2009

Redescription of *Anovia circumclusa* (Gorham) (Coleoptera: Coccinellidae: Noviini), with First Description of the Egg, Larva, and Pupa, and Notes on Adult Intraspecific Elytral Pattern Variation

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Zootaxa 2112: 25–40 (2009)
www.mapress.com/zootaxa/

Article

ISSN 1175-5326 (print edition)
ZOOTAXA
ISSN 1175-5334 (online edition)

Redescription of *Anovia circumclusa* (Gorham) (Coleoptera: Coccinellidae: Noviini), with first description of the egg, larva, and pupa, and notes on adult intraspecific elytral pattern variation

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Abstract

Anovia circumclusa (Gorham), a neotropical lady beetle, recently was recorded in North America for the first time. Previously, only the adult form of this beneficial predator had been described. This paper provides a redescription of the adult and the first descriptions of the egg, larva, and pupa. Diagnostic characters for the genus and species are given, and intraspecific color variation in *Anovia* adults is discussed.

Key words: ladybird, lady beetle, coccinellid, larva, morphology, taxonomy, scale predator, color variation

Introduction

Members of the charismatic beetle family Coccinellidae are well known for their appealing coloration. In agricultural circles, though, they are equally famous for their efficacy as biological control agents. One of the earliest examples of successful biological control involved a lady beetle from the tribe Noviini: *Rodolia cardinalis* (Mulsant) (Koebele 1892; Olliff 1895). This beetle was imported into the U.S. from Australia in the late 19th century and was instrumental in the protection of California's citrus crops from the cottony cushion scale, *Icerya purchasi* Maskell (Caltagirone and Doutt 1989). Interest in noviines as biocontrol agents has been renewed by the recent discovery of an introduced pest scale in Florida, *Crypticerya genistae* (Hempel) (Hodges 2006). Subsequently, a newly introduced noviine, *Anovia circumclusa* (Gorham) was found feeding on this adventive scale insect (Forrester and Vandenberg 2008). Both predator and prey have been collected from Honduras, Mexico, and Panama, and are apparently native to the Neotropics (Gordon 1972; Gordon 1985; Hodges 2006).

Noviini consists of ~80 described species and three genera: *Anovia* Casey, *Novius* Mulsant, and *Rodolia* Mulsant. Despite the large number of species, little taxonomic work has focused on immature stages. Of those 80 nominal species, only seven have had immature stages described: *Anovia virginalis* (Wickham), *Novius cruentatus* Mulsant, *Rodolia koebelei* Olliff, *R. cardinalis* (Mulsant), *Rodolia concolor* Lewis, *Rodolia fausti* (Weise) and *Rodolia limbata* Motschulsky. A review of literature pertaining to larval Noviini is provided in Table 1. Noviine species are effective biocontrol agents as both larvae and adults, so larval descriptions for the tribe are desirable (Rees *et al.* 1994).

Accepted by A. Cline: 18 Apr. 2009; published: 20 May 2009

TABLE 1. Summary of taxonomic literature on Noviini immature stages, parenthetical letters are defined as follows: e = egg, l = larva, p = pupa.

