12 × longer than eye length in lateral view (0.47:0.42) (Figure 11A). POL ~ 1.27 × broader than diameter of

anterior ocellus (0.11:0.14). Face weakly sculptured, mostly finely punctate, ~ 0.85 × longer than its width (0.73:0.86). Clypeus with two strongly developed tubercles; width of clypeus ~ 2.59 × longer than its length (0.70:0.27). Galea elongated, ~ 2.15 × longer than clypeus height (0.58:0.27) (Figure 11C). Mandible bidentate. Fifth maxillary palpomere as long as apical palpomere (0.15:0.15). Mesosoma. Notauli entirely crenulate and meeting acutely at base (Figure 11B). Scutellar sulcus broad, with six or seven crenulae. Length of scutellum ~ 0.83 × longer than basal width of scutellum (0.54:0.65). Postscutellar depression crenulate, as long as anterior width of dorsellum. Dorsellum with or without median carina. Pronotum medially sculptured, carinate-rugose. Mesopleuron mostly smooth. Precoxal sulcus medially moderately crenulate not reaching anterior and posterior margins of mesopleuron. Episternal scrobe shallow and wavy. Posterior mesopleural furrow entirely crenulate. Metapleuron anteriorly smooth, posteriorly rugose; groove between metepimeron and metepisternum crenulate. Propodeum mostly confused-rugulose; propodeal spiracle ovoid; median areola of propodeum well defined with carinate margin, carinate margin narrowly meeting anteriorly, posteriorly reaching submedian of nucha, its median width as long as its median length, transverse carina of propodeum reaching lateral margin of propodeum. Legs. Fore basitarsus ~ 0.90 × longer than combined length 2nd–4th tarsomeres (0.47:0.52). Mid-basitarsus ~ 0.89 × longer than combined length of 2nd–4th tarsomeres (0.54:0.61). Maximum width of hind femur ~ 1.65 × longer than apical width of hind tibia (0.51:0.31); cup-like projection of hind tibia absent; basal spur on hind tibia ~ 0.74 × longer than basitarsus (0.58:0.78). Hind basitarsus laterally slightly expanded, but not as expanded as *Hartemita* Cameron, 1910, ~ 0.90 × longer than combined length 2nd–4th tarsomeres (0.79:0.88) (Figure 11E). Claws pectinate with obtuse apical tooth. Wings. Fore wing

wing length: ~ 5.21 mm. Hind wing length: ~ 4.36 mm. Fore wing apically infuscate; 1r absent; 3r basally spectrally present (3♀) (Figure 11F) or absent (2♀, 1♂); 3RSb broken basally, angled at basal fourth; second submarginal cell elongated; 1a absent. Hind wing infuscate at apical third; r entirely nebulous and pigmented; RS tubular at base, apically nebulous and pigmented; M+CU apparently shorter than 1M; M tubular at base, apically nebulous and pigmented, gradually fading apically; 2–1A present as basal stump. Metasoma. T1 ~ 1.15 × longer than its apical width (0.69:0.60). T2 entirely smooth, median length ~ 0.70 × longer than median length of T3 (0.38:0.54). Fourth and fifth metasomal sterna membranous posteriorly, medially unfolded. Hypopygium medially slightly impressed, acute apically, its surface anteriorly fully sclerotized medio-posteriorly less sclerotized (Figure 11D), its length as long as its height in lateral view (0.90:0.90). Ovipositor sheath slightly downcurved and gradually expanding from base to apex, anteriorly bare, posteriorly densely setose with long setae; length of protruded ovipositor sheath ~ 0.47 × longer than hind tibia (0.92:1.96). Ovipositor downcurved.

Male. Same as female except for the following characters: antenna 33-segmented, scutellar sulcus with eight crenulae, scutellum antero-medially with melanic spot, propleuron ventrally melanic, mesopleuron mostly melanic, hind coxa brown medially.

Color. Body mostly pale; the following areas are melanic: antenna, vertex, frons, apical mandible, galea, median mesonotal lobe mostly, lateral mesonotal lobe anteriorly, ventral mesopleuron, inner hind tibia apically, apical hind tarsus, ovipositor sheath. Wings apically infuscate, stigma apically melanic.

Host. Unknown.

Distribution. Members of *Schoenlandella latigena* sp. nov. are known from Bandar Abbas, Minab, and Rudan counties as well as Boo Moosa island, Hormozgan, Iran (Figure 12).

Etymology. From the Latin, *lati*-, meaning “broad” and *gena*, meaning “cheek”.

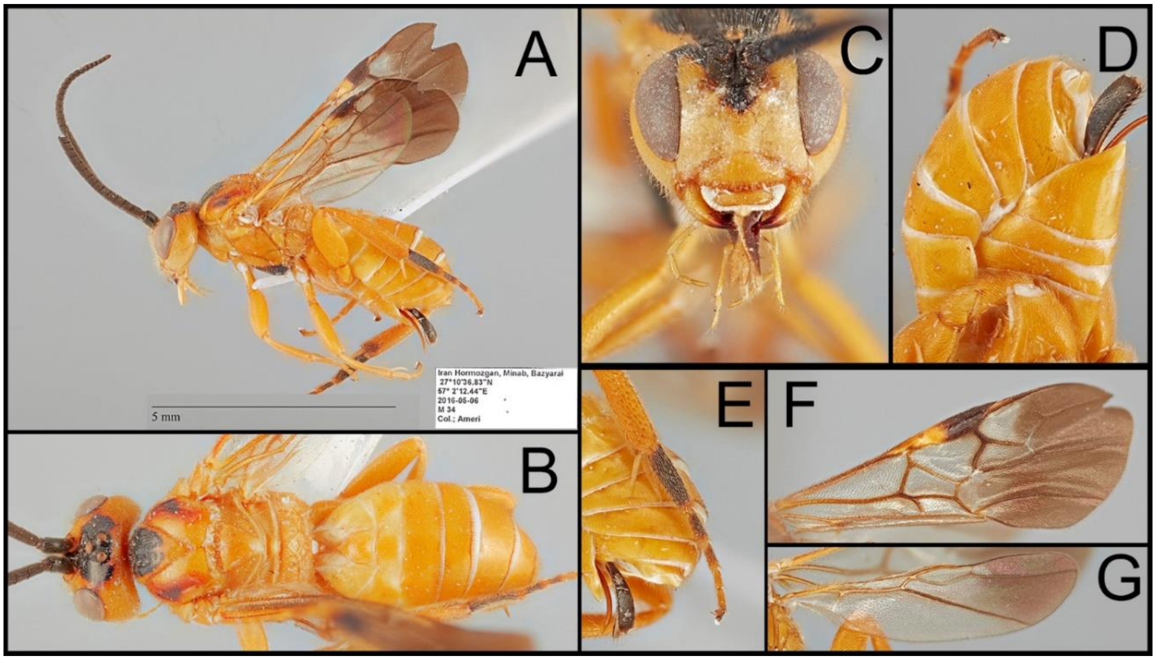

Figure 11. *S. latigena* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head dorsal mesonotum; D) ventro-lateral metanotum; E) hind tarsus; F) fore wing; H) hind wing.

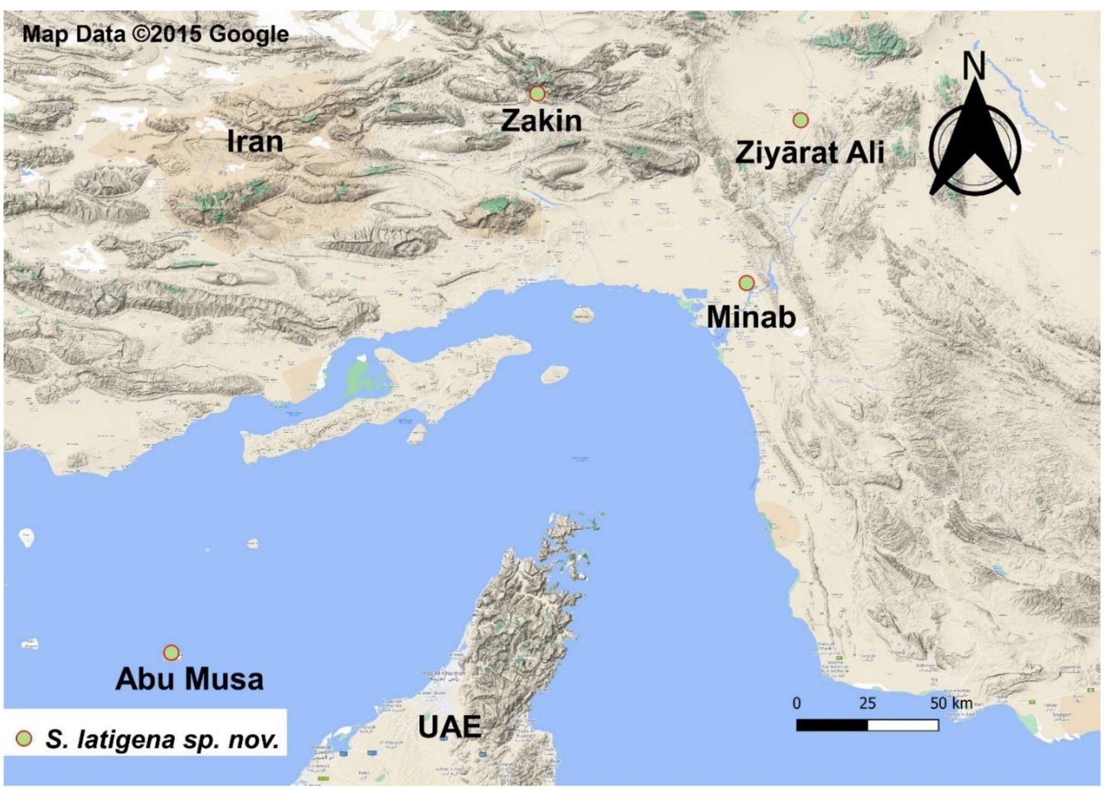

Figure 12. Distribution map of the members of *S. latigena* sp. nov. in Iran.

Discussion. There were several changes in the taxonomic status of *Schoenlandella*. The genus was first described by Cameron (1904) and synonymized with *Cardiochiles* by Szépligeti (1911). In Whitfield and Dangerfield (1997), *Schoenlandella* was resurrected and treated as a valid genus by Dangerfield et al. (1999). Mercado and Wharton (2003) and Papp (2014) indicated difficulty in distinguishing members of *Schoenlandella* from those of *Cardiochiles* Nees, 1819. Mercado and Wharton (2003) retained *Schoenlandella* as a valid genus, but Papp (2014) subsumed *Schoenalandella* into *Cardiochiles* as a subgenus. Edmardash et al. (2018) followed the definition of Dangerfield et al. (1999) and treated *Schoenlandella* as a valid genus. Based on morphological data and using the phylogenetic data of Dangerfield et al. (1999) and Murphy et al. (2008), Kang et al. (2021b) also treated *Schoenlandella* as a valid genus. There were no additional species of *Schoenlandella* recorded from Iran since 1955 by Telenga (1955) even though the country is close to the Afrotropical region and has arid climate, which is preferred by the members of *Schoenlandella*. From this project, two new Iranian species, *S. angustigena* sp. nov. and *S. latigena* sp. nov. were newly recorded as expected. In future collecting across the country, there is a high probability of finding additional new species of *Schoenlandella*.

CHAPTER 4. NEW TAXA OF CARDIOCHILINAE (HYMENOPTERA: BRACONIDAE) FROM THE NEW WORLD WITH BIOLOGICAL NOTES

4.1. New Distribution Records of *Bohayella* Belokobylskij, 1987 (Hymenoptera: Braconidae: Cardiochilinae) from Costa Rica and Ecuador

Introduction. *Bohayella* Belokobylskij, 1987 is a rarely collected genus of Cardiochilinae Ashmead, 1900. Before this project, all nine species were described from the Old World that includes the Afrotropical, Australasian, Oriental, and southern central Palearctic regions (Dangerfield et. al. 1999; Mercado and Wharton 2003; Yu et. al. 2016). *Cardiochiles nigricans* Mao, 1949 was included as a New World member of *Bohayella* by Dangerfield et al. (1999) but transferred to *Toxoneuron* Say, 1836 by Mercado and Wharton (2003). From 2003 to 2020, there were no new species or transferred species of *Bohayella* in the New World. The validity of *Bohayella* was supported by phylogenetic data based on morphological data in Dangerfield et al. (1999) as well as phylogenetic data based on molecular data by Murphy et al. (2008), which indicated that *Bohayella* was resolved as a monophyletic group. Among the nine

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Section 4.1 was partially published as Kang I, Shaw SR, Lord NP (2020b) "Two new species and distribution records for the genus *Bohayella* Belokobylskij, 1987 from Costa Rica (Hymenoptera, Braconidae, Cardiochilinae)," *ZooKeys* 996: 93−105. Copyright © Ilgoo Kang et al. [https://doi.org/10.3897/zookeys.996.59075]

Section 4.1 was also partially published as Kang I (2022a) "*Bohayella rodrigodiazi* sp. nov.: a new species from Ecuador with an updated key to the New World species of *Bohayella* Belokobylskij (Hymenoptera, Braconidae, Cardiochilinae)," *Journal of Hymenoptera Research* 89: 1−8. Copyright © Ilgoo Kang. [https://doi.org/10.3897/jhr.89.77687]

Section 4.2 was previously published as Kang I (2022b) "Three new species of *Retusigaster* Dangerfield, Austin & Whitfield, 1999 (Hymenoptera: Braconidae: Cardiochilinae) with an illustrated key to the New World species," *ZooKeys* 1092: 47−62. Copyright © Ilgoo Kang. [https://doi.org/10.3897/zookeys.1092.80560]

Section 4.3 was previously published as Kang I, Sharkey MJ, Diaz R (2021b) "Revision of the genus *Schoenlandella* (Hymenoptera, Braconidae, Cardiochilinae) in the New World, with a potential biological control agent for a lepidopteran pest of bitter gourd (*Momordica charantia* L.)," Copyright © Ilgoo Kang et al. *Journal of Hymenoptera Research* 86: 47−61. [https://doi.org/10.3897/jhr.86.72690]

Section 4.4 was previously published as Kang I, Whitfield JB, Owens BE, Chen J (2022c) "Resurrection of *Neocardiochiles* Szépligeti, 1908 (Hymenoptera: Braconidae: Cardiochilinae) with descriptions of five new species from the Neotropical region," Copyright © Ilgoo Kang et al. *Journal of Hymenoptera Research* 91: 41−68. [https://doi.org/10.3897/jhr.91.84937]

species, biology information of two species, *B. adina* (Wilkinson, 1930) and *B. exiguurus* (Huddleston & Walker, 1988) are known. Members of *B. adina* were eclosed from caterpillars of *Phazaca theclata* (Guenée, 1857) (Lepidoptera: Uraniidae) in New Forest, India, (Beeson and Chatterjee 1935; Dangerfield 1995; Dangerfield et al. 1999), and specimens of *B. exiguurus* were reared from caterpillars of *Cleora tulbaghata* (Felder and Rogenhofer, 1875), (Lepidoptera: Geometridae) from South Africa in 1955 (Dangerfield et al. 1999). In the beginning of this project, three new species of *Bohayella* were discovered from two countries in the Neotropical region, Costa Rica and Ecuador, which are biologically highly diverse regions. The total estimated hymenopteran fauna of Costa Rica is about 20,000 species, including about 2,000 estimated species of braconid wasps (Gaston et al. 1996). Until 2012 (Yu et al. 2012), 552 species of braconids were recorded from the country. Before this study, three species of Cardiochilinae were recorded from Costa Rica, *Hansonia chavarriai* Dangerfield, 1996, *Neocardiochiles hasegawai* (Dabek & Whitfield, 2020) and *Neocardiochiles kidonoi* (Dabek & Whitfield, 2020). There was no total estimated hymenopteran fauna of Ecuador available, but 228 braconid species were recorded from Ecuador as of 2012 (Yu et al. 2012). Only one genus and two species of Cardiochilinae were recorded from Ecuador, *Cardiochiles aterrimus* Fischer, 1958 and *C. purpureus* Fischer, 1958 (Yu et al. 2012). Herein, species descriptions of three new species are included with image plates, and an illustrated key to the species of the New World *Bohayella* is included.

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters: 2.1., 2.2., 2.3., and 2.4. Specimens were borrowed from TAMU and UWIM.

Taxonomy. Taxonomic information of the genus with an identification key to species of New World *Bohayella*, and descriptions of new species are included in the following:

Bohayella Belokobylskij, 1987

Type species. *Bohayella tobiasi* Belokobylskij, 1987

Diagnosis. *Bohayella* can be identified by the following characters: eyes sparsely setose with microsetae (Figs. 15B, 16C, 17C); clypeal tubercles absent; mouthparts (galea and glossa) short (Figs. 15B, 16C, 17C); occipital carina absent; notauli deep and broad, with crenulae (Figs. 15C, 16D, 17D); scutella sulcus deep and broad, and at least with a longitudinal carina (Figs. 15B, 16C, 17C); scutellum with a cup-like pit posteriorly; epicnemial carina present (Figs. 15B, 16C, 17C); precoxal sulcus well-defined and crenulate (Figs. 15A, 16A, 17A); medial areola on propodeum present and completely developed (Figs. 15D, 16E, 17E); hind tarsus without an apical cup-like projection (Figs. 15A, 16A, 17A); tarsal claw pectinate (Figure 15E); T1 narrow, ≧ ~ 4.6 × longer than broad (Figs. 15F, 16E, 17E); lateral suture of T2 with a ball-like projection anteriorly connected to socket of T1 (Figs. 15A, 16A, 17A); hypopygium apically truncate never with acute angle, and evenly sclerotized (Figs. 15A, 16A, 17F); ovipositor short and down curved; ovipositor sheath short (Figs. 15A, 16A, 17F).

Key to species of New World *Bohayella*

1. A. Scutellar sulcus with a median crenula...*B. geraldinae*

   B. Scutellar sulcus with three crenulae 2

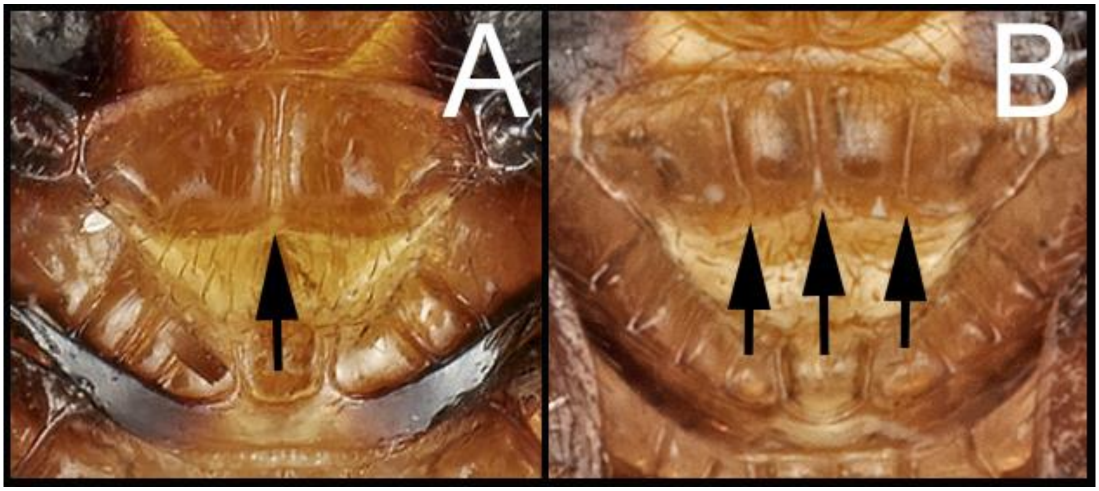

Figure 13. Key image of couplet 1 of the key to species of New World *Bohayella*.

2(1). A. Median crenula of notauli apparently shorter than median crenula of scutellar sulcus; apical cuplike pit of scutellum with V-shape posterior margin .... *B. hansoni*

B. Median crenula of notauli slightly shorter than median crenula of scutellar sulcus; apical cuplike pit of scutellum with U-shape posterior margin .... *B. rodrigodiazi*

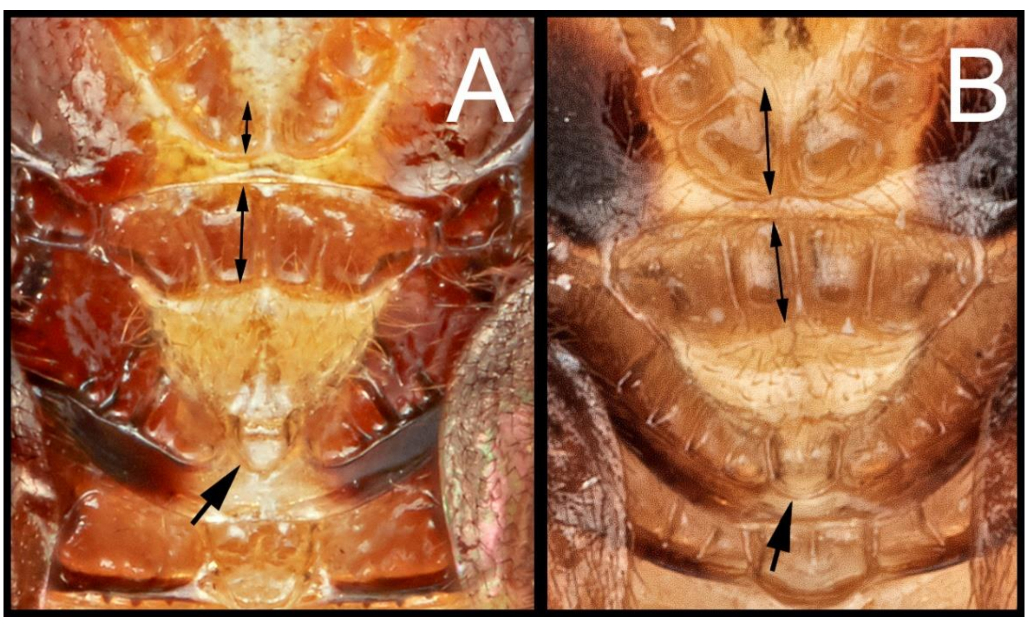

Figure 14. Key image of couplet 2 of the key to species of New World *Bohayella*.

Bohayella geraldinae **Kang sp. nov.**

(See Figure 15)

Material examined. Holotype Costa Rica • ♀**;** female, Heredia, 3 km S. Puerto Viejo OTS, La Selva; 100 m; x.1992; P. Hanson; huertos Malaise trap set by G. Wright. Paratypes Costa Rica • ♀**;** same data as for holotype; xi.1992 • ♂**;** male; same collecting data as for preceding; 10°26´N, 84°01´; 4.iv.1987; H. A. Hespenheide.

Diagnosis. Body mostly pale and orange (Figure 15A). Fore wing entirely infuscate (Figure 15F); median longitudinal carina of notauli as long as median longitudinal carina of scutellar sulcus (Figure 15C); scutellar sulcus broad and deep, with a median longitudinal carina (Figure 15C); T5−T8 melanic (Figure 15F).

Description. Body ~ 4.7 mm, small compared to other cardiochilines. Head: Antenna 34-segmented. Interantennal space with well-developed median carina. Eye sparsely setose; median width of eye about ~ 1.6 × shorter than the median width of temple in lateral view. Gena extended ventro-posteriorly into moderate prominence. Clypeal tubercles absent. Mandible bidentate. Maxillary palpus five-segmented. Labial palpus four-segmented. Galea short and broad. Glossa short. Occipital carina absent. Mesosoma: Mesoscutum with sharp margin. Notauli present, deeply and widely impressed, with eleven crenulae, and converging broadly at base. Scutellar sulcus broad and deep, with a median longitudinal carina. Scutellum with a median cup-shaped pit posteriorly. Postscutellar depression present. Propodeum rugulose, with well-defined median areola; median transverse carina on the propodeum reaching lateral margin. Pronotum carinate posterodorsally and smooth anteroventrally. Mesopleuron with crenulate margin dorsally and posteriorly, precoxal sulcus well-defined and crenulate, epicnemial carina present and sharply defined. Metapleuron rugulose. Discrimen with few barely perceptible crenulae. Legs: Basal spur on fore tibia about ~ 0.9 × longer than basitarsus. Hind tibia expanded and without apical cup-like projection. Hind tarsal claw pectinate with four sharp

teeth. Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid, about ~ 2.0 × longer than height; 1r absent; 3r present, but spectral; 3RSb sharply angled near basal third; stigma about ~ 3.0 × longer than wide medially. Hind wing 2−1A absent. Metasoma: T1 elongate, about ~ 5.3 × longer than broad apically, with medial raised node at base, forming a socket for a ball-like projection of T2, with a pair of lateral sutures reduced posteriorly. T2 with a ball-like projection anteriorly connected to socket of T1. T3 about ~ 2.0 × longer than T2 medially. Hypopygium truncate and obtuse apically as viewed laterally, evenly sclerotized. Ovipositor short and downcurved. Ovipositor sheath about ~ 0.17 × longer than hind tibia, paddle-like and densely setose apically.

Color. Body mostly pale; the following areas melanic: Antenna, vertex, frons, dorsal occiput, maxillary palpus, labial palpus, lateral mesonotal lobe (pale basally), lateral scutellum, margin of metanotum, apical fore femur, fore tibia, apical fore tarsus, apical mid femur, mid tibia, apical mid tarsus, apical hind femur, basal and apical hind tibia, apical hind tarsus, posterior T5, posterior T6, entire T7 and T8, ovipositor sheath. Wings entirely infuscate, stigma entirely melanic.

Host. Unknown.

Distribution. *B. geraldinae sp. nov.* is only known from the La Selva Biological Station, Heredia, Costa Rica at elevation of 100 m (Figs. 18, 19).

Male. Same as female except for the following characters: antenna 32-segmented, melanic color does not reach the dorsal margin of foramen magnum.

Etymology. This species is named in honor of Dr. Geraldine Wright who is a former student of the second author (SRS), Rhodes Scholar, currently professor in the Department of

Zoology in the University of Oxford in the UK and the person who set the trap that collected the specimens.

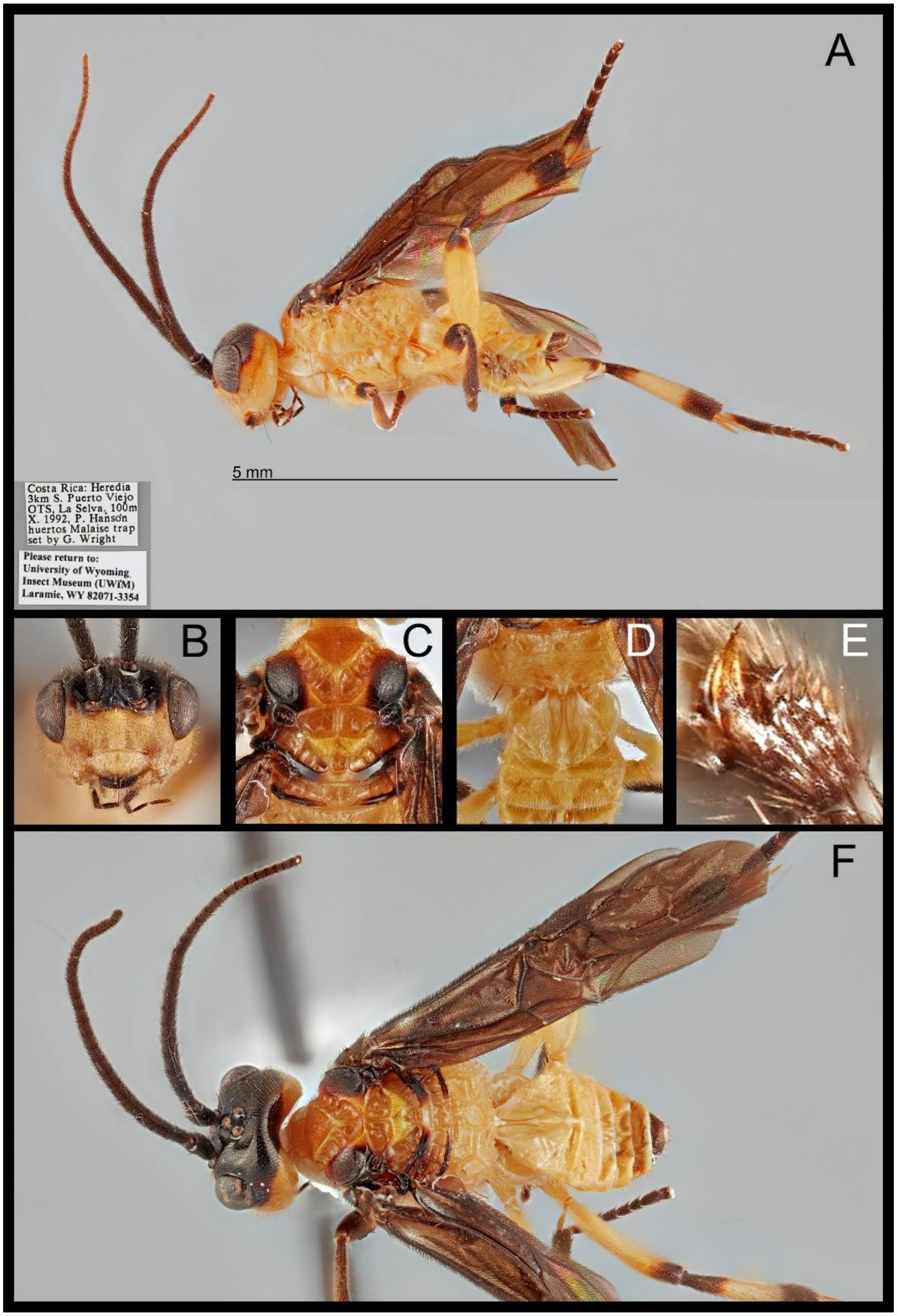

Figure 15. *Bohayella geraldinae* sp. nov. A) Lateral habitus; B) anterior head; C) dorsal mesonotum; D) dorsal propodeum and T1–T3; E) claw; F) dorsal habitus.