Taxon	Developmental stage, notes	Reference	Pages
Noviini	(l) diagnosis	Emden van 1949	278
Noviini	(l) diagnosis	Kamiya 1964	86–93
Noviini	(l) key	Kamiya 1966	82–83
Noviini	(p) description, key, illustrations	Phuoc & Stehr 1974	6, 19, 43, 50
Noviini	(l) diagnosis, key	Sasaji 1968	109–110
Noviini	(l) diagnosis, key	Savoiskaya 1973	37, 40
Noviini	(l) description, key	Savoiskaya 1983	144
Noviini	(l, p) description	Ślipiński 2007	141
Noviini	(l, p) description, life history notes	Vandenberg 2002	372
Anovia virginalis	(l) diagnosis	Gordon 1972	25
Anovia virginalis	(l) description, illustration	Rees 1947	118–119
Anovia virginalis	(l) diagnosis, illustration	Rees *et al*. 1994	404, 410
Novius cruentatus	(l) description, illustrations	Klausnitzer & Shulz 1975	359–361
Novius cruentatus	(e, l, p) development, life history	Weise 1887	181–183
Novius cruentatus	(l) description, illustrations, biology	Perris 1862	226–229, pl. 6
Rodolia cardinalis	(e, l, p) development, life history	Balduf 1935	139–146
Rodolia cardinalis	(l) diagnosis	Gordon 1972	25
Rodolia cardinalis	(e, l, p) photographs, life history	Grafton-Cardwell 2002	3
Rodolia cardinalis	(l) diagnosis, illustration	Kamiya 1964	86–93
Rodolia cardinalis	(l) diagnosis	Kamiya 1966	82
Rodolia cardinalis	(e, l, p) description, illustrations	LeSage 1991	485–490
Rodolia cardinalis	(p) description, illustration	Phuoc & Stehr 1974	6, 13
Rodolia cardinalis	(e, l, p) description, illustrations	Priore 1963	131–161
Rodolia cardinalis	(l) description, illustrations	Rees 1947	117–118
Rodolia cardinalis	(l) diagnosis, illustration	Rees *et al*. 1994	404, 410
Rodolia cardinalis	(l) description, illustration	Sasaji 1968	110–111
Rodolia cardinalis	(l) diagnosis, illustration	Savoiskaya 1973	43, 45
Rodolia cardinalis	(l) description, illustration	Savoiskaya 1983	144–148
Rodolia concolor	(l) diagnosis	Kamiya 1966	83
Rodolia concolor	(l) description	Kawaguchi 1935	208
Rodolia concolor	(l) description, illustration	Sasaji 1968	112–113
Rodolia concolor	(l) description, illustration	Savoiskaya 1983	148
Rodolia fausti	(l) diagnosis, illustration	Savoiskaya 1973	43, 45
Rodolia fausti	(l) description, illustration	Savoiskaya 1983	145
Rodolia koebelei	(l) description	Rees 1947	117–118
Rodolia limbata	(l) description, illustration	Sasaji 1968	111–112
Rodolia limbata	(l) diagnosis, illustration	Savoiskaya 1973	43, 45
Rodolia limbata	(l) description, illustration	Savoiskaya 1983	146

Materials and methods

Specimens of all life stages were examined using a Meiji Techno RZ® stereoscopic microscope. The egg was photographed using a Zeiss® ESEM (Environmental Scanning Electron Microscope). Photographs of the pupal and adult habitus were taken with a Microptics® digital imaging system (Photografix®, Inc., Richmond, Virginia) used in conjunction with Combine Z® software. All photographs were edited with Adobe® Photoshop® (Adobe® Systems, Inc., 2003, San Jose, California). Dissections of freshly killed larvae and adults were performed in warm water and 75% ethanol, respectively. All dissections were slide mounted in glycerol. Illustrations were rendered using a camera lucida attached to a Leitz® DMRB compound microscope (Leica® Microsystems, Inc., Bannockburn, Illinois). Line drawings were rendered using Adobe® Illustrator® CS2 (Adobe® Systems, Inc., 2003, San Jose, California). Label data are provided verbatim, with all line breaks, capitalization, and punctuation recorded exactly. Integumental armature follows the terminology of Gage (1920). All immature specimens were obtained from laboratory-reared cultures maintained by USDA, APHIS, Plant Protection and Quarantine, Miami, Florida.

Anovia Casey 1908
(Figs. 1–41)

Anovia Casey, 1908: 408. Leng, 1920: 214. Korschefsky, 1931: 96. Gordon, 1972: 26. (Type species: *Scymnus virginalis* Wickham, by monotypy).

The type species for *Anovia* was originally described as *Scymnus virginalis* Wickham, but subsequent authors questioned the placement in *Scymnus* (Casey 1908). Casey (1908), noting several morphological similarities to both *Rodolia* Mulsant and *Novius* Mulsant, erected *Anovia* to accommodate this species and included all three genera in Exoplectrini. Leng (1920) included *Anovia, Novius,* and *Rodolia* in Noviini for the first time.

Diagnosis. Adults of *Anovia* are diagnosed by the following combination of characters: body convex, subhemispherical dorsum that is widest just posterior to humeral angles (Figs. 17–22); all surfaces including eye facets covered with pale, posteriorly-directed vestiture; eye margin entire, not interrupted by an ocular canthus (Fig. 23); clypeal apex horizontal (Fig. 23); antenna with 8 articles, weakly clubbed (Fig. 25); and tarsi trimerous (Figs. 32–34).