Bohayella hansoni **Kang *sp. nov.***

(See Figure 16)

Material examined. Holotype Costa Rica • ♀; female, Puntarenas, San Vito, Estac. Biol., Las Alturas; 1,500 m; vi.1992; Paul Hanson; traps #1 + #2, Malaise. Paratypes Costa Rica • 2♀; same data as for holotype • 2♀; same collecting data as for preceding • 1♀; female; same collecting data as for preceding; 1,700 m; 11.iv.1993.

Diagnosis. Body mostly pale (Figure 16A). Fore wing entirely infuscate (Figure 16A); median longitudinal carina of notauli about ~ 0.3 × longer than median longitudinal carina of scutellar sulcus (Figure 16D); scutellar sulcus broad and deep, with three longitudinal carinae (Figure 16D); T2–T8 melanic (Figure 16B).

Description. Body ~ 4.0 mm, small compared to other cardiochilines. Head: Antenna 32-segmented. Interantennal space with well-developed median carina. Eye sparsely setose; median width of eye about ~ 1.3 × shorter than the median width of temple in lateral view. Gena extended ventroposteriorly into moderate prominence. Clypeal tubercles absent. Mandible bidentate. Maxillary palpus 5-segmented. Labial palpus four-segmented. Galea short and broad. Glossa short. Occipital carina absent. Mesosoma: Mesoscutum with sharp margin. Notauli present deeply and widely impressed, with eleven crenulae, and meeting at base. Scutellar sulcus broad and deep, with three longitudinal carinae. Scutellum with a medial cup-shaped pit posteriorly. Postscutellar depression present. Propodeum rugulose, with well-defined median areola; median transverse carina on the propodeum reaching lateral margin. Pronotum carinate posterodorsally and smooth anteroventrally. Mesopleuron with crenulate margin dorsally and posteriorly, precoxal sulcus well-defined and crenulate, epicnemial carina present and sharply defined. Metapleuron rugulose. Discrimen with few barely perceptible crenulae. Legs: Basal spur

on fore tibia about ~ 0.9 × longer than basitarsus. Hind tibia expanded and without an apical cup-like projection. Hind tarsal claw pectinate with four sharp teeth. Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid, about ~ 2.7 × longer than height; 1r absent; 3r absent; 3RSb sharply angled near basal third; stigma about ~ 3.0 × longer than wide medially. Hind wing 2−1A absent. Metasoma: T1 elongate, about ~ 6.2 × longer than wide apically, with medial raised node at base, forming a socket for ball-like projection of T2, with a pair of lateral sutures reduced posteriorly. T2 with a ball-like projection anteriorly connected to socket of T1. T3 about ~ 2.1 × longer than T2 medially. Hypopygium truncate and obtuse apically as viewed laterally, evenly sclerotized. Ovipositor short and downcurved. Ovipositor sheath about ~ 0.25 × longer than hind tibia, paddle-like and setose apically.

Color. Body mostly pale; the following areas melanic: Antenna, vertex, frons, dorsal occiput, maxillary palpus, labial palpus, lateral mesonotal lobe (pale basally), lateral scutellum, margin of metanotum, apical fore femur, fore tibia, apical fore tarsus, apical mid femur, mid tibia, apical mid tarsus, apical hind femur, basal and apical hind tibia, apical hind tarsus, T2 to T8, ovipositor sheath. Wings entirely infuscate, stigma entirely melanic.

Male. Unknown.

Host. Unknown.

Distribution. *B. hansoni sp. nov.* is only known from the Las Alturas Biological research station owned and operated by Stanford University in Las Alturas, San Vito, Costa Rica at elevation of 1,500 m and 1,700 m (Figs. 18, 20).

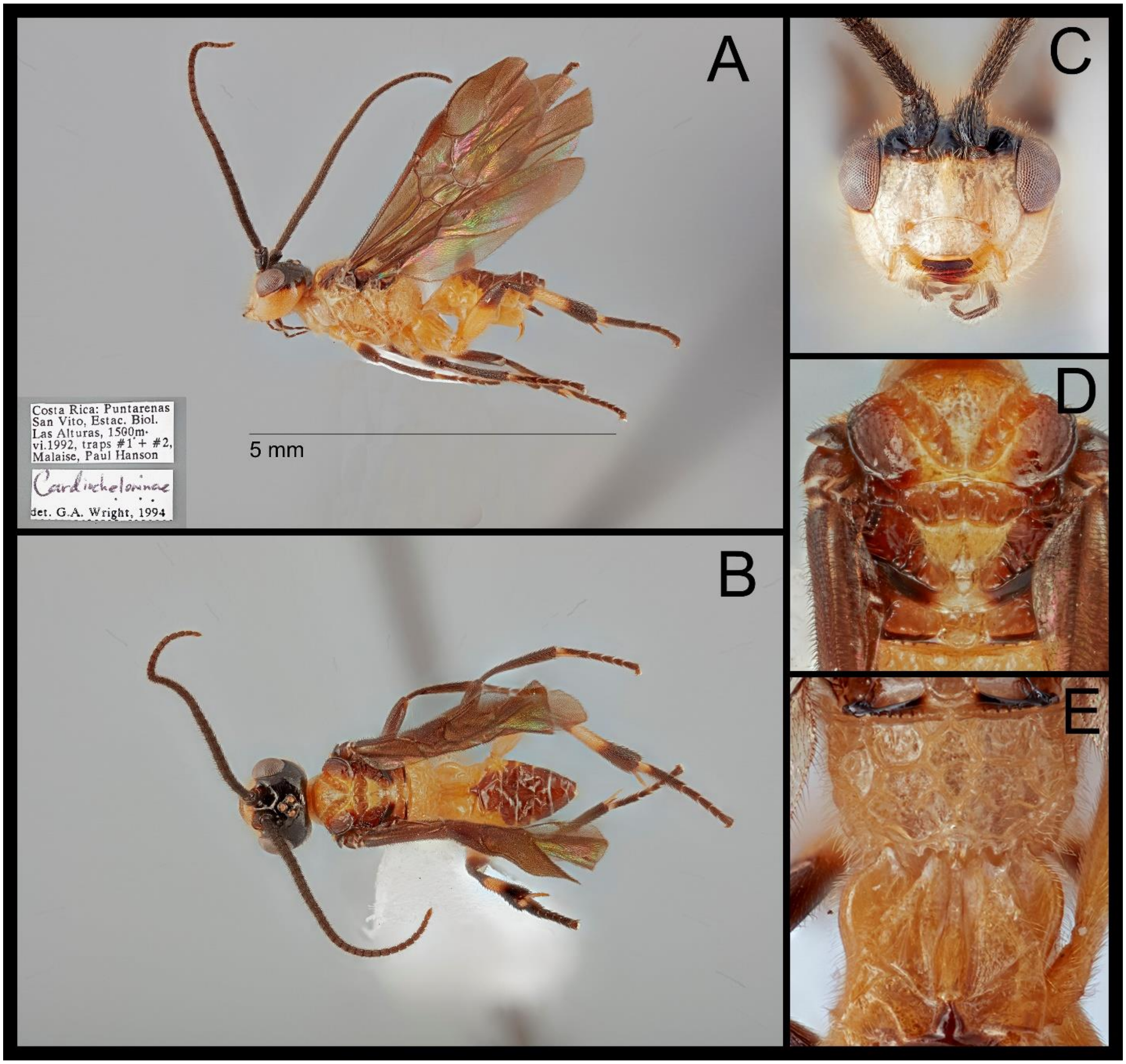

Figure 16. *Bohayella hansoni* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) dorsal mesonotum; E) dorsal propodeum and anterior metasoma.

Etymology. This species is named in honor of Dr. Paul Hanson, who is our collaborator and a professor in the Escuela de Biología, in the Universidad de Costa Rica. He worked tirelessly for many years collecting and sorting Costa Rican braconids from Malaise samples. SRS is highly grateful of his dedication to Hymenoptera studies.

Bohayella rodrigodiazi Kang sp. nov.

(See Figure 17)

Material examined. Holotype Ecuador • ♀; female, Sucumbíos, Rio Napo, Sacha Lodge; 0° 30′S, 76° 30′W, 270m; 4–14.iii.1994; Malaise Trap; P. Hibbs leg. Paratypes Ecuador • ♀; same data as for holotype; 78° 30′W; 220–230m; 12–22.vi.1995. • ♀; same collecting data as for preceding (Note: According to the GPS coordinates, Sacha Lodge is located near 0° 30′S, 76° 30′W.).

Diagnosis. *B. rodrigodiazi* sp. nov. can be distinguished from *B. geraldinae* Kang by the following characters: apical maxillary palpomere slightly longer than penultimate maxillary palpomere (Figure 17C); scutellar sulcus with three crenulae (Figure 17D); T4 medially melanic (Figure 17E). *B. rodrigodiazi* sp. nov. can be distinguished from *B. hansoni* Kang by the following characters: median crenula of notauli as long as median crenula of scutellar sulcus (Figure 17D); apical cuplike pit of scutellum with U-shape posterior margin (Figure 17D); hind basitarsus antero-posteriorly slightly expanded; a ball-like projection of T2 pale (Figure 17E).

Description. Body ~ 4.95−5.06 mm. Fore wing length: ~ 4.46 mm. Hind wing length: ~ 3.50 mm. Antenna length: ~ 4.84−5.11 mm. Head. Antenna 33–34-segmented. Interantennal space with median carina. POL ~ 1.31 × longer than diameter of anterior ocellus (0.17:0.13). Eye sparsely setose with microsetae; length of eye 0.78 × longer than median width of gena in lateral view (0.39:0.50). Gena ventro-posteriorly extended into moderate prominence. Width of clypeus ~ 2.04 × longer than height (0.49:0.24). Malar space ~ 1.83 × longer than basal width of mandible (0.22:0.12). Mandible bidentate. Maxillary palpus five-segmented; apical maxillary palpomere ~ 1.11 × longer than fifth maxillary palpomere (0.21:0.19). Mesosoma. Mesoscutum with sharp margin. Notauli broadly converging at base, with eleven crenulae; median crenula of

notauli ~ 0.82 × longer than median crenula of scutellar sulcus (0.18:0.22). Scutellar sulcus with three crenulae. Apical cuplike pit of scutellum with U-shape posterior margin. Postscutellar depression present. Propodeum rugulose; median areola of propodeum apparent; median transverse carina of the propodeum reaching lateral margin. Pronotum anteriorly smooth and posteriorly crenulate. Mesopleuron dorsally and posteriorly with crenulate margin. Epicnemial carina medially present. Metapleuron anteriorly smooth and posteriorly crenulate. Legs. Basal spur on fore tibia ~ 0.76 × longer than basitarsus (0.34:0.45). Basal spur on mid tibia ~ 0.89 × longer than basitarsus (0.42:0.47). Width of hind femur ~ 0.34 × longer than its length (0.46:1.35). Basal spur on hind tibia ~ 0.82 × longer than basitarsus (0.65:0.79). Hind tarsal claw pectinate. Wings. Fore wing second submarginal cell trapezoidal, ~ 0.35 × longer than its maximum width (0.30:0.86); 3r absent; 3RSb sharply angled at basal third; stigma ~ 3.31 × longer than medial width (1.16:0.35); 1CUa short, ~ 0.26 × longer than 1Cub (0.13:0.50). Hind wing 2−1A absent. Metasoma. T1 with a pair of lateral sutures posteriorly reduced, median length of T1 ~ 4.78 × longer than apical width (0.67:0.14). T2 with a ball-like projection, medially ~ 0.31 × longer than T1 (0.21:0.67). T3 ~ 1.81 × longer than T2 medially (0.38:0.21). Protruded ovipositor sheath ~ 0.15 × longer than hind tibia and apically setose (0.26:1.74).

Color. Body mostly pale; the following areas darker: antenna, vertex, frons, dorsal occiput, labrum, mandible apically, maxillary palpus, labial palpus, lateral mesonotal lobe posteriorly, tegula, margin of metanotum posteriorly, apical fore tibia, fore tarsus, apical mid femur, mid tibia, mid tarsus, apical hind femur, basal and apical hind tibia, apical hind tarsus mostly, T4–T8 (one specimen with melanic T3 medially), ovipositor sheath. Wings entirely infuscate, stigma darker.

Male. Unknown.

Host. Unknown.

Distribution. *B. rodrigodiazi* sp. nov. is known only from Sacha Lodge, Rio Napo, Sucumbíos, Ecuador at the elevations of 220 m and 270 m.

Etymology. This species is named in honor of Dr. Rodrigo Diaz, Associate Professor of biological control in the Department of Entomology, Louisiana State University. He is the PhD advisor of the author of this paper (IK) and originally from Quito, Ecuador.

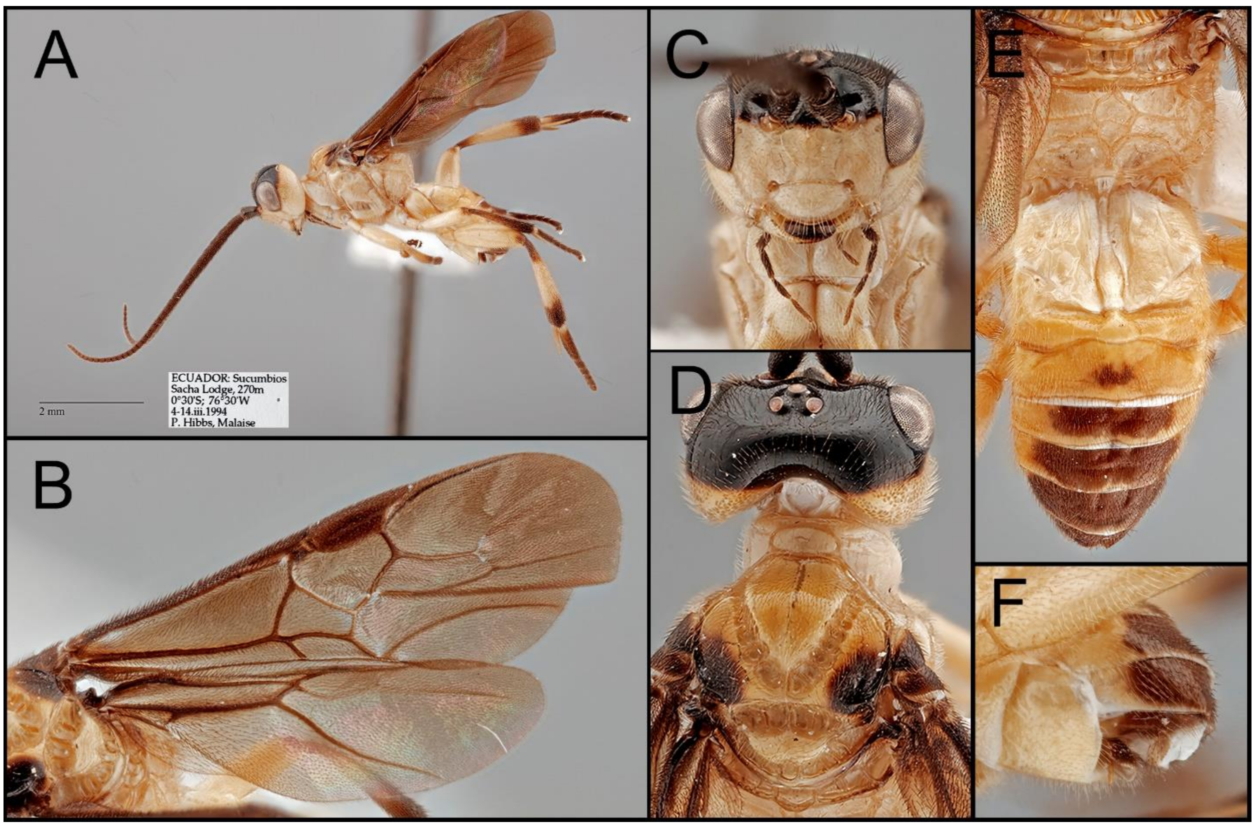

Figure 17. *Bohayella rodrigodiazi* sp. nov. A) Lateral habitus; B) wings; C) anterior head; D) dorsal head and mesonotum; E) dorsal propodeum and metanotum; F) latero-ventral hypopygium.

Discussion. Many genus-level diagnostic characters are shared by members of both Old World and the New World species. The following characters are only shared by New World members: angled 3RSb vein of fore wing (Figs. 15F, 16A, 17B), pectinate hind tarsal claw with sharp apical tooth (Figure 15E), and antero-posteriorly slightly expanded hind basitarsus (Figs.

15A, 17A). As melanism correlated to the altitudes of the habitats found from other insects (Braconids: Abe et al. 2013, Fernandez-Triana et al. 2014a; other hymenopterans: de Souza et al. 2020, Mora and Hanson 2019; coleopterans: Stanbrook et al. 2021), the melanism pattern associated with high altitudes was also observed from the members of the three New World *Bohayella*. Even though they have similar body coloration, colors of their tergites are diagnostic. Specimens of *B. geraldinae* sp. nov. collected at altitudes of ~ 100 m in Costa Rica have the palest metasoma. Specimens of *B. rodrigodiazi* sp. nov. collected at the altitudes of ~ 250 m in Ecuador have more melanistic metasoma than the members of *B. geraldinae* sp. nov. and paler tergites than specimens of *B. hansoni* sp. nov. collected at the highest altitudes above 1,500 m, which possess the darkest metasoma among the three species. The two Costa Rican species, *B. geraldinae* sp. nov. and *B. hansoni* sp. nov., might be one species in the past. The geographic changes in altitudes in the past might affect temperatures of habitats, host insects, and plants used by host insects, and those might cause the speciation between the two Costa Rican species. This pattern can be confirmed in a detailed manner when additional new species of *Bohayella* are discovered from the places in the different altitudes. Also, when more specimens of additional new Ecuadorian species are collected from the different altitudes, it will be possible to confirm whether the melanism associated with high elevation is present among species of *Bohayella* in Ecuador.

Figure 18. Distribution map of *B. geraldinae* sp. nov. and *B. hansoni* sp. nov. in Costa Rica.

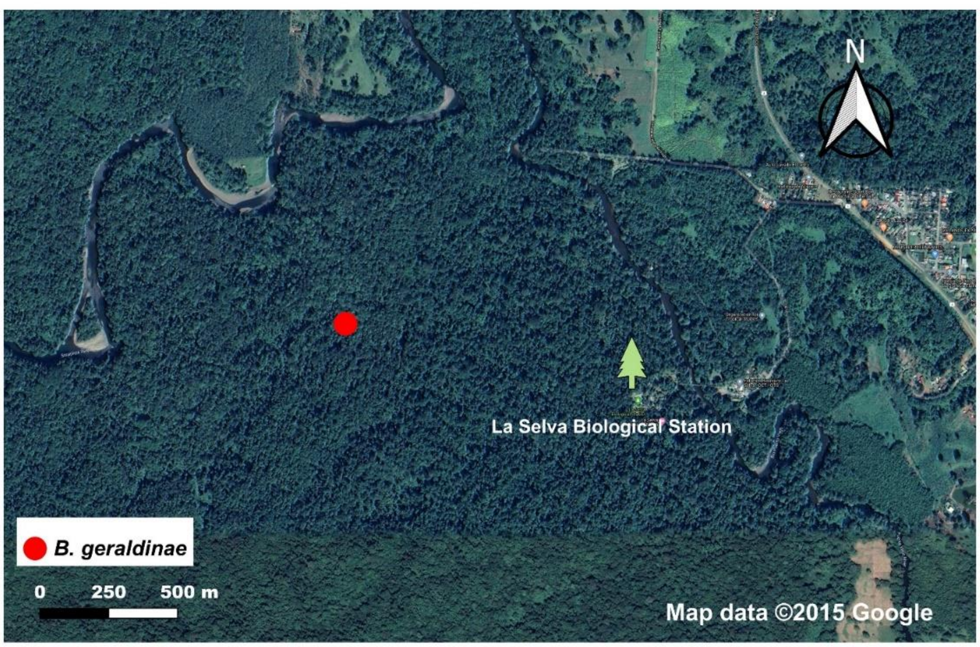

Figure 19. Distribution map of *B. geraldinae* sp. nov. in the La Selva Biological Station in Costa Rica.

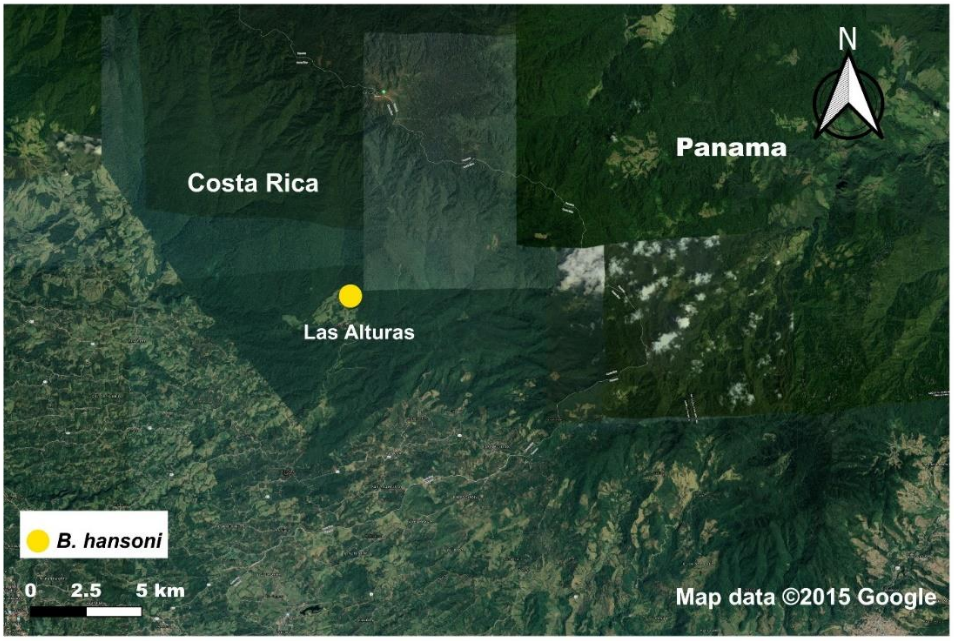

Figure 20. Distribution map of *B. hansoni sp. nov.* in the Las Alturas Biological Research Station.

4.2. Three New Species of *Retusigaster* Dangerfield, Austin & Whitfield, 1999 (Hymenoptera: Braconidae: Cardiochilinae)

Introduction. *Retusigaster* Dangerfield, Austin & Whitfield, 1999 is a small genus of Cardiochilinae Ashmead, 1900 with eight valid species (Yu et al. 2016). Seven species were recorded from the New World: *R. arugosus* (Mao, 1949), *R. albopilosus* Mercado, 2003, *R. brevitarsus* (Mao, 1949), *R. dignus* (Mao, 1949), *R. noguerai* Mercado, 2003, *R. pullus* (Mao, 1949) and *R. rubidus* (Mao, 1949). Among these New World species, five were described as *Cardiochiles*, Nees 1819 by Mao (1949) and transferred to *Retusigaster* by Dangerfield et al. (1999) based on morphology-based phylogenetic data. Dangerfield et al. (1999) also transferred one Old World species, *Cardiochiles eremitus* Kokujev, 1904 to *Retusigaster*, *R. eremita* (Kokujev, 1904). Mercado and Wharton (2003) treated *Retusigaster* as a valid genus and described two new species from Mexico, and two species-groups were defined based on the degree of thickening of the apex of hind tibia and propodeal spiracle shape and location, *R.*

rubidus (Mao, 1949) species-group and *R. arugosus* (Mao, 1949) species-group. In this subchapter, the definition of *Retusigaster* by Dangerfield et al. (1999) is followed. Two new species from Nearctic region and one new species from the Neotropical region are described. The first illustrated key to the New World species of *Retusigaster* was constructed during this research and is included. Biological information for *Retusigaster* is scarce. The first potential food source for *R. arugosus*, is reported as *Gossypium* sp. (Malvales: Malvaceae). *Purshia mexicana* (D.Don) S.L.Welsh (Rosales: Rosaceae) is reported as a potential food source for *Retusigaster purshi* sp. nov. Additionally, the species groups defined by Mercado and Wharton (2003) are re-evaluated and discussed, and the placement of *R. eremita* is discussed.

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters 2.1., 2.2., and 2.4. Specimens involved in this project were borrowed from CAS, HIC, MCZ, TAMU.

Taxonomy. Taxonomic information of the genus with an identification key to species of *Retusigaster* of the New World, and descriptions of new species are included in the following:

Retusigaster Dangerfield, Austin & Whitfield, 1999

Type Species: *Cardiochiles rubidus* Mao, 1949

Diagnosis. Dangerfield et al. (1999) and Mercado and Wharton (2003) provided detailed diagnostic characters. *Retusigaster* can be easily distinguished from other cardiochiline genera by the combination of the following characters: eye seemingly bare (Figs. 30C, 31C, 33C); clypeal tubercle absent (Figs. 30C, 31C, 33C); mouthparts short (Figs. 30C, 31C, 33C); scutellum apically with carinate margin (Figs. 30F, 31B, 33H); hind tibia without apical cuplike projection (Figs. 30A, 31A, 33A); ovipositor and ovipositor sheath short (Figs. 30A, 31A, 33A); hypopygium entirely sclerotized and ventro-apically blunt (Figs. 30A, 31A, 33A).

Distribution. Nearctic region (Canada, USA, Mexico), Neotropical region (Jamaica and Mexico), Palearctic region (Kazakhstan, Mongolia, Turkey, Turkmenistan).

Biology. Potential food sources of two species of *Retusigaster* are found. A member of *R. arugosus* was collected on cotton (*Gossypium* sp.; Malvaceae) in Texas, and a specimen of *R. purshi* sp. nov. was collected on Mexican cliffrose (*Purshia mexicana* (D. Don) S. L. Welsh; Rosaceae) in Nevada.

Key to species of *Retusigaster* of the New World

1. A. Metasoma mostly or entirely pale..2

B. Metasoma mostly or entirely dark 5

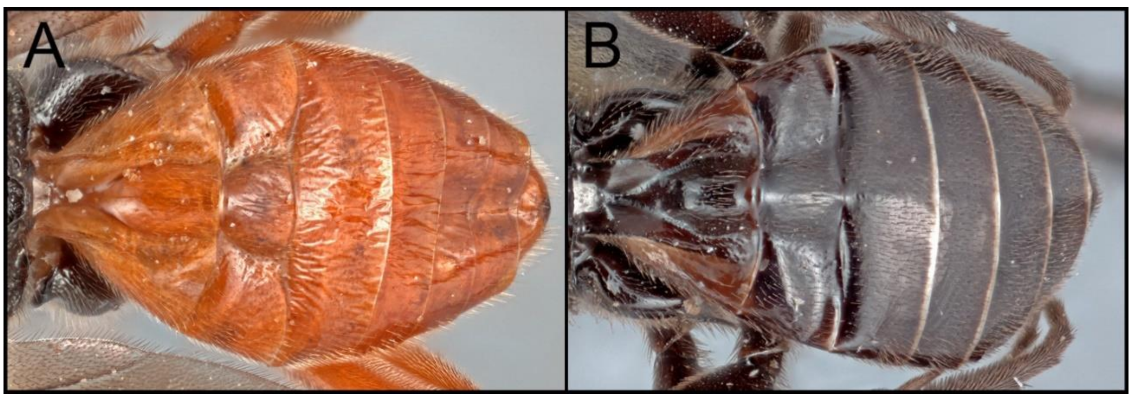

Figure 21. Key image of couplet 1 of the key to species of *Retusigaster* of the New World.

2(1). A. Mesoscutum mostly or entirely pale...3

B. Mesoscutum mostly or entirely dark...4

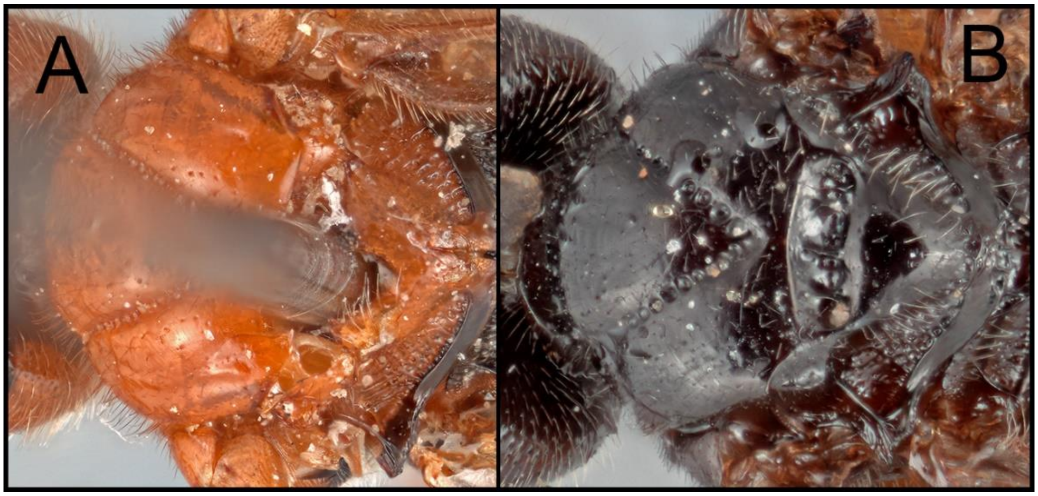

Figure 22. Key image of couplet 2 of the key to species of *Retusigaster* of the New World.

3(2). A. Notauli smooth.. *R. brevitarsus*

B. Notauli crenulate.. *R. rubidus*

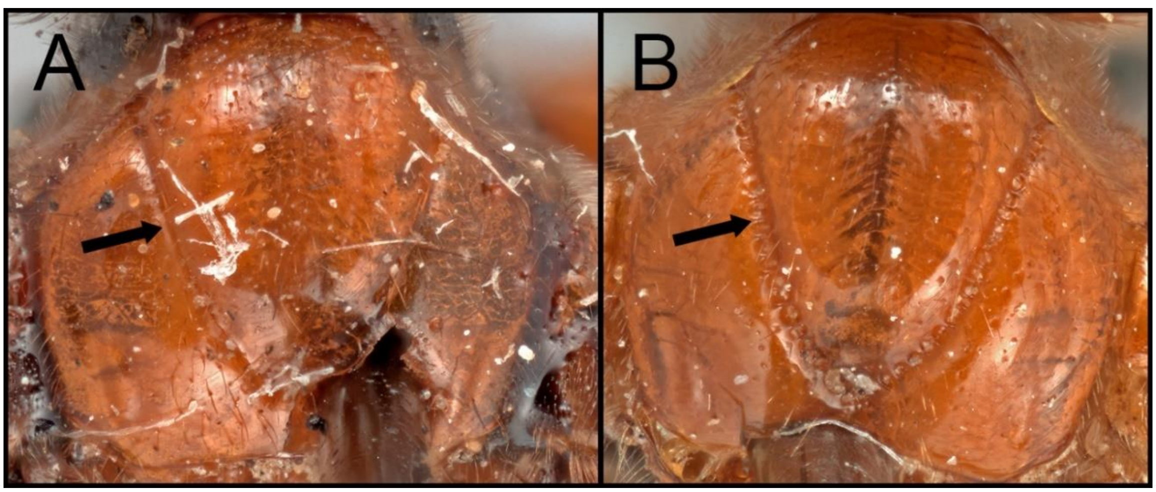

Figure 23. Key image of couplet 3 of the key to species of *Retusigaster* of the New World.

4(2). A. Fore wing apically infuscate.. *R. arugosus*

B. Fore wing entirely infuscate.. *R. pullus*

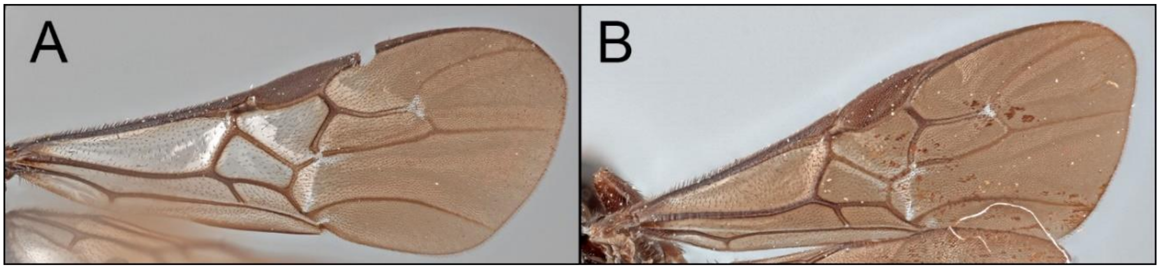

Figure 24. Key image of couplet 4 of the key to species of *Retusigaster* of the New World.

5(1). A. Fore wing apically infuscate 6

B. Fore wing entirely infuscate..9

Figure 25. Key image of couplet 5 of the key to species of *Retusigaster* of the New World.

6(5). A. Stigma entirely pale .... *R. dignus*

B. Stigma entirely dark.. 7

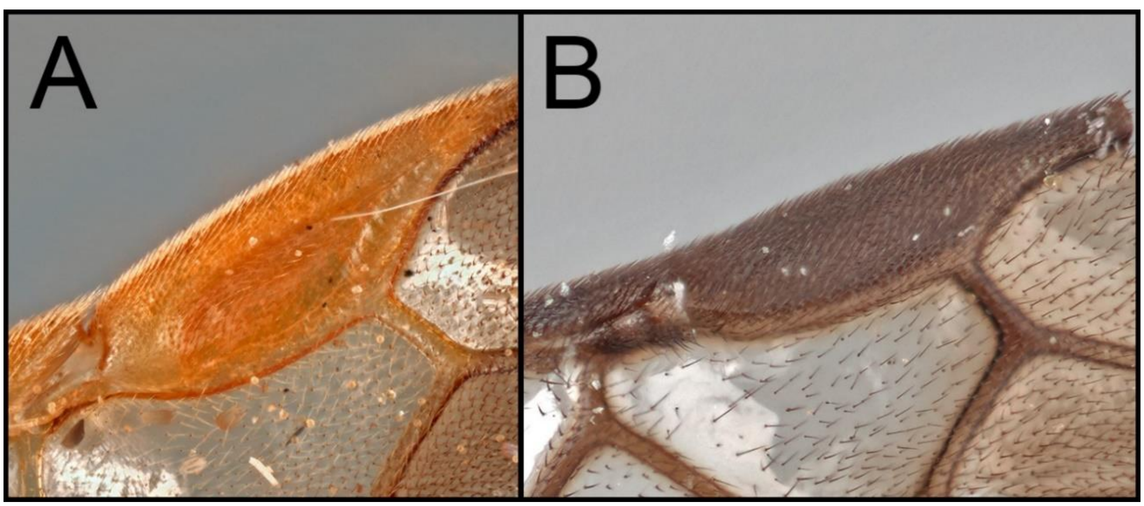

Figure 26. Key image of couplet 6 of the key to species of *Retusigaster* of the New World.

7(6). A. Fore tibia entirely dark.. *R. purshi* sp. nov.

B. Fore tibia entirely pale 8

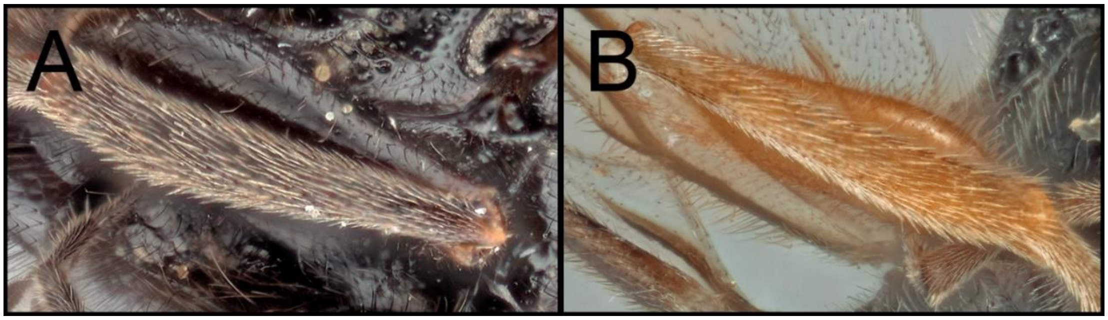

Figure 27. Key image of couplet 7 of the key to species of *Retusigaster* of the New World.

8(7). A. Metafemur entirely pale.. *R. pulawskii* sp. nov.

B. Metafemur entirely dark .... *R. albopilosus*

Figure 28. Key image of couplet 8 of the key to species of *Retusigaster* of the New World.

9(5). A. Fore tibia entirely black .... *R. vanduzeei* sp. nov.

B. Fore tibia entirely pale .... *R. noguerai*

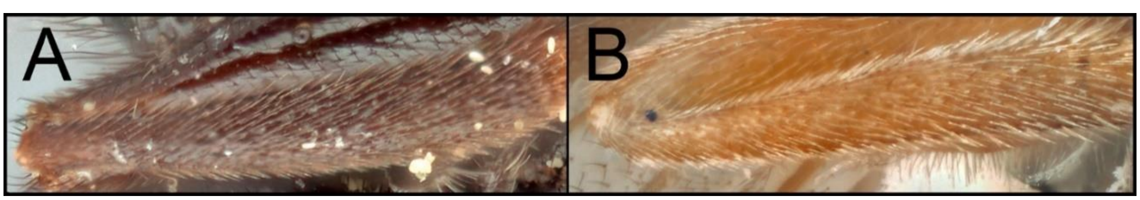

Figure 29. Key image of couplet 9 of the key to species of *Retusigaster* of the New World.

Retusigaster albopilosus Mercado, 2003

Material examined. Paratypes Mexico • 2♀; Xmatkuil, Mérida, Yucatán; 25−28.V.1996; Wharton & León; Malaise Trap. Deposited in TAMU.

Diagnosis. Members of *Retusigaster albopilosus* can be recognized by the combination of the following characters: body 3.5–5.5 mm; fore wing entirely infuscate with dark stigma (Figure 24B); fore tibia pale; mid and hind femur entirely dark; T2 entirely dark.

Description. See Mercado and Wharton (2003).

Male. See Mercado and Wharton (2003).

Biology. Unknown.

Distribution. Neotropical region (Mexico).

Retusigaster arugosus (Mao, 1949)

Material examined. Non-type specimens USA: 1♀; Lexington, Massachusetts; 8.ix.1963; H. E. Evans. Deposited in MCZ. 1♀; only collected location was labelled (Chicago). Deposited in MCZ. 1♀; only collected month was labelled (July). Identified as *Cardiochiles abdominalis* Cresson by a previous examiner. Deposited in MCZ. 1♀; near Rio Frio, Garner State Park, Uvalde Co.; 21.vii.1986; 1400'; Wooley & Zolnerowich. Deposited in TAMU. 1♀; Brazos County, Texas; 25.vi.1937; J. E. Gillaspy. Deposited in TAMU.

Diagnosis. *R*. *arugosus* is nearly identical to *R*. *pullus*. The members of both species possess dark head and pale yellow metasoma (Figure 21A). As Mao (1949) mentioned, *R*. *arugosus* is distinguished from *R*. *pullus* by having basally hyaline and apically infuscate wings (Figure 24A). Body ~ 5.5 mm.

Description. See Mao (1949).

Male. Unknown.

Biology (potential food source). Cotton (*Gossypium* sp.; Malvaceae; recorded on the label of one specimen collected in Brazos County, Texas).

Distribution. Nearctic region (Canada, USA).

Retusigaster brevitarsis **(Mao, 1949)**

Material examined. Non-type specimens USA: 1♀; Saugus, Los Angeles, California; 18.viii.1917; J. Bequaers. Deposited in MCZ. 1♀; Warren, San Diego, California; 13.viii.1917; J. Bequaers. Deposited in MCZ.

Diagnosis. Members of *Retusigaster brevitarsis* are most similar to *R. rubidus*. *R. brevitarsis* can be distinguished from other members of the genus by the following characters: body length (~ 7.0 mm); notauli smooth (Figure 23A); mesoscutum mostly orange pale; fore wing entirely infuscate with dark stigma (Figure 25B); metasoma mostly orange pale (Figure 21A).

Description. See Mao (1949).

Male. Unknown.

Biology. Unknown.

Distribution. Nearctic region (USA).

Retusigaster dignus **(Mao, 1949)**

(See Figure 30)

Material examined. Non-type specimen USA: 1♀; Pearsall, Texas. 30.ix.1936. Deposited in TAMU.

Diagnosis. *Retusigaster dignus* can be distinguished from other members of *Retusigaster* by having longer body length (~ 7.5 mm); fore wing apically infuscate with pale stigma (Figure 25A); basal spur on hind tibia 0.67 × longer than length of basitarsus; T1 pale; T2 mostly pale,

medially and submedially dark (Figure 30).

Description. See Mao (1949).

Male. Unknown.

Biology. Unknown.

Distribution. Nearctic region (USA).

Figure 30. Dorsal habitus of *Retusigaster dignus*.

Retusigaster noguerai Mercado, 2003

Material examined. Paratype Mexico: 1♀; Estación de Biología Chamela, Jalisco, Mexico; 3−9. vii. 1993; Wharton & Sharkey. Non-type specimen Mexico • 1♀; same as previous except for collecting date and collector. 8.vii.1994; I. Mercado. Deposited in TAMU.

Diagnosis. *Retusigaster noguerai* is similar to *R. vanduzeei* sp. nov. *R. noguerai* can be distinguished from other members of the genus by the combination of the following characters: body 4.5–6.0 mm; fore wing entirely infuscate with dark stigma; fore femur and tarsus pale; metasoma mostly dark; T2 1.0–1.3 × longer than its posterior width.

Description. See Mercado and Wharton (2003).

Male. See Mercado and Wharton (2003).

Biology. Unknown.

Distribution. Neotropical region (Mexico).

Retusigaster pulawskii **Kang sp. nov.**

(See Figure 31)

Material examined. Holotype Jamaica: ♀; Port Henderson, Catherine Parish; 16.xi.1986; W. J. Pulawski. Holotype will be deposited in CAS.

Diagnosis. *Retusigaster pulawskii* sp. nov. is most similar to *R. albopilosus*. The following characters can distinguish the new species from other species of *Retusigaster*: precoxal sulcus not reaching posterior margin of mesopleuron (Figure 31G); fore tibia entirely pale (Figure 31A); fore wing apically infuscate (Figure 31E); transverse carina of propodeum reaching lateral margin (Figs. 31D, 31F); stigma entirely dark (Figure 31E); hind femur entirely pale (Figure 31A); metasoma mostly dark (Figure 31B); T1 laterally orange (Figure 31D); Y-shaped suture of T1entirely smooth (Figure 31D); T2 medially orange (Figure 31D).

Description. Body ~ 4.69 mm. Head: Antenna 37-segmented. Face width ~ 1.28 × longer than its height (0.73:0.57). Interantennal space with median carina. Width of anterior ocellus ~ 0.92 × longer than POL (0.11:0.12). Eye seemingly without interommatidial setae; median width of eye about ~ 0.97 × longer than the median width of gena in lateral view (0.31:0.32). Gena extended ventroposteriorly into weak prominence. Clypeus ~ 2.25 × longer than its height (0.54:0.24); clypeal tubercles absent. Mandible bidentate. Maxillary palpus five-segmented. Labial palpus four-segmented. Galea short. Glossa short. Occipital carina absent. Mesosoma: Notauli entirely crenulate, strongly crenulate posteriorly. Scutellar sulcus ~ 0.44 × longer than width (0.19:0.43), with three carinae. Postscutellar depression finely crenulate. Pronotum dorsally crenulate and posteriorly rugulose. Mesopleulon mostly smooth, posterior margin strongly crenulate; precoxal sulcus crenulate not reaching posterior margin; epicnemial carina

absent; episternal scrobe present. Metapleuron anteriorly smooth and posteriorly rugulose. Propodeum strongly rugulose, ~ 0.36 × longer than its median width (0.36:1.00); propodeal areola heart-shaped, ~ 1.17 × longer than its maximum width (0.27:0.23); transverse carina reaching lateral margin. Legs: Basal spur on fore tibia ~ 0.58 × longer than length of basitarsus (0.19:0.33). Basal spur on mid tibia ~ 0.63 × longer than length of basitarsus (0.30:0.48). Hind tibia without apical cup-like projection; basal spur on hind tibia ~ 0.64 × longer than length of basitarsus (0.47:0.74); claws pectinate. Wings: Fore wing ~ 4.14 mm; second submarginal cell trapezoid, ~3.20× longer than height (0.80:0.25); 1r absent; 3r absent; 3RSb evenly curved; pterostigma about ~2.89× longer than wide medially (0.81:0.28). Hind wing ~ 3.43 mm; 2r-m absent; 2–1A basally present. Metasoma: T1 ~ 1.32 × longer than its posterior width (0.66:0.50), anteriorly with lateral carina; Y-shaped suture of T1entirely smooth. T2 ~ 0.34 × longer than its posterior width (0.36:1.05), ~ 0.95 × longer than T3 (0.36:0.38). T3 ~ 0.36 × longer than its posterior width (0.38:1.06). Hypopygium without median longitudinal fold. Protruded ovipositor sheath ~ 0.27 × longer than length of hind basitarsus (0.20:0.74), apically with short setae.

Color: Body mostly dark brown. Fore wing apically infuscate; stigma entirely dark. The following areas orange: fore tibia; all femora, basal mid and hind tibiae; medial and lateral T1; medial T2.

Male. Unknown.

Etymology. Named in honor of Dr. Wojciech Jerzy Pulawski, Curator of Entomology, Emeritus, at CAS, the person who collected the specimen from Jamaica.

Biology. Unknown.

Distribution. *Retusigaster pulawskii* sp. nov. is known from a single female specimen collected in Jamaica.

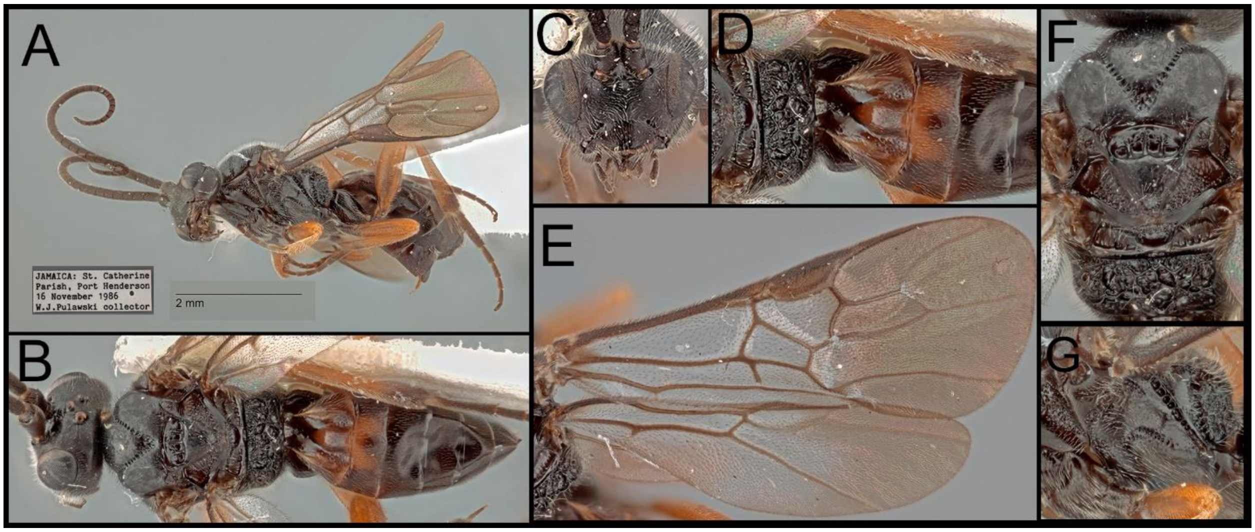

Figure 31. *Retusigaster pulawskii* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) dorsal propodeum to T3; E) wings; F) dorsal mesosoma; G) mesopleuron and metapleuron.

Retusigaster pullus (Mao, 1949)

Material examined. Non-type specimens USA • 1♀; three miles east of Presidio, Texas; 1−3.v.1963; H. E. Evans. Deposited in MCZ. 1♀; Randall County, Texas; Bushland; 26.vii.−7.viii. 1983; T. J. Kring; Malaise trap. Deposited in TAMU.

Diagnosis. By having dark head and pale yellow metasoma, members of *R*. *pullus* and *R*. *arugosus* can be distinguished from the other members of *Retusigaster*. The members of *R*. *pullus* are distinguished from the members of *R*. *arugosus* by having entirely infuscate wings (Figure 24B).

Description. See Mao (1949)

Male. Unknown.

Biology. Unknown.

Distribution. Neotropical region (Mexico).

Retusigaster purshi Kang sp. nov.

(See Figure 32)

Material examined. Holotype USA: ♀; 36°16.15'N, 115°33.29'W; Telephone Canyon, Clark County, Nevada, USA; 16.vi.1998; K. Keen & M. Andres; Collected on *Purshia Mexicana*. Holotype will be deposited in NMNH.

Diagnosis. *Retusigaster purshi* sp. nov. is most similar to *R. vanduzeei* sp. nov. The following characters can distinguish *R. purshi* sp. nov. from other species of *Retusigaster*: body ~ 7.0 mm, mostly black except for medial mandible (reddish brown) and ovipositor (Figs. 32A, 32C); precoxal sulcus crenulate reaching posterior margin (Figure 32A); propodeal areola pentagonal (Figure 32B); fore wing apically infuscate with dark stigma (Figure 32A); fore tibia entirely dark; Y-shaped suture posteriorly crenulate (Figure 32B).

Description. Body ~ 7.06 mm. Head: Head entirely with long setae. Antenna 44-segmented. Face width ~ 1.56 × longer than its height (1.28:0.82). Width of anterior ocellus ~ 0.70 × longer than POL (0.16:0.23). Eye seemingly without interommatidial setae; median width of eye about ~ 0.90 × longer than the median width of gena in lateral view (0.47:0.52). Gena extended ventro-posteriorly into moderate prominence. Clypeus ~ 2.46 × longer than its height (0.96:0.39), with punctures; clypeal tubercles absent. Mandible bidentate. Maxillary palpus five-segmented. Labial palpus four-segmented. Galea short. Glossa short. Occipital carina absent. Mesosoma: Notauli entirely evenly crenulate. Scutellar sulcus ~ 0.45 × longer than width (0.28:0.62), with seven carinae, posteriorly rugulose. Postscutellar depression dorsally rugulose and ventrally crenulate. Pronotum dorsally crenulate and posteriorly rugulose. Mesopleuron dorsally with punctures and ventrally crenulate and rugulose, posterior margin strongly crenulate; precoxal sulcus crenulate reaching posterior margin; epicnemial carina absent; episternal scrobe present. Metapleuron anteriorly smooth and posteriorly rugulose. Propodeum strongly rugulose, ~ 0.38 × longer than its median width (0.61:1.62); propodeal areola

pentagonal, ~ 1.45 × longer than its maximum width (0.48:0.33); transverse carina reaching lateral margin. Legs: Basal spur on mid tibia ~ 0.64 × longer than length of basitarsus (0.40:0.63). Hind tibia without apical cup-like projection; basal spur on hind tibia ~ 0.61 × longer than length of basitarsus (0.57:0.93); claws pectinate. Wings: Fore wing ~ 6.59 mm; second submarginal cell trapezoid, ~ 3.02 × longer than height (1.24:0.41); 1r present as basal stump; 3r absent; 3RSb evenly curved; pterostigma about ~ 3.00 × longer than wide medially (1.05:0.35). Hind wing ~ 4.57 mm; 2r-m absent; 2–1A present reaching basal half. Metasoma: T1 ~ 1.01 × longer than its posterior width (0.93:0.92), anteriorly with lateral carina; Y-shaped suture of T1 anteriorly smooth and posteriorly crenulate. T2 ~ 0.27 × longer than its posterior width (0.43:1.58), ~ 0.77 × longer than T3 (0.43:0.56). T3 ~ 0.34 × longer than its posterior width (0.56:1.64). Hypopygium without median longitudinal fold. Protruded ovipositor sheath ~ 0.29 × longer than length of hind basitarsus (0.27:0.93), apically with long setae.

Color: Body mostly black. Wings basally hyaline and apically infuscate. Pterostigma entirely dark brown. Mandible apically black. Apical tarsomeres pale.

Male: Unknown.

Etymology. Named in honor of Fredrick Traugott Pursh, a German American botanist. The genus of the potential food source was also named after him, *Purshia*.

Biology (potential food source). Mexican Cliffrose (*Purshia mexicana* (D. Don) S. L. Welsh; Rosaceae).

Distribution. *Retusigaster purshi* sp. nov. is known from one female specimen collected in Telephone Canyon, Clark County, Nevada, USA (Figure 33).

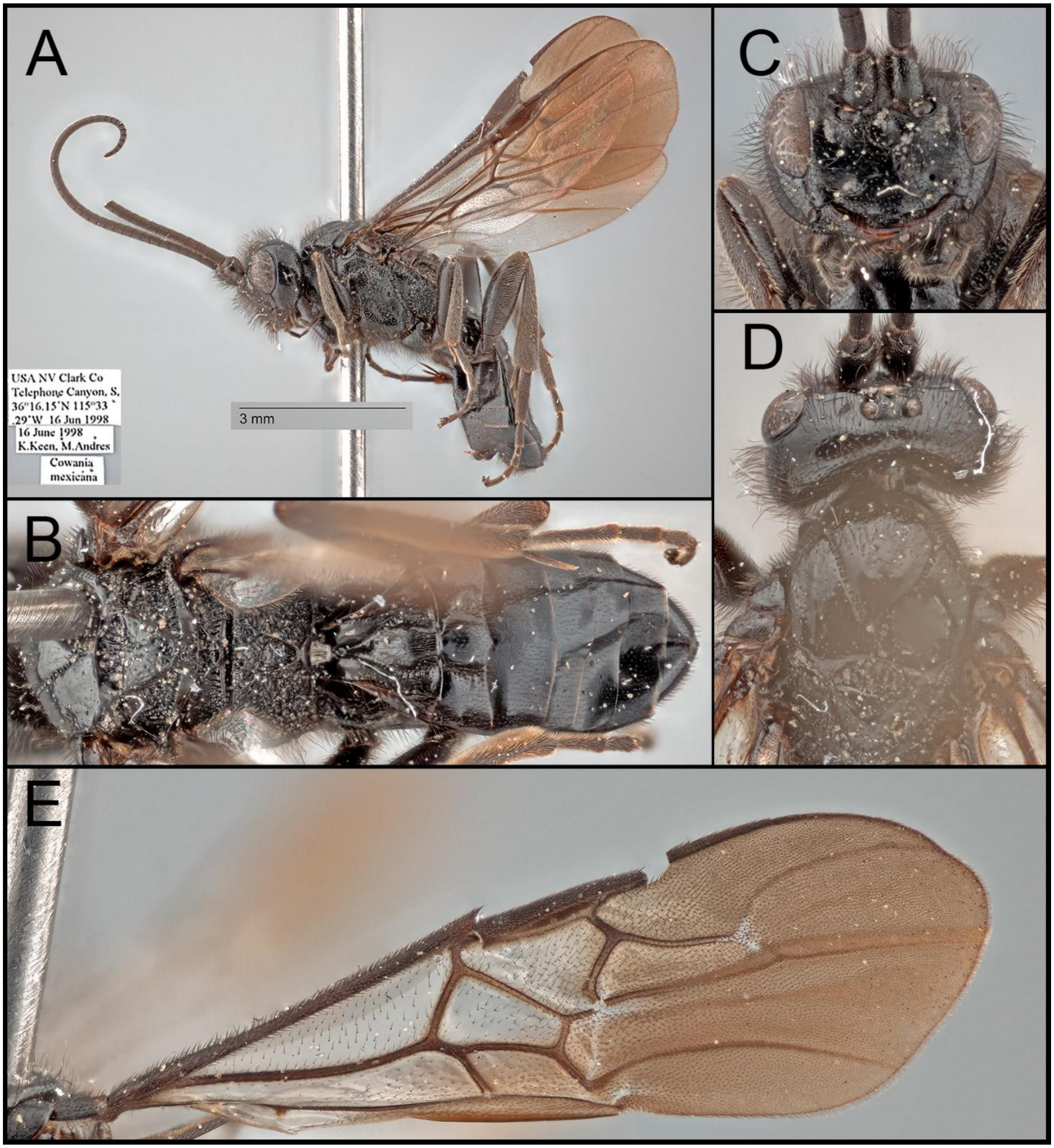

Figure 32. *Retusigaster purshi* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) dorsal mesosoma; E) fore wing.

Figure 33. Habitat near the type locality of *Retusigaster purshi* sp. nov. in Nevada, USA.

Retusigaster rubidus (Mao, 1949)

Material examined. Non-type specimens Mexico • 3♀; seven miles east of San Luis Potosí; 3.vii.1987; 6225'; R. Wharton. USA • 1♀; same as previous except for collecting date and collector. 8.vii.1994; I. Mercado. Deposited in TAMU.

Diagnosis. Members of *Retusigaster rubidus* are most similar to those of *R. brevitarsis*. *R. rubidus* can be distinguished from other members by the following characters: body ~ 7.5 mm. notauli crenulate (Figure 23B); mesoscutum mostly orange pale; fore wing with pale stigma (Figure 25A); metasoma mostly orange pale.

Description. See Mercado and Wharton (2003).

Male. Unknown.

Biology. Unknown.

Distribution. Nearctic region (USA and Mexico).

Retusigaster vanduzeei **Kang sp. nov.**

(See Figure 34)

Material examined. Holotype USA • ♀; Nixon, Washoe County, Nevada; 30.vi.1927; EP Van Duzee. Holotype will be deposited in CAS.

Diagnosis. *Retusigaster vanduzeei* sp. nov. is most similar to *R. noguerai* Mercado. Using the following characters, the members of *R. vanduzeei* sp. nov. can be distinguished from other members the genus: inner and outer orbits orange (Figs. 34C, 34D, 34E); fore wing entirely infuscate (Figure 34F); precoxal sulcus crenulate nearly reaching posterior margin (Figure 34G); propodeal areola oval (Figure 34H); metasoma entirely dark (Figure 34B); T1 antero-laterally crenulate and postero-laterally slightly rugulose; T2 ~ 0.27 × longer than its posterior width (Figs. 34B, 34H).

Description. Body ~ 6.32 mm. Head: Head entirely with long setae. Antenna 37-segmented. Face width ~ 1.50 × longer than its height (0.96:0.64). Width of anterior ocellus ~ 0.80 × longer than POL (0.16:0.20). Eyes seemingly without interommatidial setae; median width of eye about ~ 1.15 × longer than the median width of gena in lateral view (0.45:0.39). Gena extended ventro-posteriorly into moderate prominence. Clypeus ~ 2.67 × longer than its height (0.72:0.27), with punctures; clypeal tubercles absent. Mandible bidentate. Maxillary palpus five-segmented. Labial palpus four-segmented. Galea short. Glossa short. Occipital carina absent. Mesosoma: Notauli entirely evenly crenulate. Scutellar sulcus ~ 0.30 × longer than width (0.22:0.74), with six carinae; lateral margins forming cup-like pit posteriorly. Postscutellar depression entirely rugulose. Pronotum mostly rugulose. Mesopleuron dorsally and ventrally with punctures, posterior margin strongly crenulate; precoxal sulcus crenulate nearly reaching posterior margin; epicnemial carina absent; episternal scrobe present. Metapleuron anteriorly

smooth and posteriorly rugulose. Propodeum strongly rugulose, ~ 0.40 × longer than its median width (0.57:1.42); propodeal areola nearly oval, ~ 1.31 × longer than its maximum width (0.42:0.32); transverse carina absent. Legs: Basal spur on fore tibia ~ 0.58 × longer than length of basitarsus (0.29:0.50). Basal spur on mid tibia ~ 0.64 × longer than length of basitarsus (0.39:0.61). Hind tibia without apical cup-like projection; basal spur on hind tibia ~ 0.61 × longer than length of basitarsus (0.55:0.90); claws pectinate. Wings: Fore wing ~ 6.06 mm; second submarginal cell trapezoid, ~ 3.06 × longer than height (1.10:0.36); 1r absent; 3r absent; 3RSb evenly curved; pterostigma about ~ 3.34 × longer than wide medially (1.17:0.35). Hind wing ~ 4.88 mm; 2r-m absent; 2–1A present reaching basal half. Metasoma: T1 ~ 1.13 × longer than its posterior width (0.79:0.70), antero-laterally crenulate and postero-laterally slightly rugulose. T2 ~ 0.27 × longer than its posterior width (0.37:1.36), ~ 0.55 × longer than T3 (0.37:0.67). Hypopygium without median longitudinal fold. Protruded ovipositor sheath ~ 0.46 × longer than length of hind basitarsus (0.41:0.90), apically setaceous.

Color: Body mostly black. Wings entirely infuscate. Pterostigma entirely dark brown. Antenna dark brown. Inner and outer orbits orange. Mandible medially reddish brown. First laterotergite brown.

Male: Unknown.

Etymology. Named in honor of Mr. Edward P. Van Duzee, a former curator of CAS and fellow of Entomological Society of America (ESA), the person who collected the specimen.

Biology. Unknown.

Distribution. *Retusigaster vanduzeei* sp. nov. is known from Nixon, Washoe County, Nevada, USA.

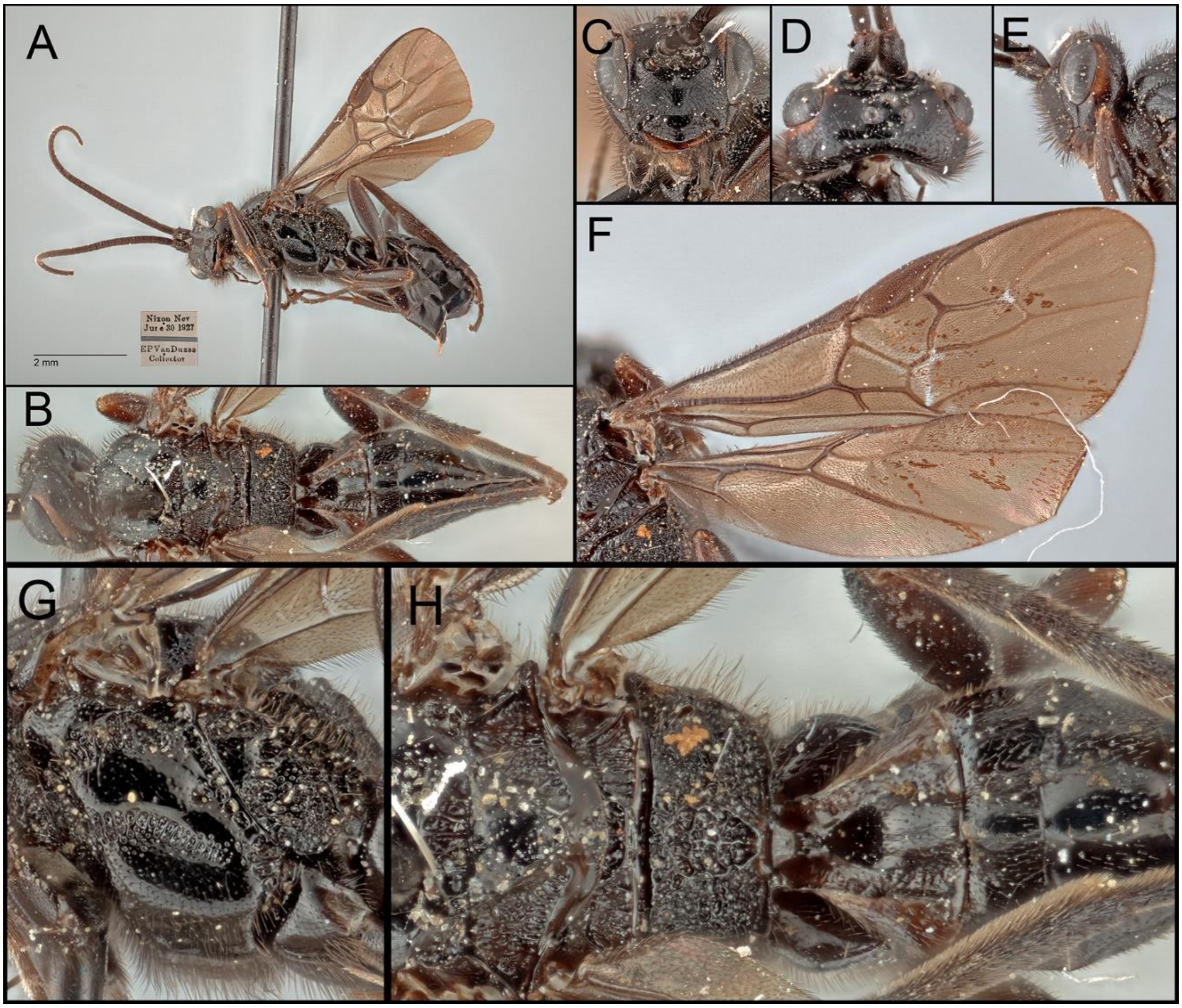

Figure 34. *Retusigaster vanduzeei* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) dorsal head; E) lateral head; F) wings; G) mesopleuron and metapleuron; H) scutellum to T3.

Discussion. With the three new species from the New World, eleven species of *Retusigaster* are currently recorded. The generic placement of the only recorded Old World species, *R. eremita*, is still suspect as Mercado and Wharton (2003) did. No specimens of *R. eremita* were examined in this research, but species descriptions by Telenga (1955) and Tobias (1995) were reviewed to evaluate the generic placement of the species. Telenga (1955) stated that simple claws and much thickened apical hind tibial tips were present in the specimens of *R. eremita*. If the members of *R. eremita* have the two characters as described by Telenga, the

specimens he examined might be instead a species of *Pseudcardiochilus* Hedwig, 1957. Tobias (1995) stated that specimens of *R. eremita* possess simple claws, but the apices of their hind tibia are not as projected as those of *Pseudcardiochilus acutus* (Tobias and Alexeev, 1977). If the members of *R. eremita* possess less projected hind tibial apieces as described by Tobias (1995), the examined specimens were likely to be *R. eremita*. However, still the generic placement of the species is unsure due to simple claws, which are not present in the other ten members of *Restusigaster.* Also, the same species recorded from Turkey by Erdoğan (2015) is probably a new species of *Retusigaster* because of the extremely different body coloration from *R. eremita* if the generic placement of the species is correct. Future work will involve examination of *R. eremita* from the Palearctic region to confirm generic placement of the species. *Restusigaster eremita* is tentatively remaining in the current genus following Tobias (1995) and Dangerfield et al. (1999).

As mentioned in the introduction of the subchapter, the two species-groups, *R. arugosus* and *R. rubidus*, were separated based on the degree of thickening of the apex of the hind tibia and propodeal spiracle shape and location (Mercado and Wharton 2003). In specimens examined in this project, the propodeal and tibial characters were compared. However, the propodeal characters were slightly different but not clearly distinct as shown in figure 35. Also, there was not a distinct difference in the hind tibial character. Because of this, the three new species described in this project are not placed in *R. arugosus* nor in *R. rubidus*. When molecular data of the members are available, it will be possible to see the relationships between the species groups.

As many adult braconids, including some cardiochilines feed on nectar of flowering plants (Jervis et al. 1993; Tooker and Hanks 2000), *R. argosus* may feed on *Gossypium* sp. and

R. purshi may feed on nectar of *P. Mexicana* in their adult stage. Additional studies are needed to confirm actual food sources of two species of *Retusigaster*.

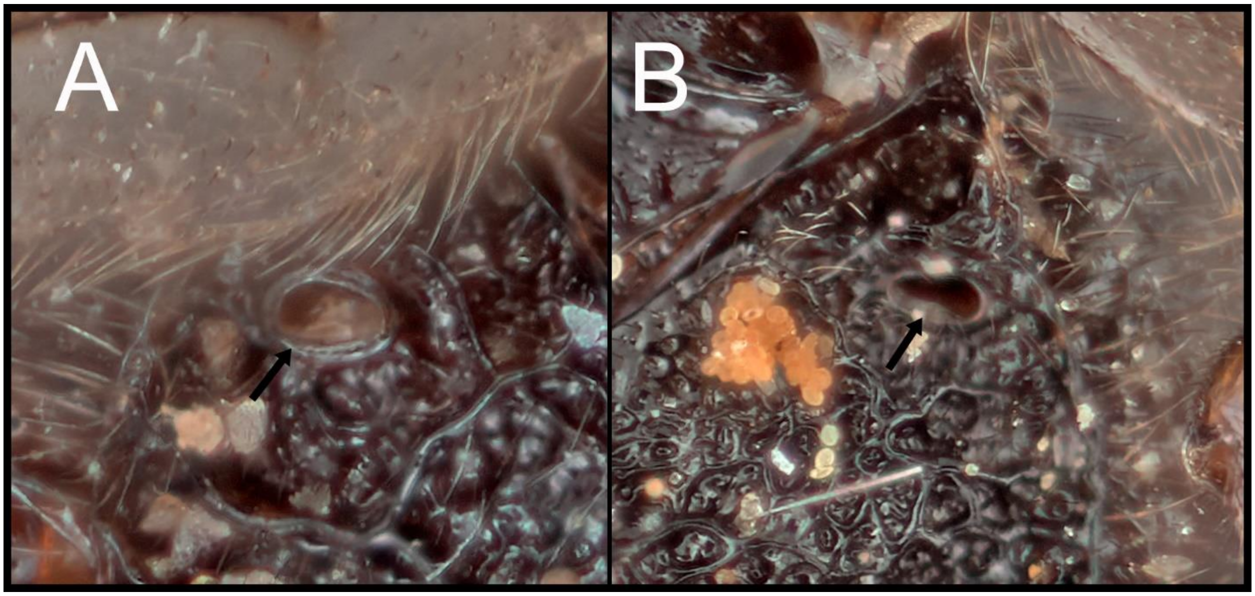

Figure 35. Propodeal spiracles of *Retusigaster*. A) Propodeal spiracle of *R. arugosus*; B) slightly more elongated propodeal spiracle of *R. vanduzeei* sp. nov.

4.3. A Potential Biological Control Agent of *Diaphania hyalinata* (Linnaeus, 1767), *Schoenlandella montserratensis* Kang, sp. nov. (Hymenoptera: Braconidae: Cardiochilinae)

Introduction. *Schoenlandella* Cameron, 1905 is the second largest genus of the subfamily Cardiochilinae with 54 recorded species (Yu et al. 2016). The members of the genus are abundant in the Old World (Dangerfield et al. 1999; Mercado and Wharton 2003; Yu et al. 2016), and only three species, *S. diaphaniae* (Marsh, 1986), *S. gloriosa* Mercado, 2003, and *S. longimala* (Mao, 1945), were recorded from the New World after Mercado and Wharton (2003) transferred the other three species into *Cardiochiles* Nees, 1819. All the known members are solitary endoparasitoids of larval lepidopteran insects, and the well-known lepidopteran host insect pests are *Crocidolomia pavonana* (Fabricius, 1794) (Crambidae), *Diaphania hyalinata* (Linnaeus, 1767) (Crambidae), *Helicoverpa armigera* (Hübner, 1808) (Noctuidae), (Huddleston and Walker 1988, Yu et al. 2016). From the braconid specimens collected in Montserrat, one of the Caribbean islands, the members of a new species of *Schoenlandella* that possess the five typical diagnostic characters designated by Dangerfield et al. (1999), conspicuously setose eyes; long and deeply bilobed glossa; elongate blade-like galea; presence of spectral 3r of fore wing; evenly sclerotized hypopygium (if a median longitudinal fold is present, the surface is not membranous), were discovered. In this project, the new species is described, and its potential host insect is reported. In addition, an identification key to species of the New World *Schoenlandella* was constructed and is provided.

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters 2.1., 2.2., 2.3., and 2.4. Specimens contained in this subchapter were borrowed from Fera Sciences Ltd., HNHM, INHS, MICR, and TAMU.

Taxonomy. Taxonomic information of *Schoenlandella* with an identification key to species of *Schoenlandella* in the Neotropical region, and descriptions of new species are included in the following:

Schoenlandella Cameron, 1905

Schoenlandella Cameron, 1905 (Cameron 1905a). Type Species: *Schoenlandella nigromaculata* Cameron, 1905 (Cameron 1905a) by subsequent designation by Viereck, 1914 (synonymized with *Cardiochiles* Nees, 1819 by Szépligeti, 1911). Removed from synonymy by Whitfield and Dangerfield, 1997.

Ernestiella Cameron, 1905 (Cameron 1905b) synonymized with *Schoenlandella* Viereck, 1914. Type species: *Ernestiella nigromaculata* Cameron 1905 (Cameron 1905b).

Diagnosis (based on Dangerfield et al. (1999) with additions and modifications). Diagnostic characters of *Schoenlandella* were described in Dangerfield et al. (1999), based mostly on Old World species. The following are diagnostic features based on both Old World and New World members. *Schoenlandella* can be distinguished from other cardiochiline genera by the following characters, Head: possessing 32–44-segmented antenna; densely setose eye (Figs. 38C, 39C, 41C); two clypeal tubercles with sharp or smooth apical margin (Figs. 38C, 39C, 41C); short to elongate malar space (Figs. 38C, 39C, 41C); bidentate mandible; six-segmented maxillary palpus; four-segmented labial palpus; absence of occipital carina; elongate galea, at least as long as malar space in lateral view (Note: narrower than galeae of members of *Cardiochiles* Nees, 1819) (Figs. 38C, 39C, 41C); glossa elongate and deeply bilobed if entirely spread (Figure 41A). Mesosoma: notaulus finely crenulate; scutellar sulcus crenulate; posterior scutellum without cup-like pit; pronotum mostly smooth; mesopleuron mostly smooth; epicnemial carina absent; metapleuron rugulose; mesosternal sulcus crenulate; propodeum

rugulose; propodeum with completely developed areola. Wings: stigma of fore wing moderate to broad; (RS+M)a of fore wing present; 1r of fore wing absent; presence of spectral 3r of fore wing mostly reaching at basal fifth to half (Figure 41F) (Note: if absent, examine characters of mouthparts and hypopygium.); 3RSb vein of fore wing angled (Figure 41F); 1a of fore wing absent (Note: if present, the vein is nebulous); 2−1A of hind wing absent. Legs: tarsal claw pectinate with sharp or obtuse apical tooth; hind basitarsus cylindrical (Figs. 38E, 39B) or slightly expanded (Figure 41A) (Note: not nearly as expanded as in *Hartemita* Cameron, 1910); Metasoma: lateral suture of T1 absent posteriorly; T2 and T3 entirely smooth; hypopygium apically acute in lateral view (Figure 38D); hypopygium uniformly sclerotized and with well-defined median longitudinal fold absent (Figure 38D) (Note: if present, the fold is entirely sclerotized or only slightly desclerotized (Figs. 39D, 41D)); ovipositor slightly downcurved (Figs. 39A, 39D); ovipositor sheath < ~ 0.6 × length of hind tibia.

Key to species of the genus *Schoenlandella* of the Neotropical region

1.A. Body mostly melanic .... *S. longimala* (Mao, 1945)

Note: Based on images of the holotype on the NMNH website (https://collections.nmnh.si.edu/search/ento/, accessed July 2022)

B. Body mostly orange or yellow pale 2

2 (1). A. Malar space < ~ 0.33 × longer than eye height in anterior view, AA. fore wing entirely infuscate..*S. montserratensis* Kang sp. nov.

B. Malar space about ~ 0.50 × longer than eye height in anterior view, BB. fore wing apically infuscate 3

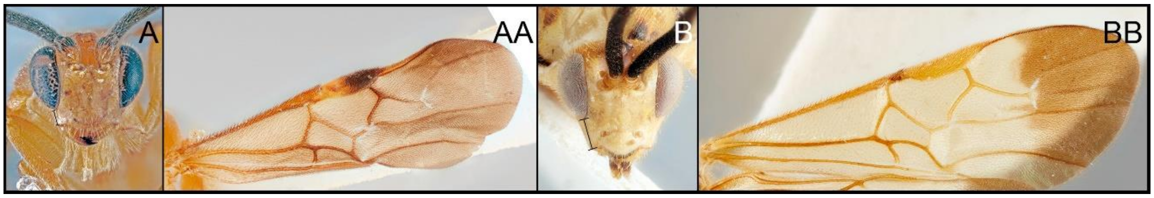

Figure 36. Key image of couplet 2 of the key to species of the genus *Schoenlandella* of the Neotropical region.

3 (2). A. Fore wing basally hyaline, and stigma entirely melanic, AA. apex of clypeal tubercle sharply angled...*S. diaphaniae* (Marsh, 1986)

B. Fore wing basally pale yellow, and stigma entirely pale, BB. apex of clypeal tubercle relatively smooth..*S. gloriosa* Mercado, 2003

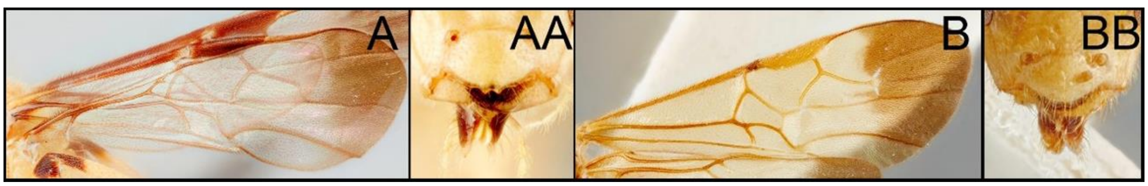

Figure 37. Key image of couplet 3 to species of the genus *Schoenlandella* of the Neotropical region.

Schoenlandella diaphaniae (Marsh, 1986)

(See Figure 38)

Cardiochiles diaphaniae Marsh, 1986 (Marsh 1986)

Schoenlandella diaphaniae (Marsh, 1986) (Dangerfield et al. 1999)

Material examined. Non-type specimen Trinidad and Tobago • ♀; female, Curepe, Trinidad and Tobago; 21.VII.1978. Malaise Trap. Deposited in INHS.

Diagnosis. Members of *S. diaphaniae* are distinguished from members of *S. gloriosa* by having shorter lower face and malar space (Figure 38C); basally hyaline fore wing (Figure 38A); stigma entirely melanic (Figure 38A).

Description. Marsh (1986) described color of the species and some morphological characters in his species description. Here, the species is re-described based on a specimen

collected in Trinidad and Tobago. Body length 4.5–5.8 mm (Marsh 1986). Antenna length: ~ 4.2 mm. Fore wing length: ~ 5.5 mm. Head: Antenna 34-segmented. Eye length ~ 0.45 × longer than its height (0.40:0.89). Dorsal width of lower face as long as its height (0.81:0.81); Malar space ~ 0.40 × longer than height of eye in anterior view (0.32:0.80), ~ 2.13 × longer than basal width of mandible (0.32:0.15) (Figure 38C). Clypeus ~ 1.53 × longer than its width (0.49:0.32); clypeal tubercles with sharp margins (Figure 38C). Galea as long as malar length in lateral view (0.32:0.32), with curved apical margin (Figure 38A). Mesosoma: Scutellar sulcus with five to six crenulae. Postscutellar depression present. Propodeum rugulose; median areola of propodeum diamond-shaped, median length as long as its width; propodeum with median transverse carina reaching lateral margin. Pronotum mostly smooth with incomplete posteroventral carina reaching posterior margin. Mesopleuron mostly smooth and polished; precoxal sulcus medially present with five crenulae. Metapleuron rugulose. Mesosternal sulcus crenulate. Legs: Basal spur on mid tibia ~ 0.83 × mid-basitarsus (0.49:0.59). Hind femur medially ~ 0.33 × broader than its length (0.45:1.37). Basal spur on hind tibia ~ 0.66 × longer than hind basitarsus (0.60:0.90). Hind basitarsus cylindrical. Hind tarsal claw pectinate with five teeth; apical tooth basally rounded and apically angled; basal four teeth sharp. Wings: Fore wing second submarginal cell with maximum width ~ 2.87× longer than its maximum length (0.89:0.31); 3r absent; 3RSb broken basally and angled at basal sixth; stigma about ~ 3.44 × longer than width medially (0.93:0.27). Hind wing 2−1A present in basal third (Figure 38A). Metasoma: Medial length of T1 ~ 2.59 × longer than medial length of T2 (0.75:0.29). Medial length of T2 ~ 0.22 × longer than its apical width (0.29:1.29). T3 about ~ 1.66 × longer than T2 medially (0.48:0.29). Hypopygium entirely sclerotized, with shallow area medially (Figure 38D). Ovipositor moderately downcurved. Ovipositor sheath elongate and moderately downcurved, ~ 0.57 × longer than hind tibia

(1.01:1.76), slightly widened apically, anterior 2/5 depilous and posterior 3/5 pilose apically with long setae.

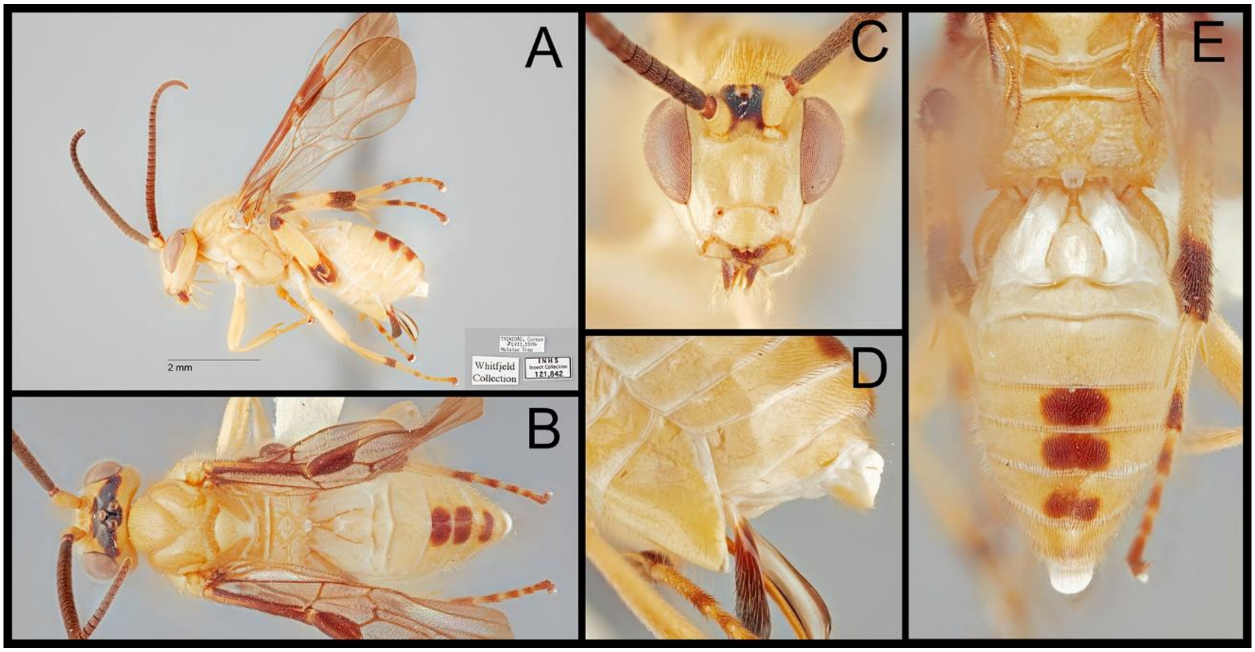

Figure 38. *Schoenlandella diaphaniae*, non-type. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) lateral hypopygium; E) dorsal propodeum and mesonotum.

Color. Body mostly bright yellow; the following areas melanic: flagellomeres, pedicel mostly, outer scape; ocellary field and frons dorsally, labrum, apical mandible, galea mostly, mid tibia apically, hind coxa apically, hind trochanter and trochantellus, hind femur basally and apically, hind tibia apically, hind tarsomeres apically, entire ovipositor sheath. T4–T6 medially (Figure 38E). Wings basally hyaline and apically infuscate, C+SC+R vein in fore wing mostly melanic, stigma mostly melanic.

Male. See Marsh (1986).

Hosts. *Diaphania nitidalis* (Stall) and *D. hyalinata* (L.) (Marsh 1986).

Distribution. Colombia, Venezuela, and Trinidad and Tobago.

Schoenlandella gloriosa **Mercado, 2003**

(See Figure 39)

Material examined. Paratypes Mexico • ♀; female, 3 mi E Papantla, Veracruz, Mexico; VI,7,1965; Burke, Meyer, Schaffner • ♀; female, 2 mi SE Tecpan de Galeana, Guerrero, Mexico; VII,14,1966; P.M and P.K Wagner • 2♂; males, Hotel Covandonga, 12 km S Valles, Ruta 85, San Luis Potosi, Mexico; 27–29,VI,1981; C. Porter, L. Stange. Deposited in TAMU. Non-type material Costa Rica • ♀; female, 10 km NW Cañas, Mojica, Guanacaste, Costa Rica; 26.ix.–10.x.2011; P. Hanson. Deposited in MICR. Honduras • ♀; female, Tela, Lancetilla, Atlántida, Honduras; 30.IV.1995; 15° 43´ N, 87°27´ W; R. Cave. ♀; same as previous except for the collecting date, 15.V.1995. ♂; same as previous except the collecting date, male, 31.VIII.1995. Deposited in HNHM.

Diagnosis. Members of the *S. gloriosa* are nearly identical to *S. diaphaniae*. The following combination of characters differentiate *S. gloriosa* from *S. diaphaniae*: face concave; malar space relatively elongate (~ 0.50 × longer than height of eye in anterior view) (Figure 39C); two clypeal tubercles with smooth margins (Figure 39C); fore wing basally yellow and apically infuscate; stigma entirely pale; fore wing with junction of angled Rs not swollen (Figure 39F).

Description. Modified from Mercado and Wharton (2003), including additional characters. Body 5.5–8.0 mm. Head: Antenna 32–34-segmented. Eye width ~ 0.41 × longer than height (0.35:0.85). Dorsal width of lower face ~ 1.05 × longer than height of lower face (0.79:0.75). Clypeus 1.20–1.53 × longer than its width, two clypeal tubercles with smooth margin (Figure 39C). Malar space 0.47–0.50 × longer than height of eye in anterior view (0.35:0.75–0.40:0.80), 2.75–3.42 × longer than basal width of mandible (0.33:0.12–0.41:0.12). Galea 1.30–1.40 × longer than malar length as viewed laterally (0.43:0.33–0.56:0.40) (Figure 39A). Mesosoma: Scutellar sulcus with five to seven crenulae. Propodeum with median

transverse carina reaching lateral margin. Pronotum weakly carinate medially. Mesopleuron mostly smooth; precoxal sulcus smooth, not reaching posterior margin. Legs: Basal spur on mid tibia 0.83–0.90 × mid-basitarsus length. Hind femur medially 0.31–0.32 × broader than long (0.52:1.64–0.48:1.55). Wings: Fore wing: maximum width of second submarginal cell ~ 2.26× longer than maximum length (1.13:0.50); 3r absent; 3RSb vein angled at basal fourth (Figure 39F). Hind wing: 2-1A present as basal stump (Figure 39F). Metasoma: Medial length of T1 2.00–2.47 × longer than medial length of T2 (0.78:0.39–0.75:0.30). Medial length of T2 0.21–0.26 × longer than its apical width (0.30:1.40–0.39:1.49). T3 about 1.46–1.60 × longer than T2 medially (0.57:0.39–0.48:0.30). Hypopygium evenly sclerotized, median longitudinal fold absent (Note: A weakly depressed medial longitudinal area is present in females collected in Honduras, but never membranous and folded like Chinese fan) (Figure 39D). Ovipositor moderately downcurved. Protruded ovipositor sheath moderately downcurved, 0.45–0.50 × longer than hind tibia, broadened apically, anteriorly depilous and moderately pilose apically with long setae.

Color. See Mercado and Wharton (2003). Melanic areas of the Costa Rican specimen (female) and Mexican specimens are slightly darker than specimens collected in Honduras.

Male. See Mercado and Wharton (2003).

Host. Unknown.

Distribution. Costa Rica, Honduras, and Mexico.

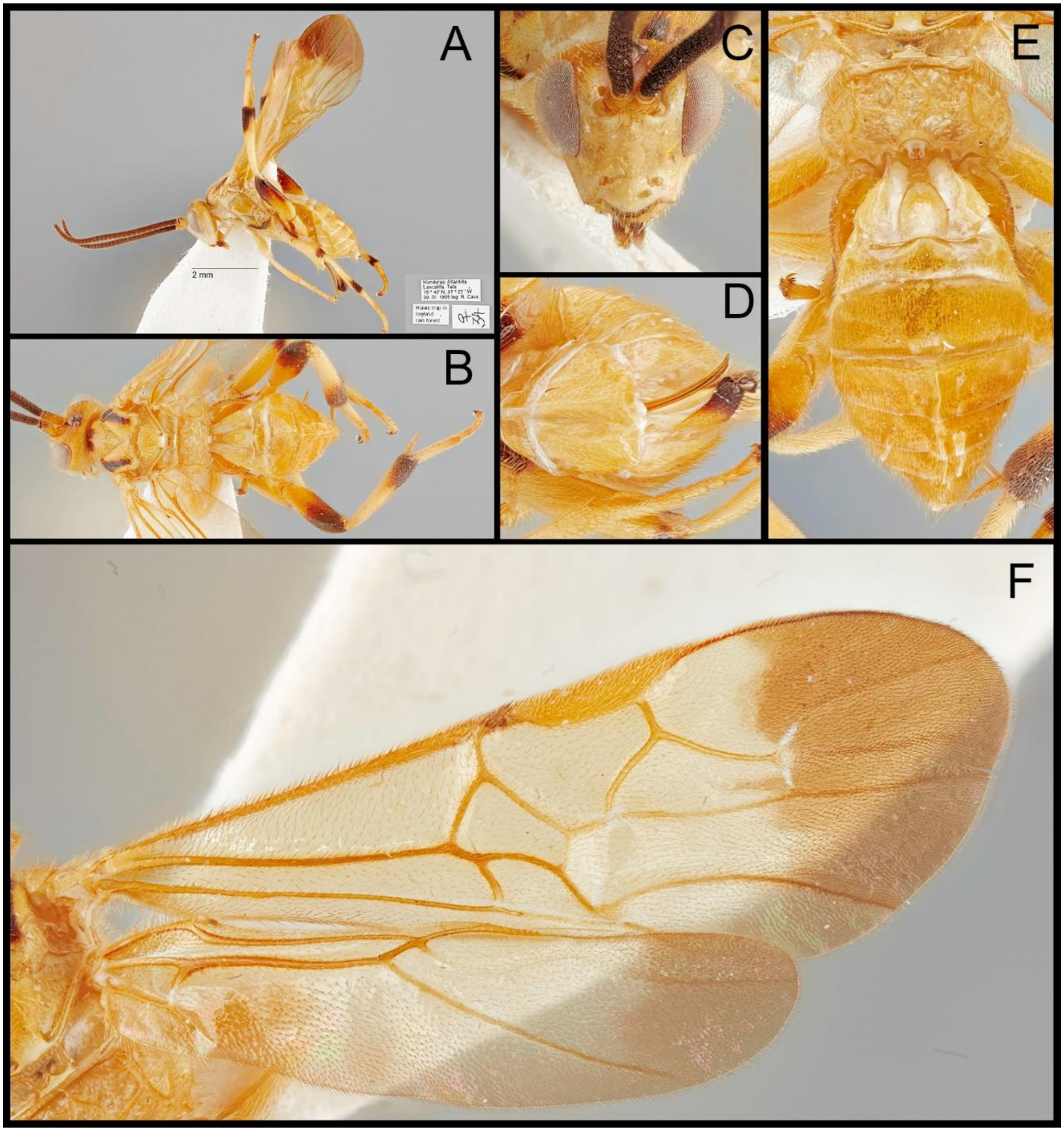

Figure 39. *Schoenlandella gloriosa*, non-type. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) ventral metasoma; E. dorsal propodeum and mesonotum; F) wings.

Schoenlandella longimala **(Mao, 1945)**

Cardiochiles longimala Mao, 1945 (Mao 1945)

Schoenlandella longimala (Mao, 1945) (Dangerfield et al. 1999)

Type material. Holotype Mexico • ♂, Guadalajara, Mexico; 2.viii.1914; Deposited in NMNH.

Diagnosis (based on images of the holotype on the NMNH website). Body mostly black except for legs. Malar space shorter than basal width of mandible. Mouthparts moderately elongated. Scutellar sulcus with six crenulae. Lateral side of scutellum mostly rugulose. Pronotum medially rugose. Propodeal areola anteriorly angled. Fore wing entirely infuscate; stigma entirely melanic; 3r vein absent; 1a present as a nebulous vein.

Description. See Mao (1945).

Host. Unknown.

Distribution. Mexico.

Schoenlandella montserratensis **Kang sp. nov.**

(See Figure 41)

Material examined. Holotype MONTSERRAT • ♀; female, MONTSERRAT; 16°45´34.19´´N, 62°13´1.58´´W; woodlands, private farm. Single adult on *Momordica charantia* L. (bitter melon), hand caught in plastic pot. leg. Elvis Gerald (Ref. CM-Mt-2019-41). Paratype same data as for holotype.

Diagnosis. *Schoenlandella montserratensis* sp. nov. is distinguished from other New World *Schoenlandella* species by having shorter malar space (Figure 41C); longer mouthparts (Figure 41C); stigma basally pale and apically melanic (Figure 41F); 3r vein of fore wing present at basal half (Figure 41F).

Description. Body 4.21–4.40 mm. Fore wing length: ~ 4.45 mm (holotype). Antenna length: ~ 3.25 mm (paratype). Head: Antenna 34-segmented (paratype). Eye length ~ 0.52 × longer than its height (0.31:0.60). Malar space slightly shorter than basal width of mandible.

Clypeus ~ 2.08 × longer than its width (0.50:0.23); two clypeal tubercles with smooth margins. Galea ~ 2.12 × longer than malar space in lateral view (0.36:0.17), apically narrowed. Mesosoma: Scutellar sulcus with five crenulae. Propodeal median transverse carina reaching lateral margin. Pronotum medially crenulate, ventrally costate. Mesopleuron mostly smooth; precoxal sulcus strongly crenulate with about ten crenulae, not reaching posterior margin. Legs: Basal spur on mid tibia ~ 0.88 × mid-basitarsus (0.30:0.34). Basal spur on hind tibia ~ 0.68 × longer than hind basitarsus (0.36:0.53). Hind basitarsus laterally broaden. Tarsal claw pectinate with five teeth; apical tooth obtuse, other remaining teeth sharp. Wings: Fore wing second submarginal cell width ~ 2.79 × longer than height (0.78:0.28); 3r apparently present at basal half and slightly curved; 3RSb angled at basal two-fifths; stigma about ~ 3.36 × longer than wide medially (0.74:0.22); 1a absent (Figure 41F). Hind wing 2−1A absent (Figure 41F). Metasoma: Medial length of T1 ~ 2.68 × longer than medial length of T2 (0.59:0.22). Medial length of T2 ~ 0.20 × longer than its apical width (0.22:1.10). T3 entirely smooth, ~ 1.27× longer than T2 medially (0.28:0.22). Hypopygium surface entirely sclerotized with a distinct median longitudinal fold (Figure 41D). Ovipositor slightly downcurved; protruded ovipositor sheath ~ 0.40 × longer than hind tarsus, broadened apically.

Color. Body mostly pale orange; the following areas melanic: apical scape, pedicel, flagellomere, apical mandible, hind tarsus, external ovipositor sheath. Wings entirely lightly infuscate, stigma dark brown at apical half.

Male. Unknown.

Etymology. This species is named after the collecting site, “Montserrat”, a volcanic Caribbean Island.

Host. Unknown but see details in the following discussion section.

Distribution. *Schoenlandella montserratensis* sp. nov. is only known from Montserrat (Figure 40).

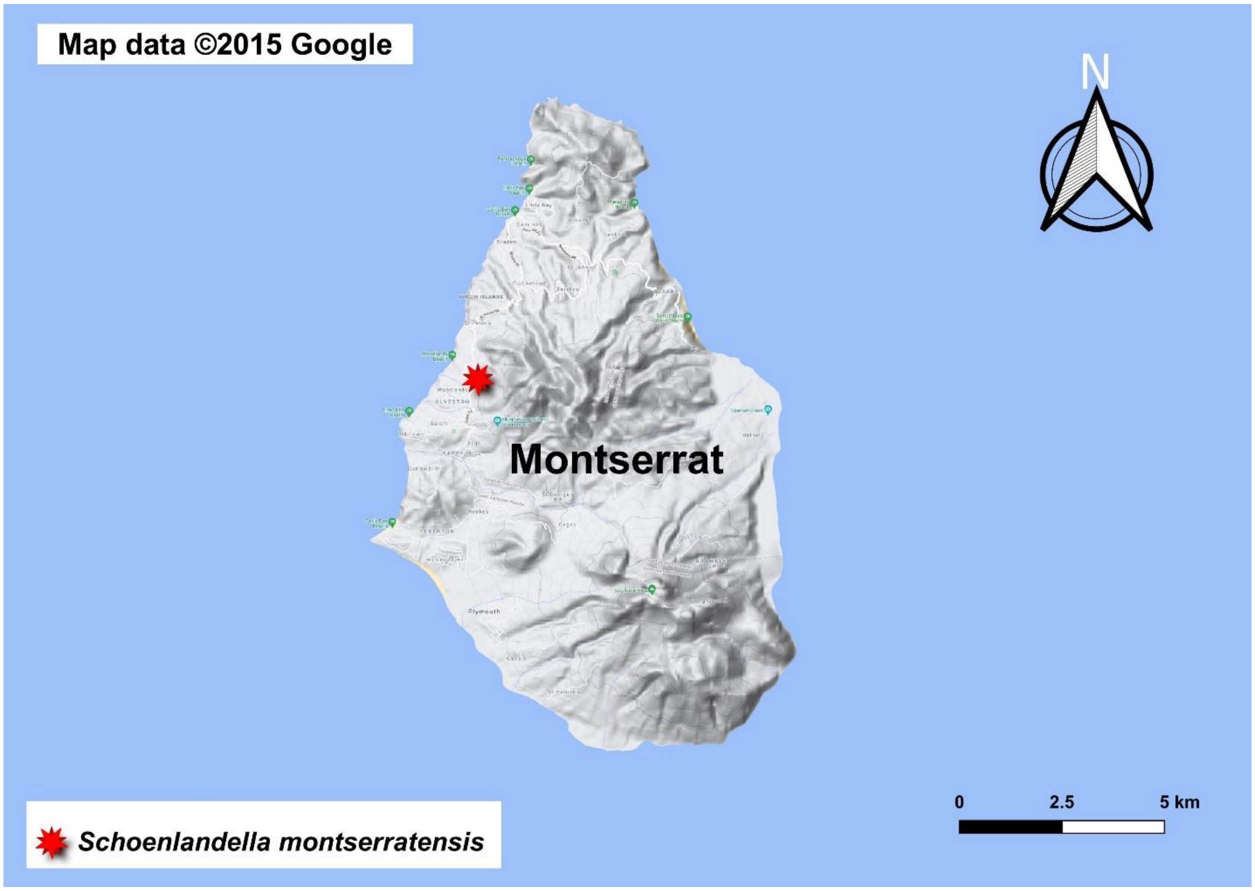

Figure 40. Distribution map of *S. montserratensis* sp. nov. in Montserrat.

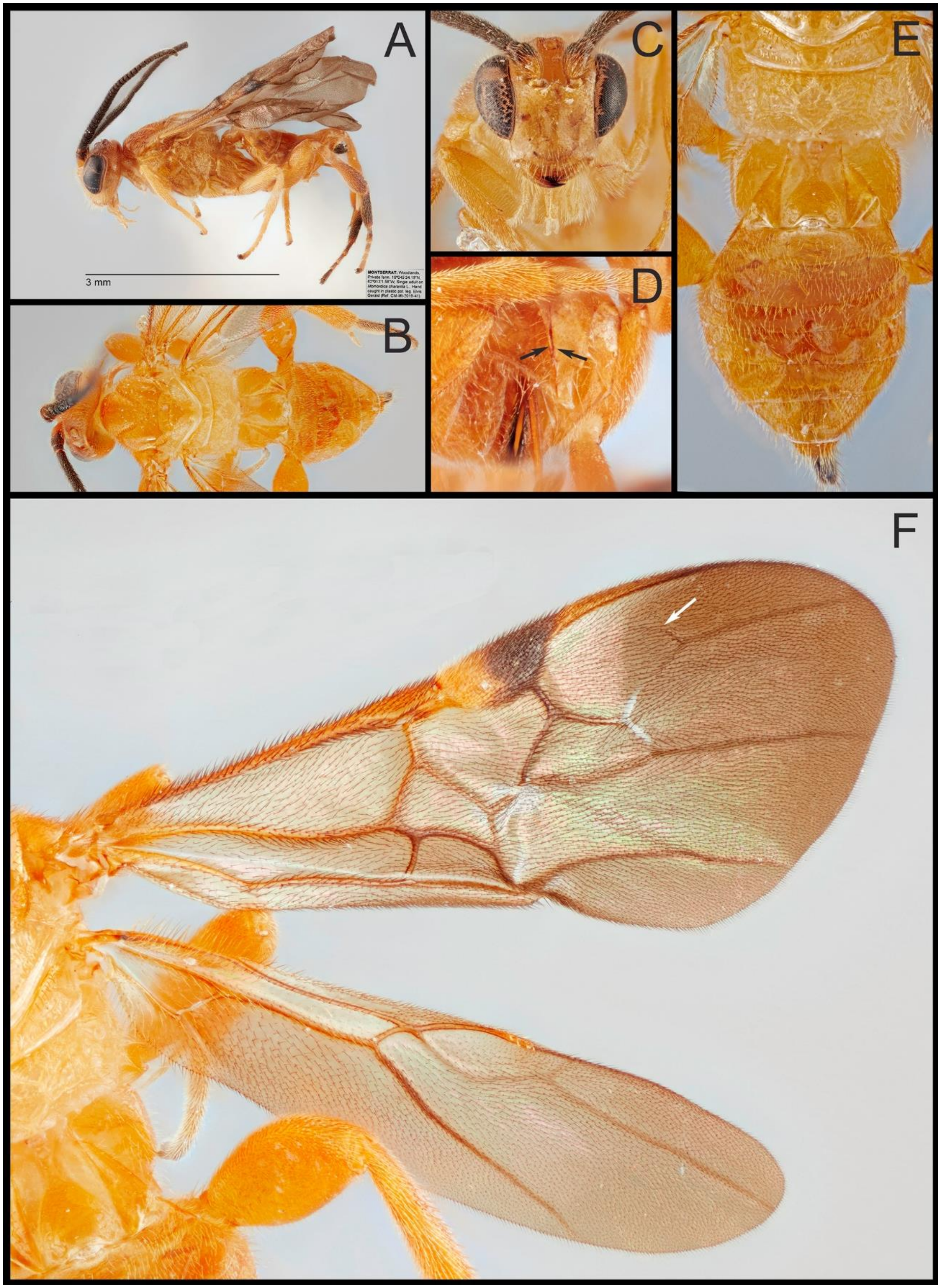

Figure 41. *Schoenlandella montserratensis* sp. nov. A) Lateral habitus B) dorsal habitus C) anterior head D) ventral metasoma; arrow: median fold on hypopygium; E) dorsal propodeum and mesonotum; F) wings; arrow: 3r vein on fore wing.

Discussion. As mentioned in the subchapter 3.2., the validity of the taxonomic status of *Schoenlandella* Cameron, 1905 has fluctuated several times. In the current work, *Schoenlandella* is treated as a valid genus. Regarding generic diagnostic characters of the genus in the New World, Mercado and Wharton (2003) indicated that the New World members do not possess some of five typical diagnostic characters mentioned in the introduction of this subchapter. I also confirmed that some of those five were absent in specimens of the New World members except *S. montserratensis* sp. nov. *S. montserratensis* sp. nov. is the first New World *Schoenlandella* species that have those five generic diagnostic characters.

Most cardiochiline members in the other genera of Cardiochilinae possess short mouthparts including the members of the most plesiotypic genera, *Wesmaelella* Spinola, 1851 and *Heteropteron* Brullé, 1846. Elongate mouthparts character is discovered in some members of *Asiacardiochiles* Telenga, 1955, *Neocardiochiles alexeyi* Kang, 2022, some of *Toxoneuron* Say, 1836, and many *Schoenlandella* species. Based on phylogeny by Dangerfield et al. (1999), the character independently evolved in three clades (*Heteropteron* clade (including *Neocardiochiles*); *Toxoneuron* clade; *Cardiochiles* clade (including *Asiacardiochiles* and *Schoenlandella*)). The elongate mouthpart length of the members of the two genera is likely to be related to feeding habits if they feed on nectar in the adult stage as *Agathis malvacearum* Latreille, 1805 (Hymenoptera: Braconidae: Agathidinae) and *Camptothlipsis* Enderlein, 1920 (Hymenoptera: Braconidae: Agathidinae) (Juhala 1967, Tucker et al. 2012). The other cardiochiline members with short mouthparts may not feed on nectar in the adult stage. If the members with short mouthparts are still nectar feeders, nectar of the host plants is likely to be present basally.

Female adults of *S*. *montserratensis* sp. nov. were collected in a bitter gourd field in Montserrat in 2019. Four potential lepidopteran host species were also confirmed in the same location in the same period: *Diaphania hyalinata* (L., 1767) (Melonworm moth; Crambidae); *Plutella xylostella* (L. 1758) (Diamondback moth; Plutellidae); *Calpodes ethlius* (Larger canna leafroller; Hesperiidae), and unidentified bagworm (Psychidae) (Dr. Chris Malumphy pers. comm.). Among these species, caterpillars of *D*. *hyalinata* were the most serious pests in the field. Because crambid and noctuid larvae are the most preferred host insects of *Schoenlandella* species (Huddlestone and Walker 1988; Yu et al. 2016), the melonworm moth caterpillar may be the most preferred host insect of *S*. *montserratensis* sp. nov. After the detailed biology and host range of *S*. *montserratensis* sp. nov. are confirmed in the further research, females of *S*. *montserratensis* sp. nov. can be developed as effective biological control agents for *D*. *hyalinata* if females of *S*. *montserratensis* sp. nov. lay an egg in *D*. *hyalinata*.

4.4. Resurrection of the Cardiochiline Genus, *Neocardiochiles* Szépligeti, 1908 (Hymenoptera: Braconidae: Cardiochilinae)

Introduction. Members of the cardiochiline genera, *Heteropteron* Brullé, 1846, *Neocardiochiles* Szépligeti, 1908 and *Wesmaelella* Spinola, 1853 are rarely-collected braconid wasps in the Neotropical region, which possess a relatively large body size (6.5–13mm). These three genera have been treated as the most plesiotypic members of the Cardiochilinae Ashmead, 1900 based on morphological characters (Dangerfield et al. 1999). *Heteropteron* was confirmed as an early-diverging genus based on molecular data (Murphy et al. 2008). Prior to the current publication, only seven species were recorded from the three genera, including two recently described species: *N*. *hasegawai* (Dabek & Whitfield, 2020), comb. nov. and *N*. *kidonoi* (Dabek & Whitfield, 2020), comb. nov. Detailed biological information for these two species was

collected by Drs. Daniel Janzen and Winnie Hallwachs and their team members at the Area de Conservación Guanacaste (ACG) (Dabek et al. 2020).

Despite the rarity of the specimens of the three genera in museum collections, their relationships have been frequently discussed and have fluctuated even in recent decades (Dabek et al. 2020). All three genera were considered valid by Whitfield and Dangerfield (1997), but Dangerfield et al. (1999) later subsumed *Neocardiochiles* and *Wesmaelella* into *Heteropteron*. Mercado and Wharton (2003) partly agreed with these synonymies, resurrecting *Wesmaelella* as a valid genus while retaining *Neocardiochiles* as a junior synonym of *Heteropteron* based on wing venation. Papp (2014) and Dabek et al. (2020) further validated separation of *Heteropteron* and *Wesmaelella*. Herein, *Neocardiochiles* is resurrected as a valid genus based on a morphological analysis of previously recorded and new species. In addition, both traditional and interactive identification keys to species of *Neocardiochiles* are given for identification, and molecular data for four species of *Neocardiochiles* are included.

Materials and Methods. Materials and methods follow same methods mentioned in the following subchapters 2.1., 2.2., 2.4., 2.5., 2.6., 2.7., and 2.8. Specimens contained is this subchapter were borrowed from HIC, HNHM, INHS, RBINS, TAMU and UWIM.

Taxonomy. Taxonomic information of *Neocardiochiles* with an identification key to species of *Neocardiochiles* in the Neotropical region, and descriptions of new species are included in the following:

***Neocardiochiles* Szépligeti, 1908**

Type Species: *Neocardiochiles fasciipennis* Szépligeti, 1908

Heteropteron Brullé, 1846, synonymized by Dangerfield, Austin, and Whitfield (1999) and confirmed by Mercado and Wharton (2003), Papp (2014), Dabek et al. (2020). Type species: *Heteropteron macula* Brullé, 1846, designated by Viereck (1914)

New combinations: *Heteropteron whitfieldi* Mercado, 2003 to *Neocardiochiles whitfieldi* (Mercado, 2003); *Heteropteron kidonoi* Dabek & Whitfield, 2020 to *Neocardiochiles kidonoi* (Dabek & Whitfield, 2020); *Heteropteron hasegawai* Dabek & Whitfield, 2020 to *Neocardiochiles hasegawai* (Dabek & Whitfield, 2020).

Diagnosis. *Neocardiochiles* is most similar to the genera *Heteropteron* and *Wesmaelella* and shares the following characters: eyes without setae; median areola on propodeum absent; notauli weekly impressed and posteriorly absent; scutellar sulcus without any crenula. However, members of *Neocardiochiles* differ from *Heteropteron* and *Wesmaelella* by possessing pectinate claws; propodeum with median longitudinal furrow (Figs. 58E, 59E, 60E, 62E, 63D, 64E), posterior submarginal carinae, and carinate lateral margin (Figs. 58E, 59E, 60E, 62E, 63D, 64E); hypopygium with median longitudinal fold (Figs. 59D, 60D, 62E, 64D).

Description. Body 6.5–11 mm. Head: Antenna 34–40-segmented. Face width 1.36–1.73 × longer than its height. Interantennal space with well-developed median carina. Width of anterior ocellus 0.96–1.15 × longer than POL. Eyes bulged and without interommatidial setae (Figs. 58D, 59C, 60C, 62C, 63C, 64C); median width of eye about 0.90–1.32 × longer than the median width of gena in lateral view. Gena extended ventroposteriorly into sharp prominence. Clypeus 1.64–2.61 × longer than its height; clypeal tubercles absent. Mandible bidentate. Maxillary palpus six-segmented. Labial palpus four-segmented. Galea short (except for *Neocardiochiles alexeyi* sp. nov.). Glossa short (except for *Neocardiochiles alexeyi* sp. nov.). Occipital carina absent. Mesosoma: Notauli weakly impressed and absent posteriorly (Figs. 58C,

59B, 60B, 62B, 63B, 64B). Scutellar sulcus weakly impressed except for *Neocardiochiles alexeyi* sp. nov., without crenula. Postscutellar depression absent. Pronotum entirely or mostly smooth with ventral longitudinal carina. Mesopleulon mostly smooth; posterior margin crenulate; precoxal sulcus absent (Figure 61B). Metapleuron mostly smooth. Propodeum 0.39–0.50 × longer than its median width; mostly smooth; with median furrow; curved submarginal longitudinal carina on propodeum present posteriorly; lateral margin of propodeum carinate (Figs. 58E, 59E, 60E, 62E, 63D, 64E). Legs: Basal spur on mid tibia 0.56–0.71 × longer than length of basitarsus. Hind tibia without apical cup-like projection; basal spur on hind tibia 0.48–0.62 × longer than length of basitarsus. Claws pectinate. Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid; 1r absent; 3r absent; 3RSb evenly curved. Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 1.06–2.22 × longer than its posterior width, anterior width 0.53–0.83 × longer than posterior width, entirely separated with laterotergite by suture; Y-shaped suture present. T2 nearly rectangle, 0.30–0.49 × longer than its posterior width. Hypopygium with median fold (Figs. 59D, 60D, 62E, 64D). Ovipositor sheath nearly straight to slightly downcurved, as long as hind tarsomeres 1–3 combined as long as mesosoma, evenly setose except for base.

Distribution. Neotropical region: Costa Rica, Ecuador, French Guiana, Mexico, and Suriname.

Biology**.** The two species for which hosts are known attack pyralid and depressariid caterpillars on *Roupala* (Proteaceae) (Dabek et al. 2020).

Diversity. Nine species (Szépligeti 1908; Mercado and Wharton (2003); Dabek et al. 2020; current work).

Key to species of *Neocardiochiles* in the New World

1. Hind femur entirely melanic 2

Hind femur bicolored.. 4

Hind femur entirely pale 6

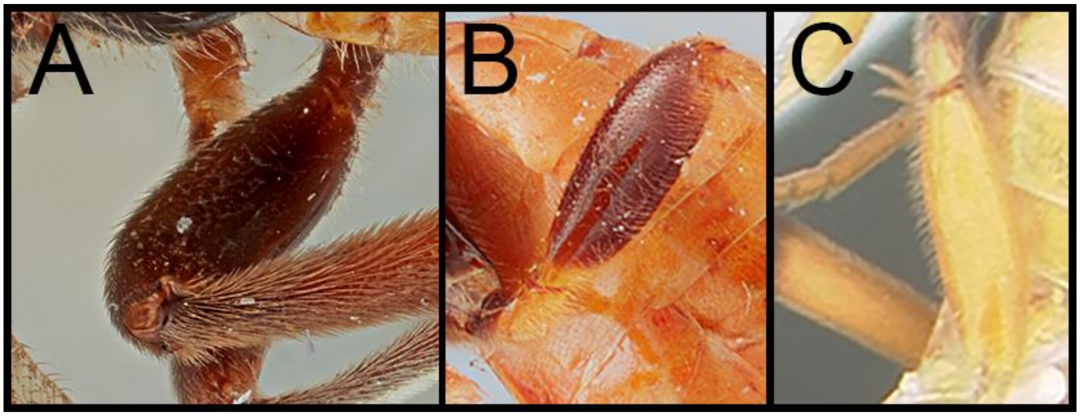

Figure 42. Key image of couplet 1 of the key to species of *Neocardiochiles* in the New World.

2(1). Fore wing entirely infuscate .... *N. whitfieldi*

Fore wing two-banded 3

Figure 43. Key image of couplet 2 of the key to species of *Neocardiochiles* in the New World.

3(2). T1 ~ 1.06 × longer than its posterior width .... *N. chriscarltoni* sp. nov.

T1 ~ 1.63 × longer than its posterior width .... *N. braeti* sp. nov.

Figure 44. Key image of couplet 3 of the key to species of *Neocardiochiles* in the New World.

4(1). Mesoscutum entirely dark .... *N. fasciipennis*

Mesoscutum entirely pale 5

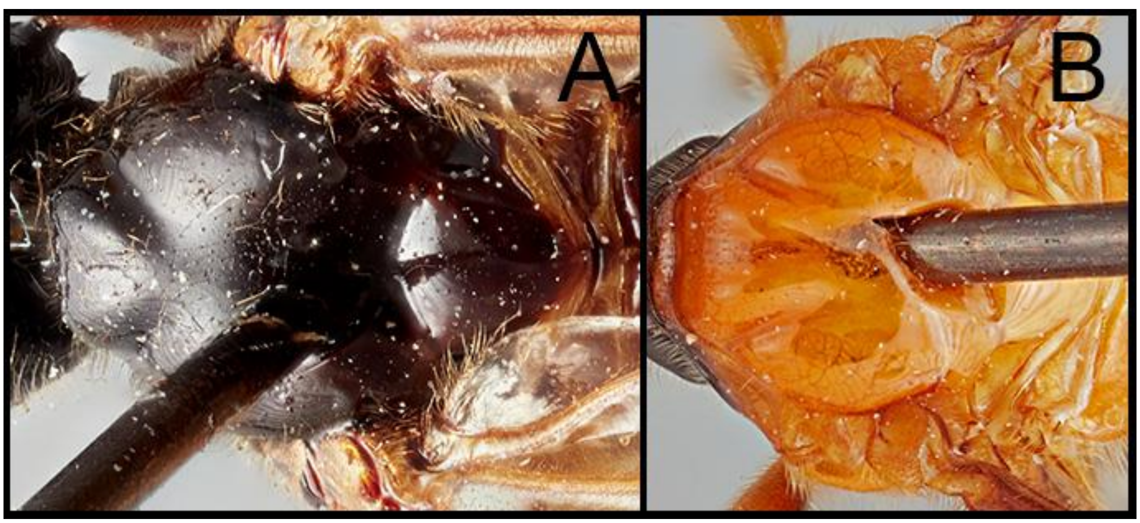

Figure 45. Key image of couplet 4 of the key to species of *Neocardiochiles* in the New World.

5(4). Hind tibia mostly pale.. *N. kidonoi*

Hind tibia mostly dark .... *N. victoriae* sp. nov.

Figure 46. Key image of couplet 5 of the key to species of *Neocardiochiles* in the New World.

6(1). Mesoscutum entirely pale .... *N. hasegawai*

Mesoscutum entirely dark 7

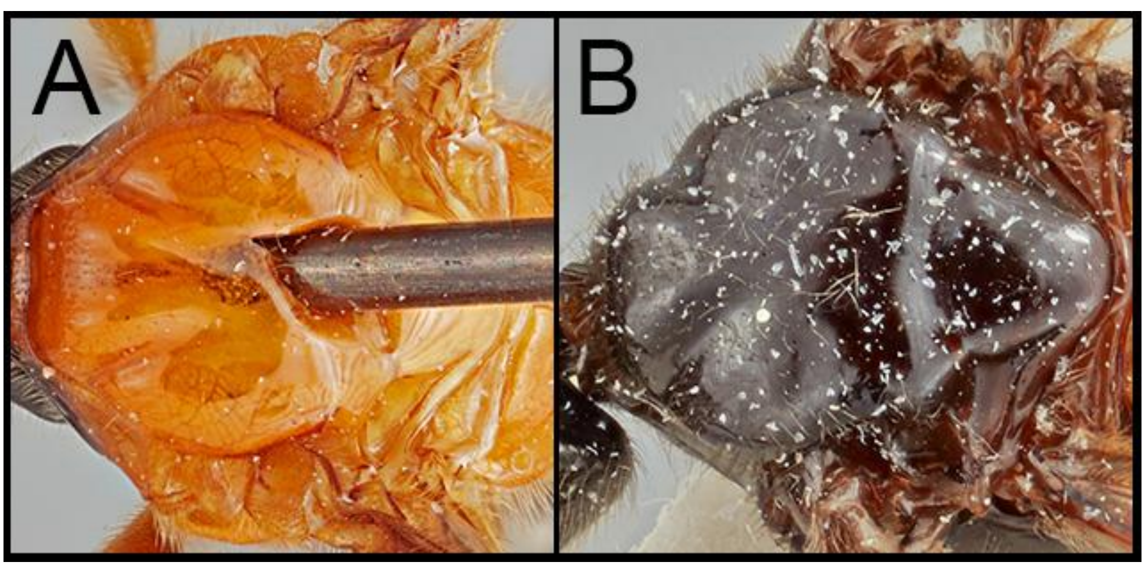

Figure 47. Key image of couplet 6 of the key to species of *Neocardiochiles* in the New World.

7(6). T1 ~ 2.22 × longer than its posterior width, nearly rectangle .... *N. alexeyi* sp. nov.

T1 ~ 1.09 × longer than its posterior width, trapezoid .... *N. franki* sp. nov.

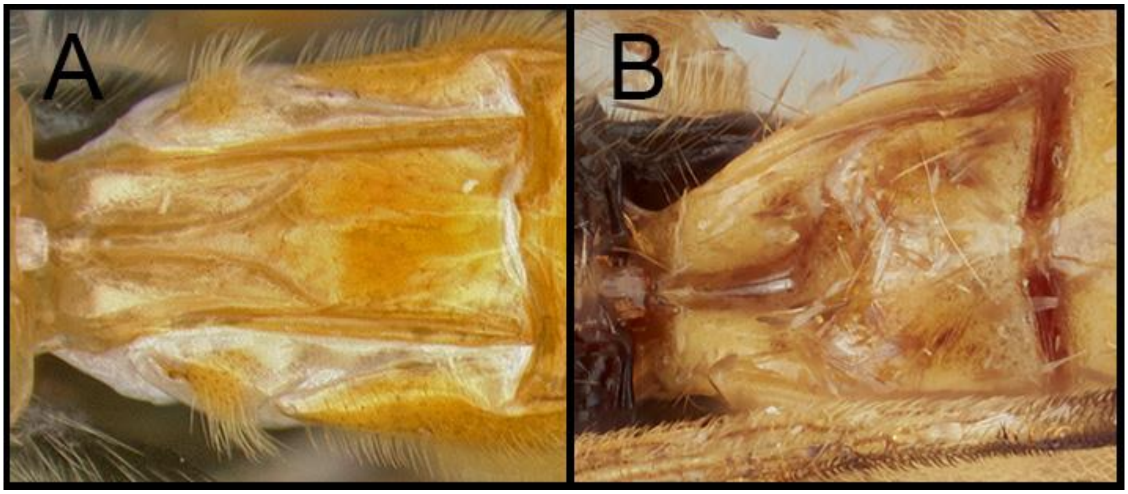

Figure 48. Key image of couplet 7 of the key to species of *Neocardiochiles* in the New World.

Interactive key. Unlike a traditional identification key, a user can begin with any character included in an interactive key. For the interactive key to species of *Neocardiochiles* in the New World, nine informative characters were included (Figs. 49−57).

To use the interactive key to species of *Neocardiochiles* in the New World:

1. Download the zipfile of the ALA version of DELTA Editor (Open DELTA 1.02 beta) (Dallwitz et al. 1999). Extract into the ‘C’ drive. The extracted folder name will be ‘open-delta-1.02-bin’. Java is required to operate DELTA Editor and Intkey.
2. Download the folder (‘Neocardiochiles_DELTA_Key’), which includes all source files and images of the interactive key, using the following link (https://drive.google.com/drive/folders/1aLS3vzdK52uMV0702IopDWgXaSllpJQm?usp=sharinghttps://drive.google.com/drive/folders/1lh_Tyb8mWY-oZFdwWkSI6U4GR5LjhfXn?usp=sharing).
3. Extract the zipfile of ‘Neocardiochiles_DELTA_Key’ into the ‘open-delta-1.02-bin’ folder.
4. In the folder ‘Neocardiochiles_DELTA_Key’, open the file ‘Neocardiochiles_Intkey’.

5. Users can then identify described species of *Neocardiochiles* using this interactive key.

Interactive characters (Figs. 49‒57)

1. Apex of antenna (Figure. 49): A. pale, B. darker, C. unknown.

Figure 49. Interactive key character 1.

2. Glossa (Figure. 50): A. ≤ ~ 1.6 × longer than height of clypeus, B. ≥ 2.0 × longer than height of clypeus.

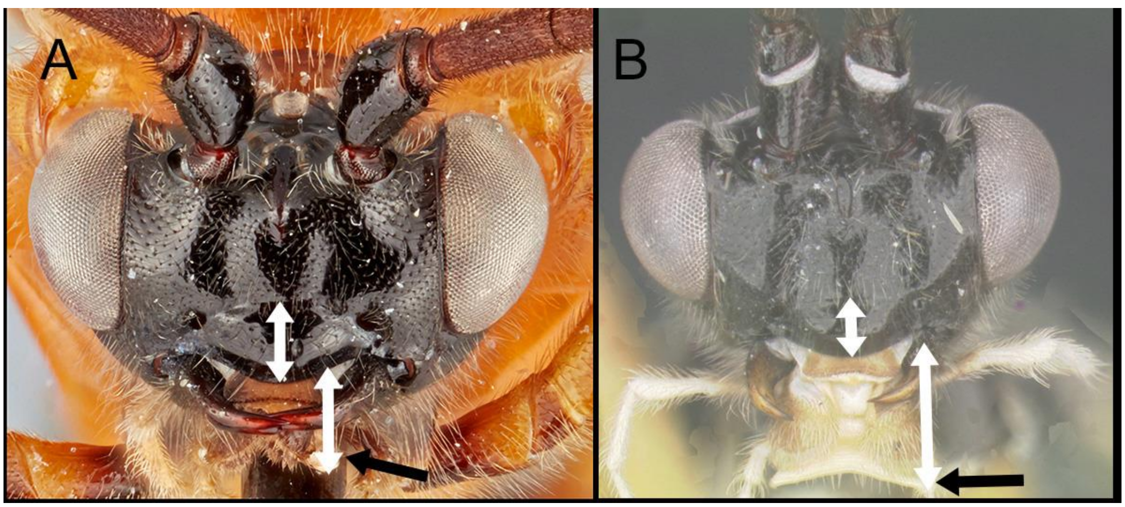

Figure 50. Interactive key character 2.

3. Hind femur (Figure. 51): A. entirely dark, B. bicolored, C. entirely pale.

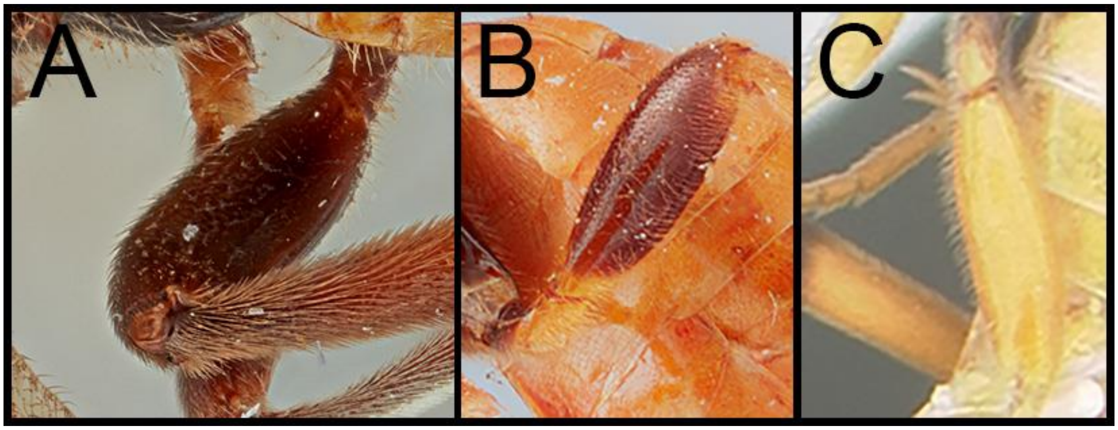

Figure 51. Interactive key character 3.

4. Hind tibia (Figure. 52): A. mostly pale, B. mostly darker.

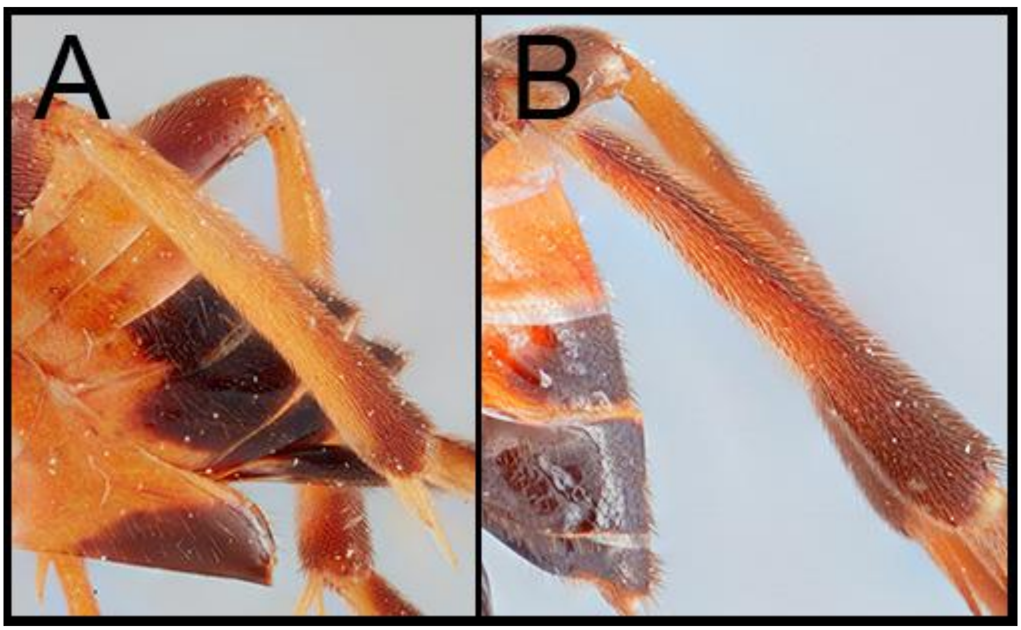

Figure 52. Interactive key character 4.

5. Median fold on hypopygium (Figure. 53): A. absent, B. present, C. unknown.

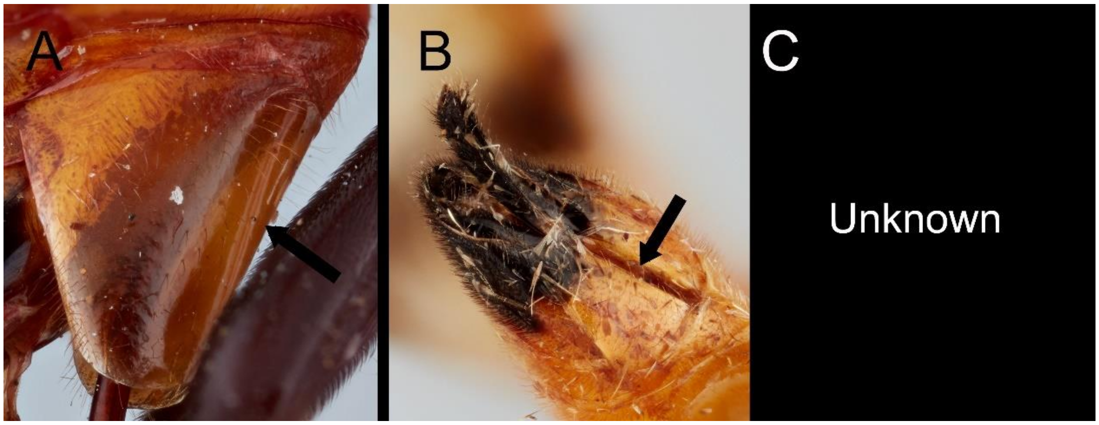

Figure 53. Interactive key character 5.

6. Mesoscutum (Figure. 54): A. mostly or entirely darker, B. mostly or entirely pale.

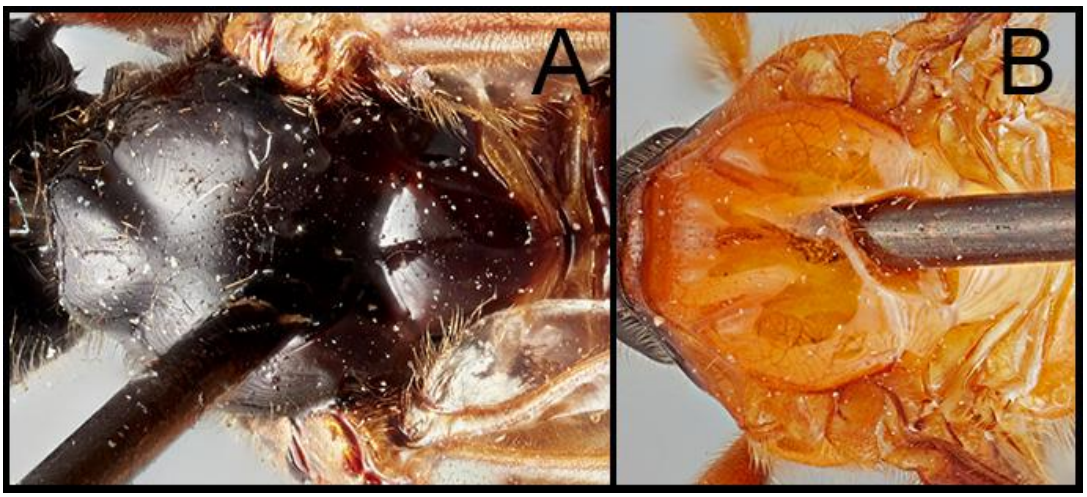

Figure 54. Interactive key character 6.

7. Protruded ovipositor sheath (Figure. 55): A. ≥ ~ 1.0 × longer than hind tibia, B. ≤ ~ 0.6 × longer than hind tibia, C. unknown.

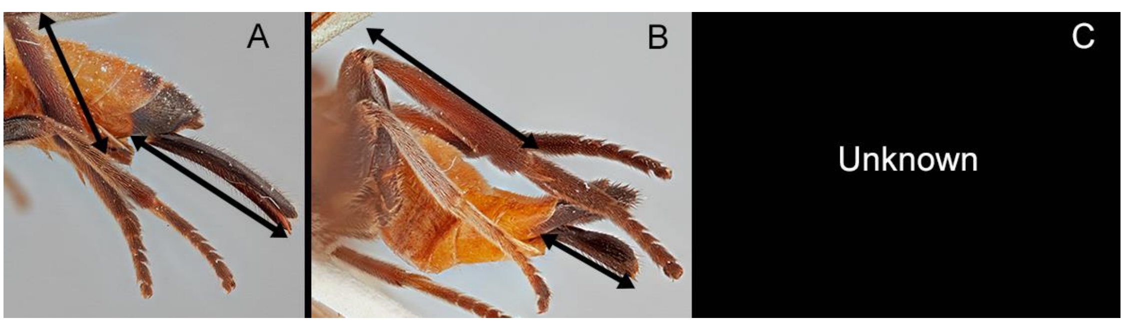

Figure 55. Interactive key character 7.

8. T1 ratio (length to width) (Figure. 56): A. ≥ ~ 2.0, B. 1.3~1.6, C. ≤ ~ 1.2.

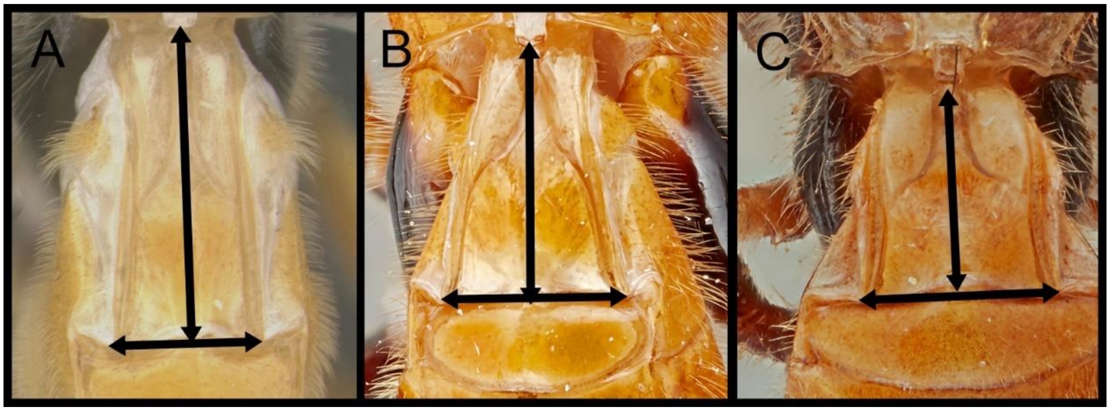

Figure 56. Interactive key character 8.

9. Fore wing (Figure. 57): A. entirely infuscate, B. with two bands.

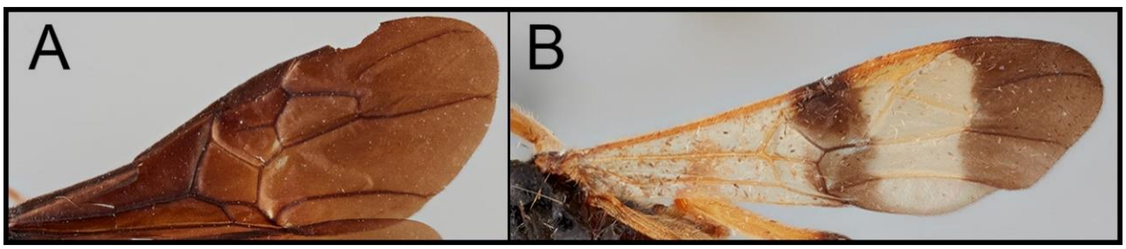

Figure 57. Interactive key character 9.

***Neocardiochiles alexeyi* Kang, sp. nov.**

(See Figure 58)

Material examined. Holotype Ecuador • ♀**;** Yasuni Research Station, Yasuni National Park, Orellana province; 00°40.4´S, 76°23.861´W; 18–24.vii.2008; A. Tishechkin; AT 853MS-2; H16634. Will be deposited in CNC.

Diagnosis. *Neocardiochiles alexeyi* sp. nov. can be distinguished from other members of the *Neocardiochiles* by the combination of the following characters: antenna 34-segmented and with pale apex (Figure 58A); glossa ~ 2.0 × longer than height of clypeus (Figure 58D); scutellar sulcus moderately impressed (Figure 58B); mesoscutum entirely dark; hind femur entirely pale; anterior width of median furrow of propodeum ~ 0.83 × longer than maximum width (Figure

58E); T1 ~ 2.22 × longer than its posterior width; lateral sutures of T1 nearly parallel (Figure 58E); T2 ~ 0.49 × longer than its posterior width (Figure 58E); ovipositor sheath ~ 0.62 × longer than length of hind tibia (Figure 58A).

Molecular data. 28S sequences (GenBank accession number: ON040823.1);

ATGAGGAGATTCACTGTTAGCATTACTAGTATTAATGCAAATTATGATATGATTATA
TGATCCTTGTGGTCACAATTATTATACTTATTTGTATTATTTTATTGGTTTTGTCAGCA
TGCACTTCTCCTCTAGTAGAACGTCGCGACCCGTTGAATGTTTATTTATGAGCCACAT
GGTAGTCTTATGTATTTTATACGCAAGACCAGTGAATTTCTAATAAACTATTTGACG
GTATCTAAAATGGTATTGAGCCGCAAATTTTTTTTGCGTTAGATTTATTACAAGCTAG
ACTTACTTTAAGCAGTACGAATTTTATGTCGTCGTTTAAACTAGTCTGCTGTTAGTGA
TAATATCTTTAACTGGCTTAATTTTACCGGTCAGCGATGCTACTGCTTTGGGTACTTA
CAGGACCCGTCTTG

Description. Body ~ 7.04 mm. Head: Antenna 34-segmented. Face width ~ 1.36 × wider than high (1.01:0.74). Width of anterior ocellus as long as POL (010:0.10). Eyes bulged and without interommatidial setae; median width of eye about ~ 1.23 × longer than the median width of gena in lateral view (0.37:0.30). Clypeus 2.20 × longer than its height (0.55:0.25). Galea 1.64 × longer than height of clypeus (0.41:0.25). Glossa 1.96 × longer than height of clypeus (0.49:0.25). Occipital carina absent. Mesosoma: Notauli weakly impressed at anterior two thirds and absent posteriorly. Scutellar sulcus straight, moderately impressed, medially shallow, laterally relatively deep, without crenula. Pronotum mostly smooth, with ventral longitudinal carina. Metapleuron mostly smooth. Propodeum ~ 0.48 × longer than its median width (0.40:0.83); median longitudinal furrow present, nearly rectangle, anteriorly opened posteriorly closed by nucha, anterior width ~ 0.83 × longer than maximum width (0.05:0.06). Legs: Basal spur on mid tibia ~ 0.60 × longer than length of basitarsus (0.38:0.63). Basal spur on hind tibia ~ 0.54 × longer than length of basitarsus (0.60:1.11). Wings: Fore wing (RS+M)a present; second submarginal cell trapezoid, ~ 2.81 × longer than height (1.32:0.47); 1r absent; 3r absent; 3RSb evenly curved. Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 ~ 2.22 × longer than its

posterior width (0.91:0.41), anterior width ~ 0.83 × longer than posterior width (0.34:0.41), dorsally nearly rectangle; Y-shaped suture present. T2 nearly rectangle, ~ 0.49 × longer than its posterior width (0.35:0.71), with straight posterior margin. Hypopygium with median fold. Ovipositor sheath nearly straight, ~ 0.62 × longer than length of hind tibia (1.31:2.11), evenly setose except for base.

Color. Body mostly yellowish pale. The following areas dark: basal antenna (mostly), head, mandible, mesonotum, pronotum, mesopleuron, metapleuron, middle coxa, hind coxa, apical hind tibia, apical hind tarsi, apical metasoma. Fore wing with two bands; stigma mostly pale.

Male. Unknown.

Etymology. Named in honor of Dr. Alexey K. Tishechkin, staff in the Plant Pest Diagnostics Branch, California Department of Food & Agriculture and a former member of the Louisiana State Arthropod Museum at LSU AgCenter, who collected the specimen in Ecuador.

Host. Unknown.

Distribution. *Neocardiochiles alexeyi* sp. nov. is known from only one female specimen collected from Yasuni Biological Station, Orellana province, Ecuador.

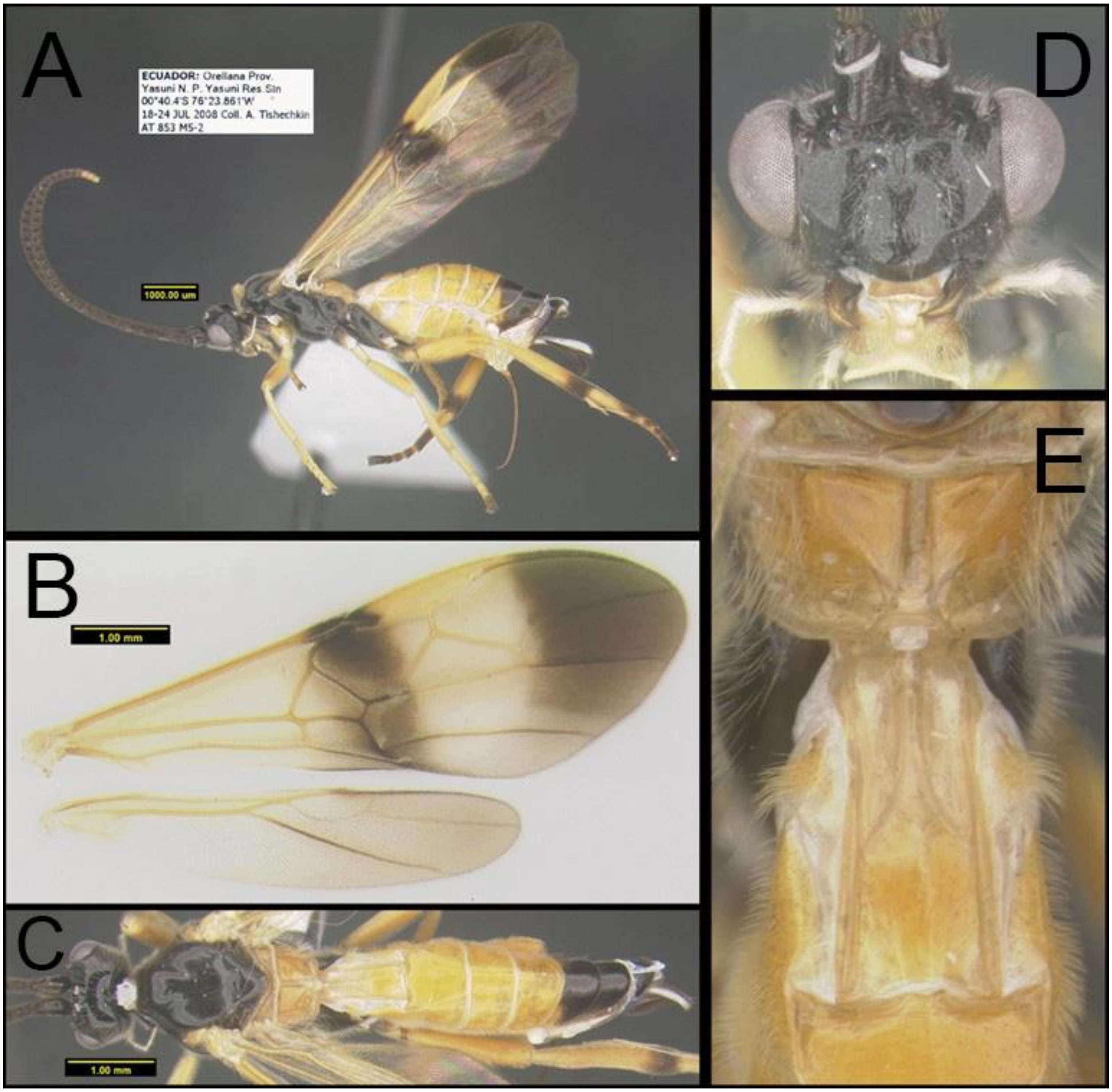

Figure 58. *Neocardiochiles alexeyi* sp. nov. A) Lateral habitus; B) wings; C) dorsal habitus; D) dorsal anterior head; E) propodeum and T1–T2.

Neocardiochiles braeti Kang, sp. nov.

(See Figure 59)

Material examined. Holotype French Guiana • ♀; Roura, Montagne des chevaux; 22.xi.2008; S.E.A.G.; 2008–2009. Will be deposited in RBINS.

Diagnosis. *Neocardiochiles braeti* sp. nov. can be distinguished from other *Neocardiochiles* species by the combination of the following characters: antenna ≥ 37-segmented; scutellar sulcus weakly impressed (Figure 59B); fore wing with two bands; hind femur entirely melanic; anterior width of median furrow of propodeum ~ 0.33 × longer than maximum width (Figure 59E); T1 ~ 1.63 × longer than its posterior width; T2 ~ 0.42 × longer than its posterior width (Figure 59E); ovipositor sheath as long as hind tibia (Figs. 59A, 59B, 59D).

Description. Body ~ 8.67 mm. Head: Antenna ≥ 37-segmented, apically broken. Face width ~ 1.46 × longer than its height (1.02:0.70) Width of anterior ocellus ~ 0.96 × longer than POL. Eyes bulged and without interommatidial setae; median width of eye about ~ 0.90 × longer than median width of gena in lateral view (0.44:0.49). Clypeus ~ 2.61 × longer than its height (0.60:0.23). Malar space 0.84 × longer than basal width of mandible. Mesosoma: Notauli anteriorly weakly impressed and absent posteriorly. Scutellar sulcus weakly impressed, medially shallow, laterally relatively deep, without crenula. Pronotum entirely smooth. Propodeum ~ 0.44 × longer than its median width (0.57:1.30); median longitudinal furrow present, elongate isosceles trapezoid, anteriorly opened posteriorly closed by nucha, anterior width ~ 0.33 × longer than maximum width (0.04:0.12). Legs: Basal spur on mid tibia ~ 0.64 × longer than length of basitarsus (0.47:0.74). Basal spur on hind tibia ~ 0.50 × longer than length of basitarsus (0.68:1.37). Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid, ~ 3.01 × longer than height (1.66:0.55); 1r absent; 3r absent; 3RSb evenly curved; stigma about ~ 4.42 × longer than wide medially (2.08:0.47). Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 ~ 1.63 × longer than its posterior width (1.19:0.73), anterior width ~ 0.63 × longer than posterior width (0.46:0.73), dorsally isosceles trapezoid; Y-shaped suture partially developed anteriorly,

absent posteriorly. T2 nearly trapezoid, ~ 0.42 × longer than its posterior width (0.44:1.06), with curved posterior margin. Hypopygium with median fold. Ovipositor sheath slightly downcurved, ~ 1.03 × longer than length of hind tibia (2.92:2.81), evenly setose except for base.

Color. Head and mesosoma mostly black, metasoma mostly orange and black apically. Legs black or dark brown except for fore tarsus. Fore wing with two bands; stigma pale at apical two thirds.

Male. Unknown.

Etymology. Named in honor of Mr. Yves Braet who provided specimens collected in French Guiana for this study.

Host. Unknown.

Distribution. *Neocardiochiles braeti* sp. nov. is known only from one female specimen collected from Roura, Montagne des chevaux, French Guiana.

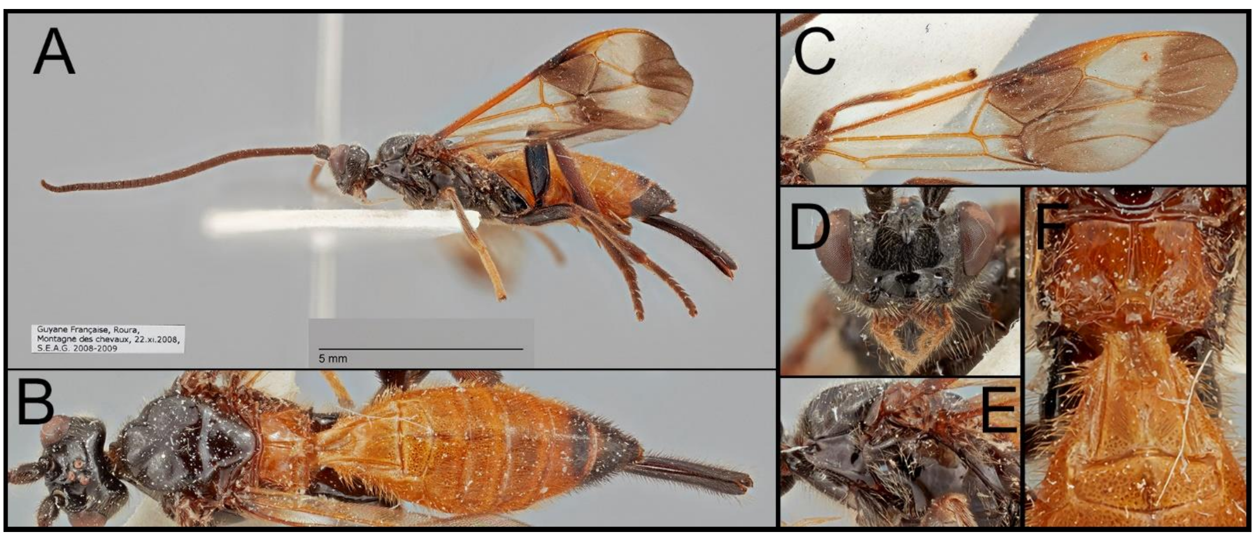

Figure 59. *Neocardiochiles braeti* sp. nov. A) Lateral habitus; B) dorsal habitus; C) fore wing; D) anterior head; E) lateral mesosoma; F) dorsal propodeum and T1.

Neocardiochiles chriscarltoni **Kang sp. nov.**

(See Figs. 60, 61)

Material examined. Holotype French Guiana • ♀; Roura, Montagne des chevaux; ix.2009; S.E.A.G.; 2008–2009, Piège Malaise. Will be deposited in RBINS.

Diagnosis. *Neocardiochiles chriscarltoni* sp. nov. is most similar to *N. braeti* sp. nov. However, *N. chriscarltoni* sp. nov. can be distinguished from other *Neocardiochiles* species by the combination of the following characters: antenna 38-segmented and with pale apex (Figure 61A); scutellar sulcus weakly impressed (Figure 60B); fore wing with two bands; hind femur entirely melanic; anterior width of median furrow of propodeum ~ 0.11 × longer than maximum width (Figure 60E); T1 as long as its width (Figure 60E); T2 ~ 0.30 × longer than its posterior width (Figure 60E); ovipositor sheath ~ 0.48 × longer than length of hind tibia (Figs. 60A, 60D).

Molecular data. 16S sequences (GenBank accession number: ON059709.1);

CACCTGTTTATCAAAAACATGTCTTTTTGAAAATAATTTAAAGTCCAATCTGCTCAAT
GATTAATTAATTTAATAGCTGCAATATTTATAATTGTACTAAGGTAGCATAATCATT
AGTTTATTAATTGTAAACTTGTATGAACGATTTGATGAAATAAATACTATTTCATTTT
AAAAAAATAAATTTTTTTTTTAAGTTAAAAAACTTAAATAATATTAAAAGACGAGAA
GACCCTTTAGAATTTTATAATAATAATTTATAAAAATTTTTATATATTTATAAATAAT
TATTATTTAATTGGGGTGATTATAAAATTTAATAAACTTTTATATAAATAAACAATA
ATTTTTGAATAAAATATATTTTTTTTAAAAAAATAAATTAAATTACCTAAGGGATAA
CAGCATAATTTTTTTAAAAAGCACAAATTTATAAAAAAGTTTATGACCTCGATGTTG
AATTAAGA

Description. Body ~ 7.43 mm. Head: Antenna 38-segmented. Face width ~ 1.47 × longer than its height (0.97:0.66). Width of anterior ocellus as long as POL (0.12:0.12). Eyes bulged and without interommatidial setae; median width of eye about ~ 1.32 × longer than the median width of gena in lateral view (0.50:0.38). Clypeus ~ 2.57 × longer than its height (0.59:0.23). Mesosoma: Notauli weakly impressed at anterior half and disappeared posteriorly. Scutellar sulcus weakly impressed, medially shallow, laterally relatively deep, without crenula. Pronotum mostly smooth, with ventral longitudinal carina. Propodeum ~ 0.39 × longer than its median width (0.53:1.36); median longitudinal furrow present, elongate isosceles trapezoid, anteriorly opened posteriorly closed by nucha, anterior width ~ 0.11 × longer than maximum width

(0.02:0.18). Legs: Basal spur on mid tibia ~ 0.56 × longer than length of basitarsus (0.38:0.68). Basal spur on hind tibia ~ 0.48 × longer than length of basitarsus (0.52:1.08). Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid; 1r absent; 3r absent; 3RSb evenly curved. Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 ~ 1.06 × longer than its posterior width (0.82:0.77), anterior width ~ 0.66 × longer than posterior width (0.51:0.77), dorsally nearly rectangular; Y-shaped suture present. T2 nearly rectangle, ~ 0.30 × longer than its posterior width (0.38:1.28), with curved posterior margin. Hypopygium with median fold. Ovipositor sheath nearly straight and posteriorly enlarged, ~ 0.48 × longer than length of hind tibia (1.07:2.25), evenly setose except for base.

Color. Body mostly melanic; the following areas pale: four apical flagellomeres, basal maxillary and labial palpi, fore tarsi, metanotum (mostly), propodeum, anterior metasoma (mostly). Fore wing with two bands; stigma entirely melanic.

Male. Unknown.

Etymology. Named in honor of Dr. Christopher E. Carlton, the emeritus professor in the Department of Entomology at LSU AgCenter.

Host. Unknown**.**

Distribution. *Neocardiochiles chriscarltoni* sp. nov. is known only from one female specimen collected from Roura, Montagne des chevaux, French Guiana.

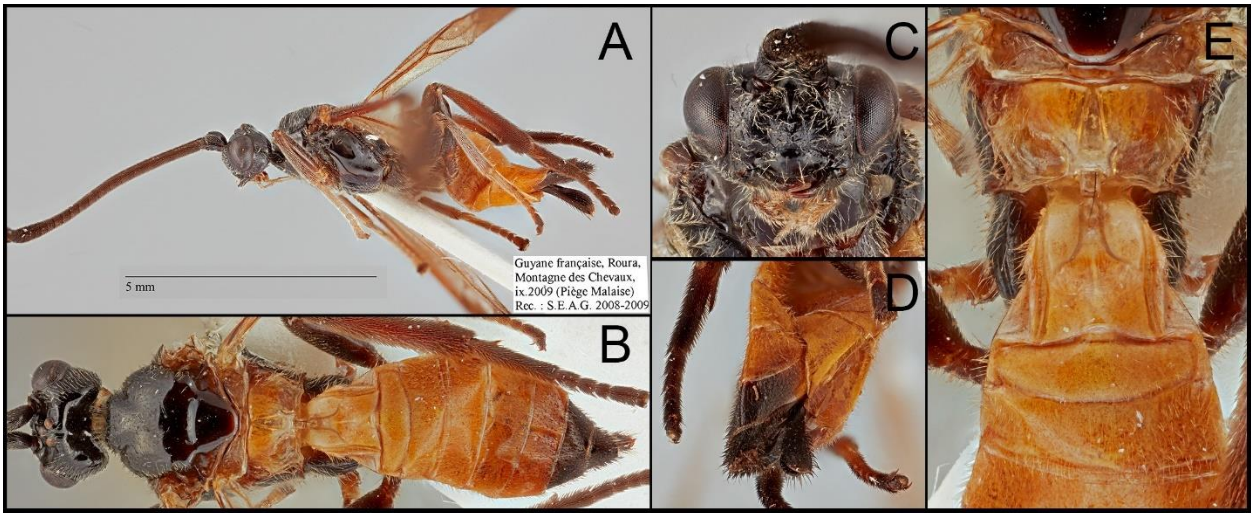

Figure 60. First image plate of *Neocardiochiles chriscarltoni* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) hypopygium and ovipositor sheath; E) dorsal propodeum and T1–T3.

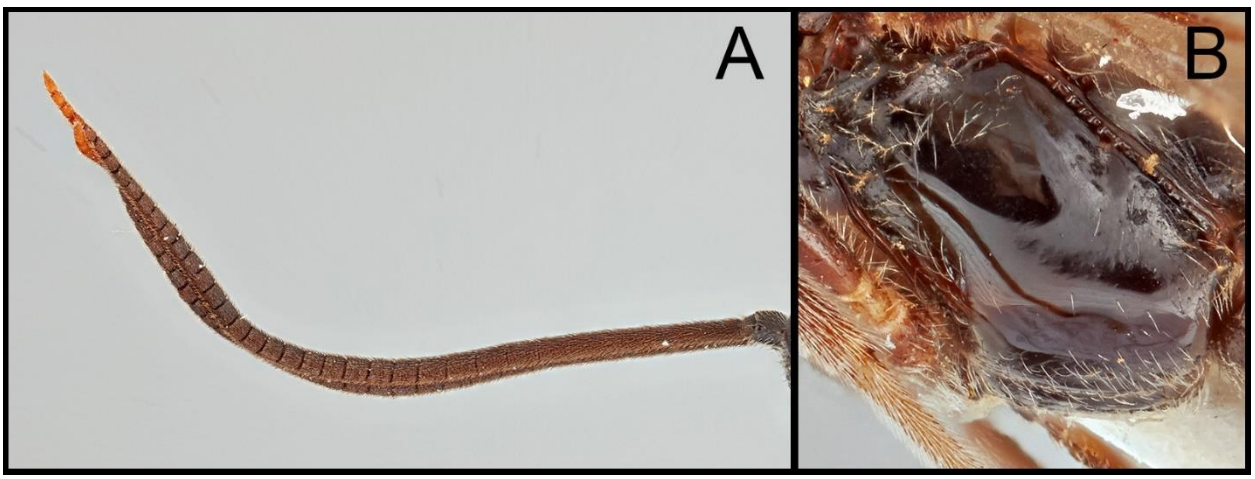

Figure 61. Second image plate of *Neocardiochiles chriscarltoni* sp. nov. A) Antennae; B) mesopleuron.

***Neocardiochiles fasciipennis* Szépligeti, 1908, comb. nov.**

(See Figure 62)

Material examined. Lectotype Suriname • ♀; Michaelis.

Diagnosis. Morphological characters of *Neocardiochiles fasciipennis* are only known from holotype. The species is distinguished from other members of *Neocardiochiles* by the combination of the following characters: body ~ 11 mm; posterior margin of mesopleuron

smooth; basal spur on hind tibia slightly shorter than the half length of hind basitarsus (Figure 62A); fore wing length ~ 13 mm; T1 ~ 1.35 × longer than apical width (Figure 62E); ovipositor sheath as long as hind tarsomeres 1–3 combined.

Description. See Papp (2014).

Male. Unknown.

Host. Unknown.

Distribution. Suriname.

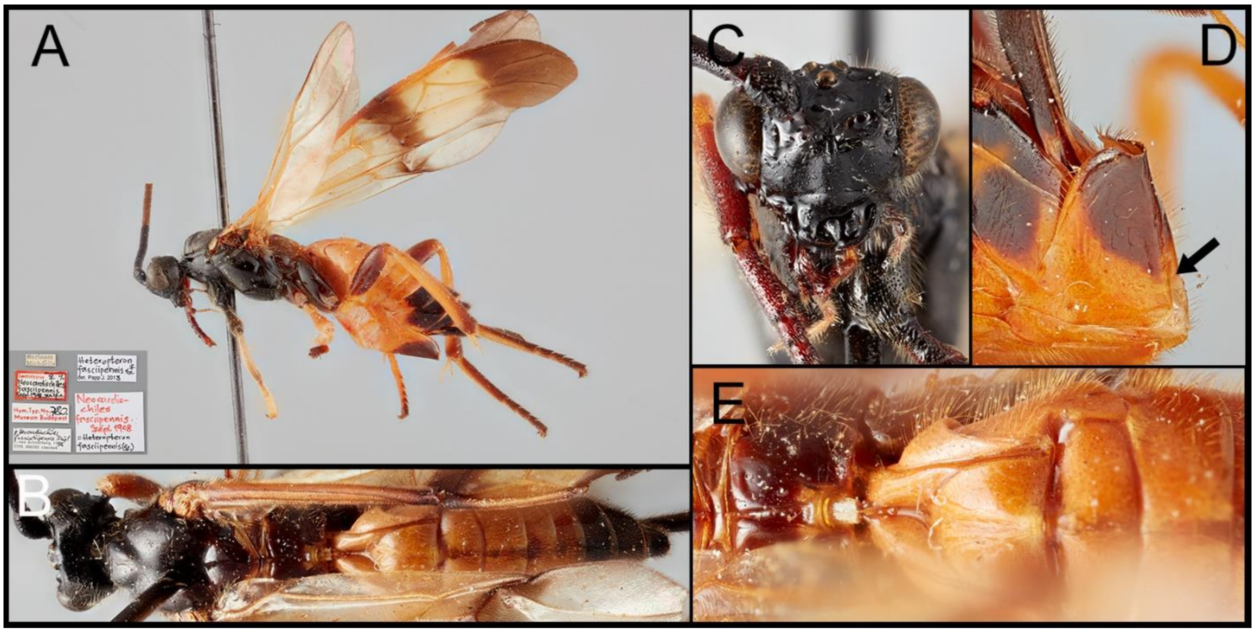

Figure 62. *Neocardiochiles fasciipennis*, lectotype. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) ventro-lateral hypopygium; arrow: median longitudinal fold; E) dorsal propodeum and T1–T3.

Neocardiochiles franki Kang, sp. nov.

(See Figure 63)

Material examined. Holotype Costa Rica • ♀; 3km SE of Rio Naranjo, Guanacaste; 1–5.vi.1992; F. D. Parker. Will be deposited in UWIM.

Diagnosis. *Neocardiochiles franki* sp. nov. is most similar to *N. alexeyi* sp. nov. However, *N. franki* sp. nov. can be distinguished from other *Neocardiochiles* species by the

combination of the following characters: antenna ≥ 37-segmented; scutellar sulcus weakly impressed (Figure 63B) mesoscutum entirely dark; hind femur entirely pale; anterior width of median furrow of propodeum ~ 0.18 × longer than maximum width (Figure 63D); T1 trapezoid and as long as its width (Figure 63B); T2, ~ 0.34 × longer than its posterior width (Figure 63B); ovipositor sheath ~ 0.58 × longer than length of hind tibia (Figure 63A).

Description. Body ~ 9.36 mm. Head: Antenna ≥ 37-segmented, apically broken. Face width ~ 1.50 × longer than its height (1.11:0.74). Width of anterior ocellus ~ 1.11 × longer than POL (0.10:0.09). Eyes bulged and without interommatidial setae; median width of eye about ~ 1.32 × longer than median width of gena in lateral view (0.47:0.44). Clypeus ~ 2.41 × longer than its height (0.77:0.32). Mesosoma: Notauli weakly impressed at anterior half and absent posteriorly. Scutellar sulcus weakly impressed, medially shallow, laterally relatively deep, without crenula. Pronotum mostly smooth, with ventral longitudinal carina. Propodeum 0.50 × longer than its median width (0.61:1.22); median longitudinal furrow present, elongate isosceles trapezoid, anteriorly opened posteriorly closed by nucha, anterior width ~ 0.18 × longer than maximum width (0.03:0.17). Legs: Basal spur on mid tibia ~ 0.60 × longer than length of basitarsus (0.47:0.78). Basal spur on hind tibia ~ 0.62 × longer than length of basitarsus (0.83:1.33). Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid, ~ 2.20 × longer than height (1.81:0.82); 1r absent; 3r absent; 3RSb evenly curved. Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 ~ 1.09 × longer than its posterior width (1.20:1.10), anterior width ~ 0.53 × longer than posterior width (0.58:1.10), dorsally nearly trapezoid; Y-shaped suture present. T2 rectangle, ~ 0.34 × longer than its posterior width (0.54:1.58), with straight posterior margin. Hypopygium with median fold. Ovipositor sheath nearly straight and

posteriorly enlarged, ~ 0.58 × longer than length of hind tibia (1.82:3.15), evenly setose except for base.

Color. Body mostly melanic; the following areas pale: maxillary and labial palpi, fore leg, middle femur; mid tibia; basal middle tarsus, hind femur, basal hind tibia, anterior metasoma (mostly). Fore wing with two bands; stigma mostly pale.

Male. Unknown.

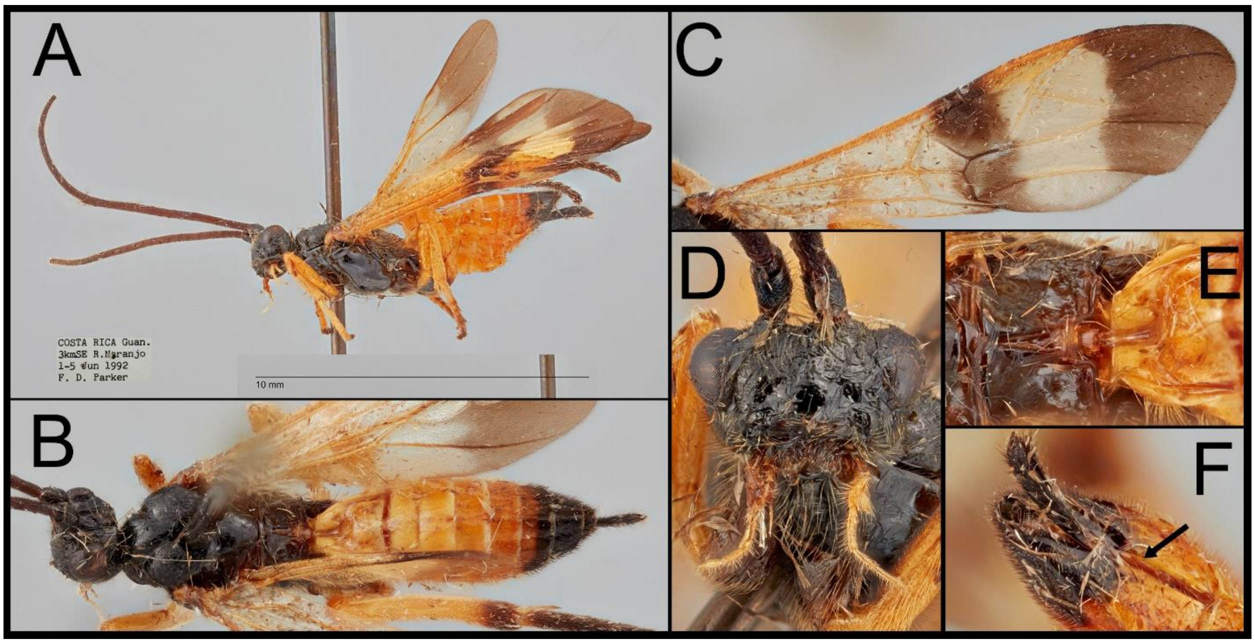

Figure 63. *Neocardiochiles franki* sp. nov. A) Lateral habitus; B) dorsal habitus; C) fore wing; D) anterior head; E) dorsal propodeum and T1; F) hypopygium, arrow: median longitudinal fold.

Etymology. Named in honor of Dr. Frank Parker, the former head of the USDA Bee lab, who collected the specimen.

Host. Unknown**.**

Distribution. *Neocardiochiles franki* sp. nov. is known only from one female specimen collected from 3km SE of Rio Naranjo, Guanacaste, Costa Rica.

***Neocardiochiles hasegawai* (Dabek & Whitfield, 2020), comb. nov.**

Material examined. Non-type specimen Costa Rica • ♀; Guanacaste, Area de Conservación Guanacaste, Sector Santa Rosa, Finca Jenny; 10.86333, -85.57443, 205m; 14.xii.2010 (host caterpillar collection date); 01.i.2011 (host caterpillar pre-pupal date); 17.i.2011 (parasitoid eclosion date); Johan Vargas; DHJPAR0045389; host caterpillar (10-SRNP-15361; *Stenoma cathosiota*) on host plant (*Roupala montana*).

Diagnosis. *Neocardiochiles hasegawai* is most similar to *N. alexeyi* sp. nov. and *N. franki* sp. nov., but the members of *N. hasegawai* differ from other *Neocardiochiles* species by possession of the two following characters: mesoscutum entirely pale; hind femur entirely pale.

Molecular data. 28S sequences (GenBank accession number: ON040755.1);

ATGAGGAGATTCACTGTTAGCATTACTAGTATTAATGCAAATTATGATATGATTATA
TATGATTCTTGTGGTCACAATTATTATACTTATTTGTATTATTTTATTGGTTTTGTCAG
CATGCACTTCTCCTCTAGTAGAACGTCGCGACCCGTTGAATGTTTATTTATGAGTCAC
ATGGTAGTCTTATGTATTTTATACGCAAGACCAGTGAATTTCTAATAAACTGTTTGAC
GGTATCTAAAATGGTATTGAGCCGCAAATTTTTTTTTGCGTTAGATTTATCACAAGCT
AGGCTTACTTTAAGCAGTACGAATTTTATGTCGTCGTTTAAACTAGTCTGCTGTTAGT
GATAATATCTTTAACTGGCTTAATTACCGGTCAGCGATGCTACTGCTTTGGGTACTTA
CAGGACCCGTCTTG

Description. See Dabek et al. (2020).

Male. Body length slightly longer than female (Dabek et al. 2020).

Host. Reared from caterpillars of *Carthara abrupta* (Pyralidae) on *Roupala montana* (Proteaceae) (Dabek et al. 2020).

Distribution. Costa Rica (ACG).

***Neocardiochiles kidonoi* (Dabek & Whitfield, 2020), comb. nov.**

Material examined. Non-type specimen Costa Rica • ♀**;** Guanacaste, Area de Conservación Guanacaste, Sector El Hacha, Quebrada Pitahaya; 11.01182, -85.53168; 320m; 11.ix.2013 (host caterpillar collection date); 14.ix.2013 (host caterpillar pre-pupal date);

02.x.2013 (parasitoid eclosion date); Roster Moraga; DHJPAR0053597; host caterpillar (13-SRNP-22162; *Stenoma cathosiota*) on host plant (*Roupala montana*).

Diagnosis. *Neocardiochiles kidonoi* is most similar to *N. victoriae* sp. nov., but members of *N. kidodoi* can be distinguished from other *Neocardiochiles* members by possession of the following characters: mesoscutum entirely pale; hind femur bicolored; hind tibia mostly pale.

Description. See Dabek et al. (2020).

Male. Body length slightly shorter than female (Dabek et al. 2020).

Host. Reared from larvae of *Stenoma cathosiota* (Depressariidae) on *Roupala montana* (Proteaceae) (Dabek et al. 2020).

Distribution. Costa Rica (ACG).

Neocardiochiles victoriae Kang, sp. nov.

(See Figure 64)

Material examined. Holotype French Guiana • ♀; Degrad Laurens, Crique Sapokaï; 95m; 24.x. –30.x1998; leg. A.E.I. Guiana; P Malaise. Will be deposited in RBINS.

Diagnosis. *Neocardiochiles victoriae* sp. nov. is most similar to *N. kidonoi*, but the member of *N. victoriae* differs from other members of *Neocardiochiles* by the following characters: antenna 40-segmented with entirely reddish flagellomeres (Figure 64A); scutellar sulcus weakly impressed; mesoscutum entirely pale; hind femur bicolored; hind tibia mostly melanic; anterior width of median furrow of propodeum ~ 0.19 × longer than maximum width (Figure 64E); T1 ~ 1.39 × longer than its posterior width (Figure 64E); T2 ~ 0.39 × longer than its posterior width (Figure 64E); ovipositor sheath as long as hind tibia (Figure 64A).

Molecular data. 28S sequences (GenBank accession number: ON040754.1);

ATGAGGAGATTCACTGTTAGCATTACTAATATTAATGCAAATTATGATATCATTATA
TGATCCTTGTGGTCACAATTATTATACTTATTTGTATTATTTTATTGGTTTTGTCAGCA

TGCACTTCTCCTCTAGTAGAACGTCGCGACCCGTTAAATGTTTATTTATGAGTCACAT
GGTAGTCTTATGTATTTTATACGCAAGACCAGTGAATTTCTAATAAACTGTTTGACG
GTATCTAAAATGGTATTGAGCCGCAAATTTTTTTTGCGTTAGATTTATTACAAGCTAG
GCTTACTTTAAGCAGTACGAATTTTATGTCGTCGTTTAAACTAGTCTGCTGTTAGTGA
TAATATCTTTAACTGGCTTAATTACCGGTCAGCGATGCTACTGCTTTGGGTACTTACA
GGACCCGTCTTG

16S sequences (GenBank accession number: ON059710.1);

TCCCCTGTTTATCAAAAACATGTCTTATTGAAAATAATTTTAAGTCAAATCTGCTCAA
TGATAATTTTATTAAATAGCTGCAGTAAATATGACTGTACTAAGGTAGCATAATAAA
TAGTTTATTAATTATAAACTTGTATGAAAGATTTAATGTAATAAATACTGTTTCAATT
TAAAAAAATAAATTTTTTTTTTAAGTAAAAAAACTTAAATAAAATTAAAAGACGAG
AAGACCCTATAGAATTTTATAAATTAATTTTAATTAATTTATTTTTAATTAAAATTAA
ATTATTTAATTGGGGAGATTATAAAATTTAAAAAACTTTTATATAAATTTACAATAA
TTATTGAATAAAATATAATTTTTAAAAAAAATAAAATAAATTACCTTAGGGATAACA
GCATAATTTTTTTTTTAAGTTCGTATTACTAAAAAAGATTATGACCTCGATGTTGAAT
TAAGA

Description. Body ~ 9.35 mm. Head: Antenna 40-segmented. Face width ~ 1.73 × longer than its height (1.28:0.74). Width of anterior ocellus ~ 1.15 × longer than POL (0.15:0.13). Eyes bulged and without interommatidial setae; median width of eye about ~ 1.04 × longer than median width of gena in lateral view (0.58:0.56). Clypeus ~ 2.39 × longer than its height (0.74:0.31). Mesosoma: Notauli weakly impressed at anterior half and absent posteriorly. Scutellar sulcus weakly impressed, medially shallow, laterally relatively deep, without crenula. Pronotum mostly smooth, with ventral longitudinal carina. Metapleuron mostly smooth. Propodeum ~ 0.39 × longer than its median width (0.66:1.68); median longitudinal furrow present, elongate isosceles trapezoid, anteriorly opened posteriorly closed by nucha, anterior width ~ 0.19 × longer than maximum width (0.03:0.16). Legs: Basal spur on mid tibia ~ 0.71 × longer than length of basitarsus (0.62:0.87). Basal spur on hind tibia 0.50 × longer than length of basitarsus (0.84:1.68); claw pectinate. Wings: Fore wing (RS+M)a vein present; second submarginal cell trapezoid; 1r absent; 3r absent; 3RSb evenly curved. Hind wing 2r-m absent; 2–1A absent. Metasoma: T1 ~ 1.39 × longer than its posterior width (1.42:1.02), anterior width ~

0.56 × longer than posterior width (0.57:1.02), dorsally isosceles trapezoid; Y-shaped suture present. T2 nearly oval, ~ 0.39 × longer than its posterior width (0.49:1.27), with curved posterior margin. Hypopygium with median fold. Ovipositor sheath slightly downcurved, ~ 1.04 × longer than length of hind tibia (3.38:3.25), evenly setose except for base.

Color. Body mostly orange. The following areas dark: antenna (reddish brown), head, ventral fore notum, fore coxa, fore trochanter and trochantellus (mostly), fore femur (mostly); middle coxa, middle trochanter and trochantellus (mostly), middle femur (mostly), mid tibia (apically); hind femur (apically); hind tibia (except for inner tibia), T5 to T8 (dorsally), ovipositor sheath. Fore wing with two bands; stigma mostly pale.

Male. Unknown.

Etymology. Named in honor of Ms. Victoria Bayless, a curator in the Louisiana State Arthropod Museum at LSU AgCenter and a former president of the Coleopterists Society, who is the best friend in LSU and has red hair as the specimen has reddish antennae.

Host. Unknown**.**

Distribution. *Neocardiochiles victoriae* sp. nov. is known only from one female specimen collected from Degrad Laurens, Crique Sapokaï, French Guiana.

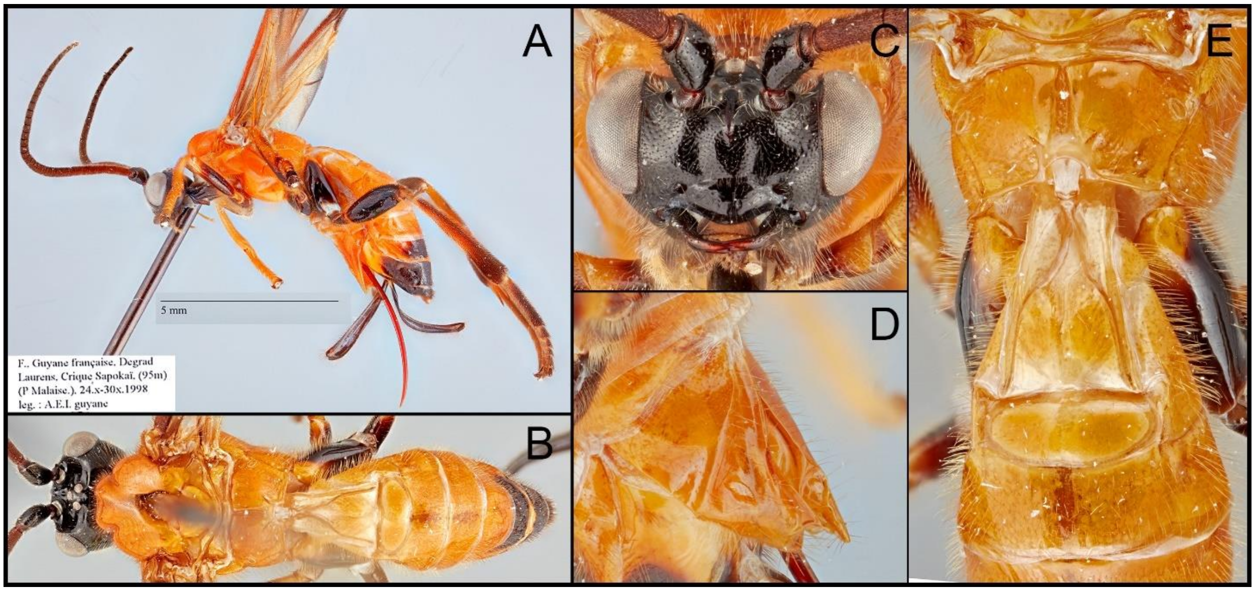

Figure 64. *Neocardiochiles victoriae* sp. nov. A) Lateral habitus; B) dorsal habitus; C) anterior head; D) hypopygium; E) dorsal propodeum and T1–T3.

Neocardiochiles whitfieldi (Mercado, 2003), comb. nov.

Material examined. Holotype Mexico • ♂; 16km north of Autlan, Jalisco; 7.vii.1984; Carrol, Schaffner, Friedlander. Deposited in TAMU.

Diagnosis. The known male of *Neocardiochiles whitfieldi* can be easily distinguished from other members of *Neocardiochiles* by the following color characters: head and mesosoma darker; wings entirely melanic; metasoma orange.

Description (Male). See Mercado and Wharton (2003).

Female: Unknown.

Host. Unknown.

Distribution. Mexico.

Discussion. The Maximum Parsimony (MP) phylogenetic analysis based on morphological characters was conducted due to the issues with *Heteropteron* and *Wesmaelella* specimens mentioned above, and the limited molecular data obtained from only a few specimens of *Neocardiochiles*. In the MP consensus tree, *Protomicroplitis* was set as outgroup, and all the

three ingroup genera are recovered as monophyletic groups. Based on the results, we resurrect *Neocardiochiles* to the generic level. A clade including *Wesmaelella* represented by *Wesmaelella nigripennis* (Szépligeti, 1902) was supported by eight synapomorphies (10-1; 13-2; 17-1; 20-1; 22-1; 33-1; 35-1; 36-1) and one homoplastic character (24-1) and recovered as the most plesiotypic member. 1r on fore wing (17-1) and RS2 (22-1) are easily observable characters to distinguish *Wesmaelella* from the members of *Heteropteron* and *Neocardiochiles*. A clade containing *Heteropteron* and *Neocardiochiles* were supported by six synapomorphies (1-2; 2-2; 21-2; 23-2; 25-2; 26-2) and five homoplastic characters (6-2 7-2 12-2 18-2 27-2). Three synapomorphies (13-1; 29-2; 30-2) and two homoplastic characters (19-2; 37-1) supported a clade with *Heteropteron* represented by the undescribed species. All the three unambiguous synapomorphies along with the ovipositor character (37-1; note: the undescribed species of *Heteropteron* possess a distinctively longer and more sinuate ovipositor than the members of *Wesmaelella* and *Neocardiochiles*) are easily visible diagnostic characters to identify *Heteropteron*. A clade including nine species of *Neocardiochiles* was supported by six synapomorphies (5-2; 8-2; 14-2; 15-2; 32-2; 34-2) and seven homoplastic characters (3-2; 9-2; 11-2; 16-2; 18-3; 28-2; 31-2) (Figure 65). Among six unambiguous synapomorphies of *Neocardiochiles*, the presence of a median longitudinal furrow on the propodeum (14-2) and pectinate claws (32-2) are easily observable diagnostic characters to distinguish the *Neocardiochiles* members from members of *Wesmaelella* and *Heteropteron*. Regarding species relationships displayed by the phylogeny (Figure 65), some *Neocardiochiles* species were not clearly delimited because we excluded characters only informative at the species-level due to the main purpose of the phylogeny (confirming the genus-level relationships). However, species of

Neocardiochiles can be easily delimited by additional morphological characters and molecular data included below.

We did not attempt to obtain molecular data from *Heteropteron* and *Wesmaelella* specimens because they were collected in the early 1900s and/or were type specimens. *Neocardiochiles* specimens collected from late 1990s to early 2010s were used to obtain molecular data. Among nine species of *Neocardiochiles*, 16S sequences of two species, *N. chriscarltoni* sp. nov. and *N. victoriae* sp. nov., and 28S sequences of three species, *N. alexeyi* sp. nov., *N. hasegawai* comb. nov., and *N. victoriae* sp. nov., were obtained. Unfortunately, attempts to obtain DNA sequences from the other five species of *Neocardiochiles* failed. In the genetic distance analyses and maximum likelihood analyses, ~465bp of 16S sequences and ~420bp of 28S sequences were utilized as the final dataset, respectively. The length of 28S sequences used in the analysis was shorter than our target length because only the forward strand of *N. hasegawai* was successfully obtained. Interspecific genetic distance between *N. chriscarltoni* sp. nov. and *N. victoriae* sp. nov. was 12.1% for 16S (Table 3). For 28S sequences, the distances ranged from 1.3% to 1.5% (Table 4). As shown in the results, 28S interspecific genetic distances between species were much lower than 16S, indicating confirmation of species boundaries based on 28S sequences would be more difficult. 16S sequences exhibited high interspecific genetic distances but mitochondrial cytochrome c oxidase subunit I (COI) barcodes obtained using universally known markers (Folmer et al. 1994; Hebert et al. 2004) may be more useful to delimit *Neocardiochiles* species than 16S as confirmed in many other braconid studies (Smith et al. 2008; Smith et al. 2012; Fernandez-Triana et al. 2014b; Kang et al. 2017; Fernandez-Triana et al. 2019; Meierotto et al. 2019; Fagan-Jeffries and Austin 2020; Sharkey et al. 2021a; Sharkey et al. 2021b; Slater-Baker et al. 2022). Two single gene trees (Figs. 66, 67)

were constructed, and the ML phylogeny based on 28S (Figure 67) was congruent with the morphology-based phylogeny (Figure 65) in confirming a relatively early-diverging position for *N. alexeyi* despite the small number of sequenced taxa (Figs. 65, 67).

Table 3. Estimates of genetic distances between 16S sequences.

	N. chriscarltoni sp. nov.	*N. victoriae* sp. nov.	*P. calliptera* (outgroup)
N. chriscarltoni sp. nov.	0		
N. victoriae sp. nov.	0.121		
P. calliptera (outgroup)	0.101	0.116	0

Table 4. Estimates of genetic distances between 28S sequences.

	N. alexeyi sp. nov.	*N. hasegawai*	*N. victoriae* sp. nov.	*P. calliptera* (outgroup)
N. alexeyi sp. nov.	0			
N. hasegawai	0.013			
N. victoriae sp. nov.	0.015	0.013		
P. calliptera (outgroup)	0.255	0.258	0.262	0

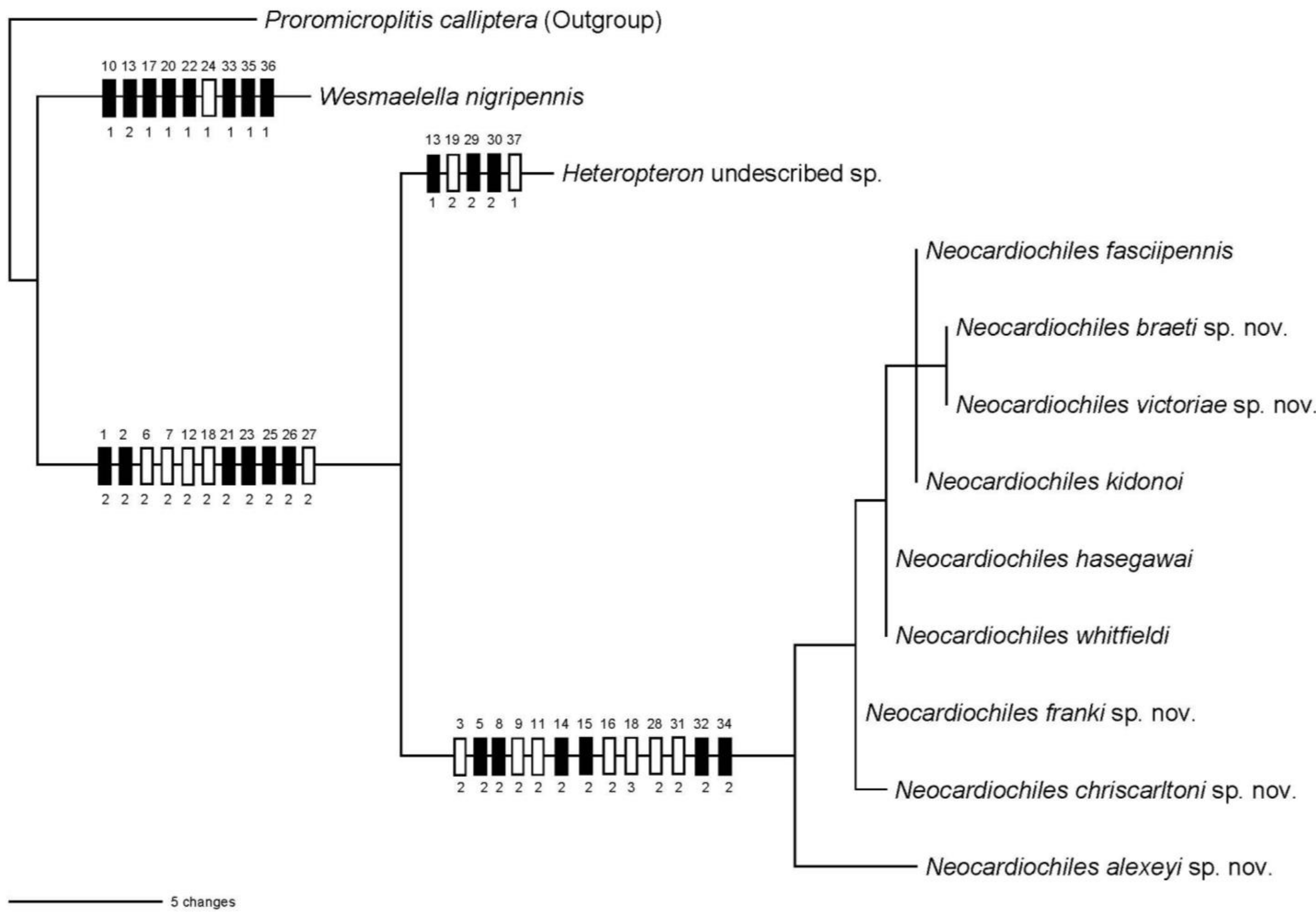

Figure 65. Maximum Parsimony (MP) phylogeny based on morphological data indicating the relationships of *Heteropteron*, *Neocardiochiles* and *Wesmaelella*. *Protomicroplitis calliptera* (Hymenoptera: Braconidae: Microgastrinae) is included as the outgroup. Synapomorphies are mapped on the phylogeny. Black bars indicate non-homoplastic characters, and white bars represent homoplastic characters. Characters are listed above bars, and character states are indicated below bars.

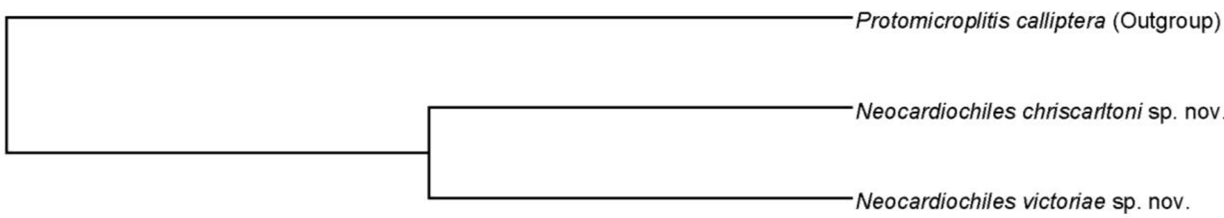

Figure 66. Maximum likelihood (ML) phylogeny based on 16S data indicating the relationships of *Neocardiochiles chriscarltoni* sp. nov. and *N. victoriae* sp. nov. *Protomicroplitis calliptera* (Hymenoptera: Braconidae: Microgastrinae) is included as the outgroup.

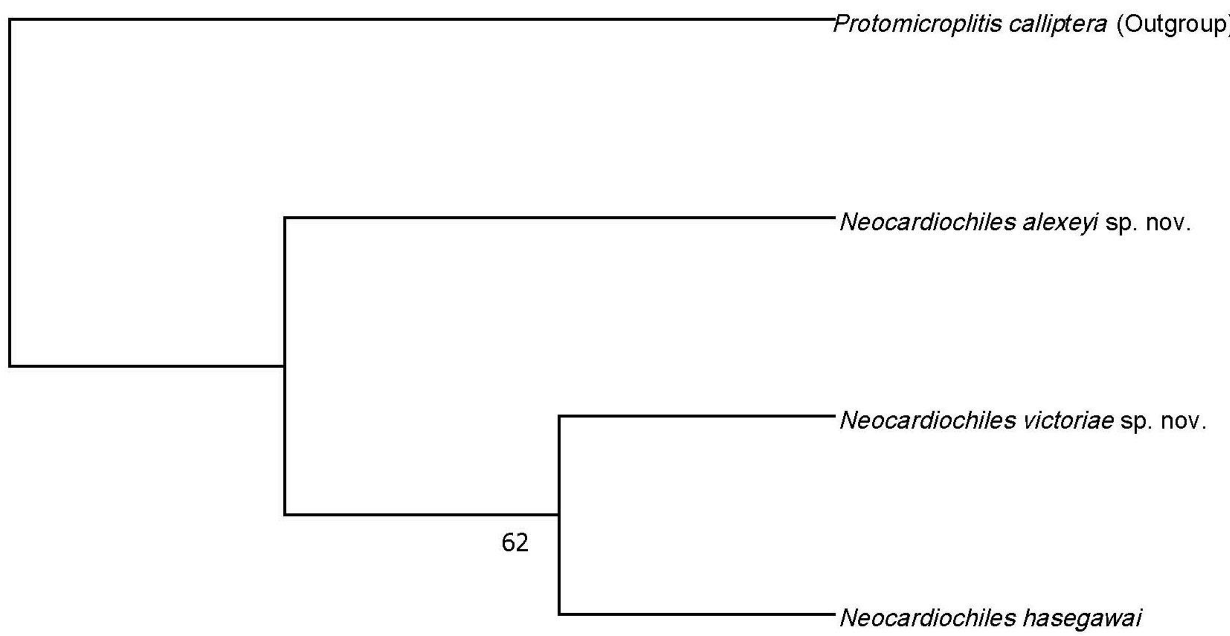

Figure 67. Maximum likelihood (ML) phylogeny based on 28S data indicating the relationships of *Neocardiochiles chriscarltoni* sp. nov. and *N. victoriae* sp. nov. *Protomicroplitis calliptera* (Hymenoptera: Braconidae: Microgastrinae) is included as the outgroup.

CHAPTER 5. SUMMARY AND CONCLUSIONS

The primary objective of this dissertation was to investigate the taxonomy of Cardiochilinae (Hymenoptera: Braconidae). Approximately 700 specimens of Cardiochilinae were examined in this study. Difficulty of acquisition of additional specimens from some other major insect collections during the COVID-19 pandemic prevented the examination of all 18 genera. Among the eighteen genera of Cardiochilinae, seven genera: *Bohayella* Belokobylskij, 1987, *Heteropteron* Brullé, 1846, *Neocardiochiles* Szépligeti, 1908, *Orientocardiochiles* Kang & Long, 2020, *Retusigaster* Dangerfield, Austin, & Whitfield, 1999, *Schoenlandella* Cameron, 1905 and *Wesmaelella* Spinola, 1851 were involved in the current research. One new genus, *Orientocardiochiles*, was described, and *Neocardiochiles* was resurrected from synonymy. Even though the other eleven genera were not included in the research, studies on those eleven genera are ongoing based on morphological and molecular data by the author. In the near future, relationships among *Austerocardiochiles* Dangerfield, Austin, and Whitfield, 1999, *Cardiochiles*, and *Schoenlandella* will be resolved and published based on molecular data-based phylogeny. The first distribution record of *Hansonia* Dangerfield, 1996 from the Old World was documented and will be reported. In the long run, with the novel taxonomic data obtained from this dissertation, a phylogeny based on molecular data that indicates generic relationships and boundaries will be available. As conducted in other genus-level or tribe-level braconid studies (Samacá-Sáenz et al. 2019; Jasso-Martínez et al. 2021), novel molecular analyses based on genomic data will elucidate more accurate relationships and boundaries of the cardiochiline genera. Regarding the species level diversity, sixteen new species have been described and many new cardiochiline species both from the Old World and the New World are in the process of being described. Still, biology of many members of Cardiochilinae is unknown and mysterious.

Further research in this field will help improve understanding and knowledge of ecology and practical utilization of the cardiochiline wasps in Agriculture. As many other braconids were tested and utilized in biological control, some cardiochilines can be developed as biological control agents after confirming host insect pest species and wasp host ranges. In applied science fields, novel tools can be inspired from structures of the parasitoid wasps as a surgical needled was recently developed based on a structure of the ovipositor of parasitoid wasps (Sakes et al. 2020). In pharmacological purposes, more attention is needed to investigate braconid venoms to find novel medicines even though there are still many obstacles remaining to investigate ichneumonoid wasps (Quicke and Butcher 2021).

APPENDIX A. DATA MATRIX FOR MORPHOLOGICAL PHYLOGENY

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
Proromicroplitis calliptera	1	1	2	1	1	1	1	1	2	2	2	1	3	1	1	2	2	1	2	2
Wesmaelella nigripennis	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
Heteropteron undescribed	2	2	1	1	1	2	2	1	1	2	1	2	1	1	1	1	2	2	2	2
Neocardiochiles fasciipennis	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2
Neocardiochiles alexeyi	2	2	2	2	2	1	1	2	2	2	2	1	3	2	2	2	2	3	1	2
Neocardiochiles franki	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2
Neocardiochiles braeti	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	2	1	2
Neocardiochiles victoriae	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	2	1	2
Neocardiochiles chriscarltoni	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2
Neocardiochiles kidonoi	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2
Neocardiochiles hasegawai	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2
Neocardiochiles whitfieldi	2	2	2	1	2	2	2	2	2	2	2	2	3	2	2	2	2	3	1	2

	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39
Proromicroplitis calliptera	1	2	3	2	1	3	1	2	1	1	2	1	2	1	2	2	2	1	1
Wesmaelella nigripennis	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Heteropteron undescribed	2	2	2	2	2	2	2	1	2	2	1	1	2	1	2	2	1	2	1
Neocardiochiles fasciipennis	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	2
Neocardiochiles alexeyi	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	1
Neocardiochiles franki	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	2	2	2
Neocardiochiles braeti	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	2
Neocardiochiles victoriae	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	2
Neocardiochiles chriscarltoni	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	2	2
Neocardiochiles kidonoi	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	2
Neocardiochiles hasegawai	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	2	1	2
Neocardiochiles whitfieldi	2	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	?	?	?

APPENDIX B. COPYRIGHT INFORMATION

Copyright Information for Sections 2.5–2.7

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RESEARCH ARTICLE

JOURNAL OF Hymenoptera RESEARCH

Resurrection of *Neocardiochiles* Szépligeti, 1908 (Hymenoptera, Braconidae, Cardiochilinae) with descriptions of five new species from the Neotropical region

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Abstract

Neocardiochiles Szépligeti, 1908, is a rare Neotropical genus of the subfamily Cardiochilinae Ashmead, 1900. The genus was previously synonymized with *Heteropteron* Brullé, 1846 by Dangerfield et al. (1999). In this study, we examined multiple specimens of *Heteropteron*-related genera: *Heteropteron*, *Neocardiochiles*, and *Wesmaelella* Spinola, 1851, and resurrect *Neocardiochiles* as a valid genus based on morphological data. As a result, five new species, *N. alexeyi* Kang, **sp. nov.** from Ecuador, *N. franki* Kang, **sp. nov.** from Costa Rica, *N. braeti* Kang, **sp. nov.**, *N. chriscarltoni* Kang, **sp. nov.**, and *N. victoriae* Kang, **sp. nov.**, from French Guiana are included as members of *Neocardiochiles* and described based on morphological and molecular data. Additionally, four species previously included in *Heteropteron* are transferred to *Neocardiochiles*: *Neocardiochiles fasciipennis* Szépligeti, 1908, **comb. nov.**, *Neocardiochiles hasegawai* (Dabek & Whitfield, 2020) **comb. nov.**, *Neocardiochiles kidonoi* (Dabek & Whitfield, 2020), **comb. nov.**, and *Neocardiochiles whitfieldi* (Mercado, 2003), **comb. nov.**. Diagnosis of each taxon and both traditional and interactive identification keys to *Neocardiochiles* species are included. Molecular data of *N. alexeyi* **sp. nov.**, *N. chriscarltoni* **sp. nov.**, *N. victoriae* **sp. nov.**, and *N. hasegawaii* (Dabek & Whitfield, 2020), are also provided.

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RESEARCH ARTICLE

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Orientocardiochiles, a new genus of Cardiochilinae (Hymenoptera, Braconidae), with descriptions of two new species from Malaysia and Vietnam

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Abstract

For the first time in 21 years, a new genus of cardiochiline braconid wasp, *Orientocardiochiles* Kang & Long, **gen. nov.** (type species *Orientocardiochiles joeburrowi* Kang, **sp. nov.**), is discovered and described. This genus represents the ninth genus in the Oriental region. Two new species (*O. joeburrowi* Kang, **sp. nov.** and *O. nigrofasciatus* Long, **sp. nov.**) are described and illustrated, and a key to species of the genus, with detailed images, is added. Diagnostic characters of the new genus are analyzed and compared with several other cardiochiline genera to allow the genus to key out properly using an existing generic treatment. The scientific names validated by this paper and morphological data obtained from this project will be utilized and tested in the upcoming genus-level revision of the subfamily based on combined morphological and molecular data.

Keywords

Malaysia, morphology, parasitoid wasp, taxonomy, type species, Vietnam

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Revision of Iranian *Schoenlandella* Cameron, 1905 (Hymenoptera, Braconidae, Cardiochilinae) with descriptions of two new species from Hormozgan province

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Abstract

The Iranian species of the genus *Schoenlandella* Cameron, 1905 are revised based on morphological characters. The current work provides a key to species of Iranian *Schoenlandella* and species descriptions of two new species: *S. angustigena* Kang **sp. nov.** and *S. latigena* Kang **sp. nov.** This work results in increasing the number of Iranian *Schoenlandella* species from one to three species.

Key Words

Old World, parasitoid wasp, taxonomy, Western Palearctic region

Introduction

The Islamic Republic of Iran (Iran) is located in the Western Palearctic region, and 26 Holdridge life zones exist in the country (Sanjerehei 2014). Approximately 40% of the country is in the subtropical latitudinal region and ~80% of the country consists of periarid, semiarid, arid, and superarid life zones (Sanjerehei 2014). One of braconid subfamilies having the highest distribution in arid regions is Cardiochilinae Ashmead, 1900 (Dangerfield et al. 1999). Nine species of Cardiochilinae have been recorded from Iran, including just one species of *Schoenlandella* Cameron, 1905, *S. deserta* (Telenga, 1955) (Gadallah and Ghahari 2019). Among cardiochiline genera, *Schoenlandella* has the most species in arid areas, especially in the Afrotropical and Australian regions. For example, in Egypt, seven species of *Schoenlandella* have been recorded, which account for ~13% of *Schoenlandella* species in the World (Edmardash et al. 2018). Despite the abundance of the members of the genus in other arid countries in the Afrotropical and Western Palearctic regions, no additional new species of *Schoenlandella* from Iran have been recorded.

In several collecting trips by the second author (AA) from 2013 to 2019, a total of forty cardiochiline specimens were collected. These specimens were sent to the first author (IK) and identified to the species-level using Dangerfield et al. (1999), Edmardash et al. (2018), Oltra and Falco (1997), and Telenga (1955). Fifteen specimens collected in Hormozgan province located in the south of Iran were confirmed as two new species of *Schoenlandella* based on morphological data. The characters of these two new species were compared with the characters of paratypes of two close Afrotropical species, *S. testacea* (Kriechbaumer, 1894) and *S. variegata* (Szépligeti, 1913). In the current paper, species descriptions of two new species are included along with images of diagnostic characters. Distribution maps of each species are created and provided.

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RESEARCH ARTICLE

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Two new species and distribution records for the genus *Bohayella* Belokobylskij, 1987 from Costa Rica (Hymenoptera, Braconidae, Cardiochilinae)

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Abstract

Two new species of *Bohayella* Belokobylskij, 1987 from Costa Rica are described: *Bohayella geraldinae* Kang, **sp. nov**. and *Bohayella hansoni* Kang, **sp. nov.** These are new distribution records for the genus in the Neotropical region. In addition, a key to species of the genus *Bohayella* of Costa Rica is presented. The current work elevates the number of species included in *Bohayella* from nine to eleven.

Keywords

Morphology, New World, parasitoid wasp, taxonomy

Introduction

Costa Rica is one of the biodiversity hotspots, and a total estimated hymenopteran fauna in the country is ~ 20,000 species, including ~ 2,000 estimated species of braconid wasps (Gaston et al. 1996). Cardiochilinae is a subfamily of Braconidae,

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RESEARCH ARTICLE

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Bohayella rodrigodiazi sp. nov.: a new species from Ecuador with an updated key to the New World species of *Bohayella* Belokobylskij (Hymenoptera, Braconidae, Cardiochilinae)

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Abstract
The New World species of *Bohayella* Belokobylskij, 1987 are revised based on morphological data, and a new species of the genus from Ecuador is described: *Bohayella rodrigodiazi* Kang, **sp. nov.** This work includes an updated identification key to species of *Bohayella* in the New World along with images of diagnostic characters. The number of recorded *Bohayella* species in the New World is increased from two to three.

Keywords
Melanism, Neotropical region, parasitoid wasp, taxonomy

Introduction

Ecuador has 228 braconid species recorded (Yu et al. 2016), including two members of the subfamily Cardiochilinae Ashmead, 1900 recorded by Fischer (1958) as *Cardiochiles aterrimus* Fischer and *C. purpureus* Fischer. A small genus of

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Three new species of *Retusigaster* Dangerfield, Austin & Whitfield, 1999 (Hymenoptera, Braconidae, Cardiochilinae) with an illustrated key to the New World species

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Abstract

Retusigaster Dangerfield, Austin & Whitfield, 1999 is a genus of the subfamily Cardiochilinae Ashmead, 1900 and exhibits high species richness in the New World. Eight species of the genus were recorded before this work: five species from the Nearctic region, two species from the Neotropical region, and one species from the Palearctic region. In this article, three new species of New World *Retusigaster* are described based on morphological characters: *R. pulawskii* **sp. nov.**; *R. purshi* **sp. nov.**; *R. vanduzeei* **sp. nov.** In addition, potential food sources of the members of *R. arugosus* (Mao, 1949) and *R. purshi* **sp. nov.** are reported, and an illustrated key to the New World species of *Retusigaster* is provided. The number of species of *Retusigaster* in the New World is increased from seven to ten.

Keywords

Gossypium sp., parasitoid wasps, *Purshia mexicana*, taxonomy

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RESEARCH ARTICLE

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Revision of the genus *Schoenlandella* (Hymenoptera, Braconidae, Cardiochilinae) in the New World, with a potential biological control agent for a lepidopteran pest of bitter gourd (*Momordica charantia* L.)

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Abstract
Schoenlandella Cameron, 1905 is the second largest genus of Cardiochilinae. Most members are recorded from the Old World, with a small number of species in the New World. Herein, the New World species of *Schoenlandella* are revised based on morphological data. This work entails a description of a new species: *S. montserratensis* Kang, **sp. nov.** and potential lepidopteran host information of the new species associated with bitter gourds on the Caribbean Island of Montserrat. *Schoenlandella diaphaniae* (Marsh, 1986) and *S. gloriosa* Mercado & Wharton, 2003 are re-described, and a key to species of New World *Schoenlandella* is provided. The taxonomic status of *Schoenlandella* is discussed.

Keywords
Caribbean Islands, Crambidae, melonworm moth, Neotropical region, parasitoid wasp

Introduction

Schoenlandella Cameron, 1905 is the second largest genus of the subfamily Cardiochilinae (Yu et al. 2016). All the members of the genus, which host data are available, are solitary endoparasitoids of exposed-feeding lepidopteran larvae such as

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Resurrection of *Neocardiochiles* Szépligeti, 1908 (Hymenoptera, Braconidae, Cardiochilinae) with descriptions of five new species from the Neotropical region

Ilgoo Kang[1], James B. Whitfield[2], Brittany E. Owens[1], Junyan Chen[1]

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Abstract

Neocardiochiles Szépligeti, 1908, is a rare Neotropical genus of the subfamily Cardiochilinae Ashmead, 1900. The genus was previously synonymized with *Heteropteron* Brullé, 1846 by Dangerfield et al. (1999). In this study, we examined multiple specimens of *Heteropteron*-related genera: *Heteropteron*, *Neocardiochiles*, and *Wesmaelella* Spinola, 1851, and resurrect *Neocardiochiles* as a valid genus based on morphological data. As a result, five new species, *N. alexeyi* Kang, **sp. nov.** from Ecuador, *N. franki* Kang, **sp. nov.** from Costa Rica, *N. braeti* Kang, **sp. nov.**, *N. chriscarltoni* Kang, **sp. nov.**, and *N. victoriae* Kang, **sp. nov.**, from French Guiana are included as members of *Neocardiochiles* and described based on morphological and molecular data. Additionally, four species previously included in *Heteropteron* are transferred to *Neocardiochiles*: *Neocardiochiles fascipennis* Szépligeti, 1908, **comb. nov.**, *Neocardiochiles hasegawai* (Dabek & Whitfield, 2020) **comb. nov.**, *Neocardiochiles kidonoi* (Dabek & Whitfield, 2020), **comb. nov.**, and *Neocardiochiles whitfieldi* (Mercado, 2003), **comb. nov.**. Diagnosis of each taxon and both traditional and interactive identification keys to *Neocardiochiles* species are included. Molecular data of *N. alexeyi* **sp. nov.**, *N. chriscarltoni* **sp. nov.**, *N. victoriae* **sp. nov.**, and *N. hasegawaii* (Dabek & Whitfield, 2020), are also provided.

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VITA

Ilgoo Kang was born in Gyeongju, South Korea. He enjoyed catching the largest cicada species in Korea, *Cryptotympana atrata* (Fabricius, 1775), when he was an elementary school student. After graduating Shilla Middle School and Gyeongju High School, he attended Kyungpook National University (KNU) and pursued a Bachelor of Agriculture in the Department of Applied biology. After serving in Korean military service, Ilgoo joined the systematic entomology lab in the department at KNU and met Dr. Yong Jung Kwon, a prominent hemipteran taxonomist in South Korea, who introduced him to insect taxonomy. With the Korean Government Scholarship Program for Study Overseas, Ilgoo was accepted as a master's student in University of Kentucky and began study on braconid taxonomy under Dr. Michael J. Sharkey, a world-authority of braconid taxonomy. His master's thesis was completed in collaboration with Dr. Daniel H. Janzen, a prominent evolutionary ecologist, as well as his team members of Area de Conservación Guanacaste (ACG) and focused on revision of the species of *Lytopylus* reared at ACG based on morphological, molecular, and host data. In Spring 2018, Ilgoo accepted a graduate research assistantship at Louisiana State University (LSU) and started his Ph.D. in Entomology. During his Ph.D., he began study on cardiochiline braconid wasps based on morphological and molecular data and published seven peer-reviewed articles, one book chapter, and six extension articles. He is currently a doctoral candidate in the Department of Entomology at LSU, planning to graduate Summer 2022. Upon completion of his doctorate, he is planning to continue study of braconid taxonomy either in South Korea or the U.S.