Anovia circumclusa (Gorham)
(Figs. 1–41)

Zenoria circumclusa Gorham, 1899: 262. Korschefsky, 1931: 108. Blackwelder, 1945: 443.
Anovia circumclusa Gordon, 1971: p.1; Gordon, 1972: 27–29. (Type depository: BMNH).

Diagnosis: The larva of this species resembles all other known noviine larvae, but is distinguishable by the presence of many chalazae on the lateral strumae of the abdominal segments (*R. cardinalis* has 2, and *R. koebelei* has 4). *Anovia circumclusa* adults are best recognized by the structure of the male genitalia. In *A. circumclusa*, the basal lobe is slender and does not extend laterally beyond the internal paramere margin, while in all other *Anovia* species the basal lobe is quite broad distally, and overlaps the medial paramere margin. Also, the basal piece is widest basally in *A. circumclusa*, not distally as in *A. virginalis*.

Egg. Length 0.5 mm, width 0.25 mm. Elongate-oval, color bright magenta. Surface granular, often covered with waxy exudate (Fig. 1). Eggs typically oriented horizontally, not placed on end; laid singly or in small clusters on exposed leaf surfaces; often laid on or under prey (Majerus 1994, JAF pers. obs.)

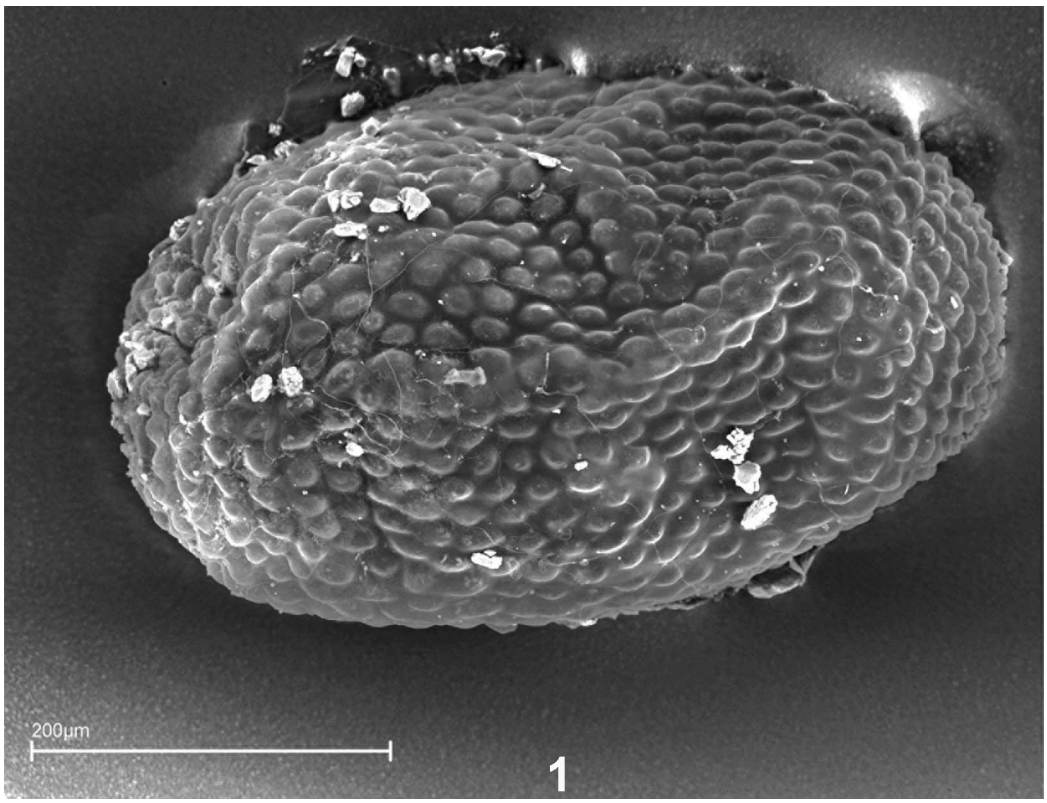


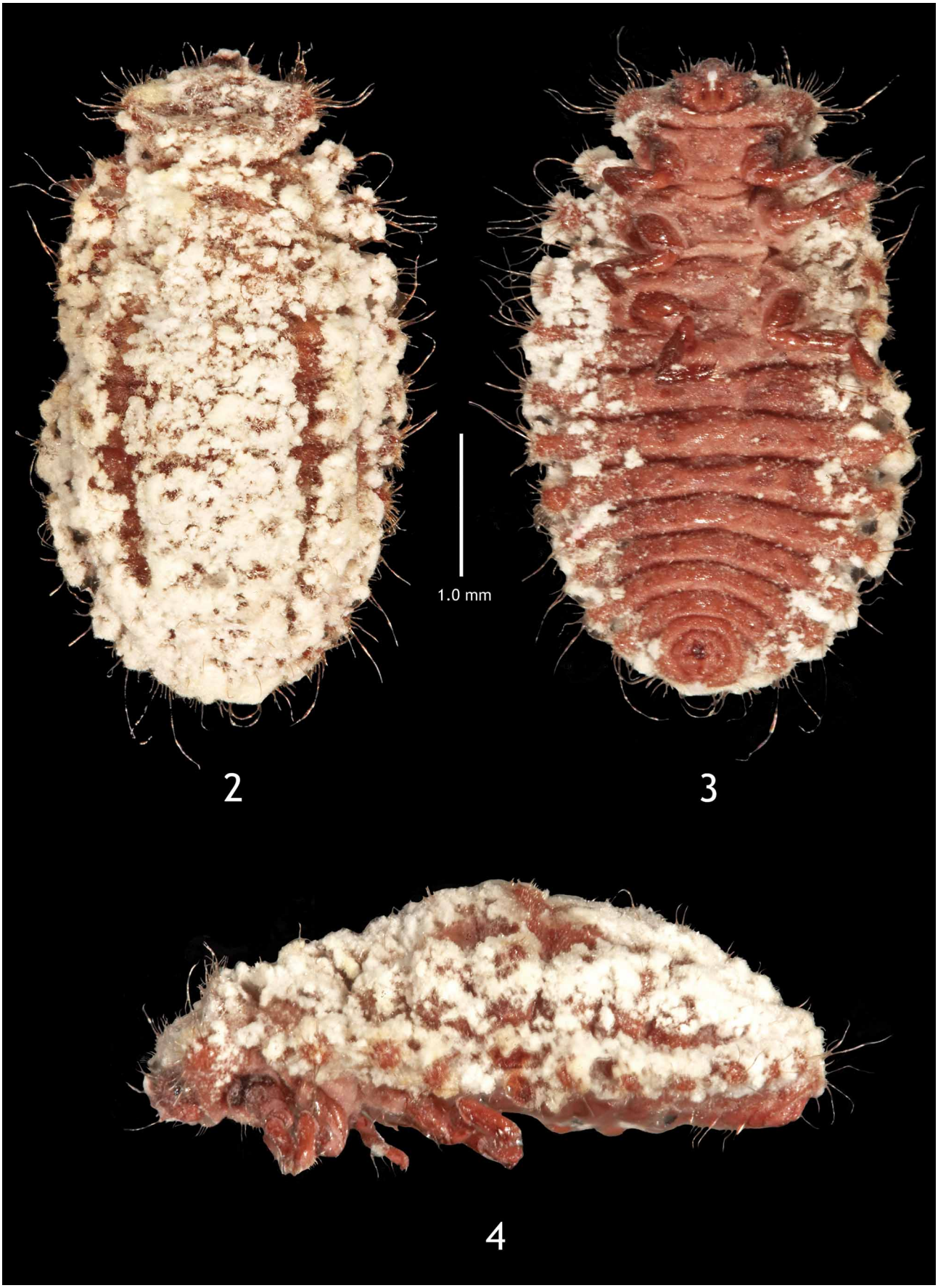
FIGURE 1. *Anovia circumclusa* (Gorham) egg.

Mature Larva. Length 5–7 mm, (Figs. 2–4). Body ovoid, convex, widest at midpoint, laterally arcuate. Color bright magenta with waxy, white exudate. Dorsal surface moderately setose, finely granulate, covered with waxy exudate (Figs. 2–4). Setae pale, erect, simple, length variable.

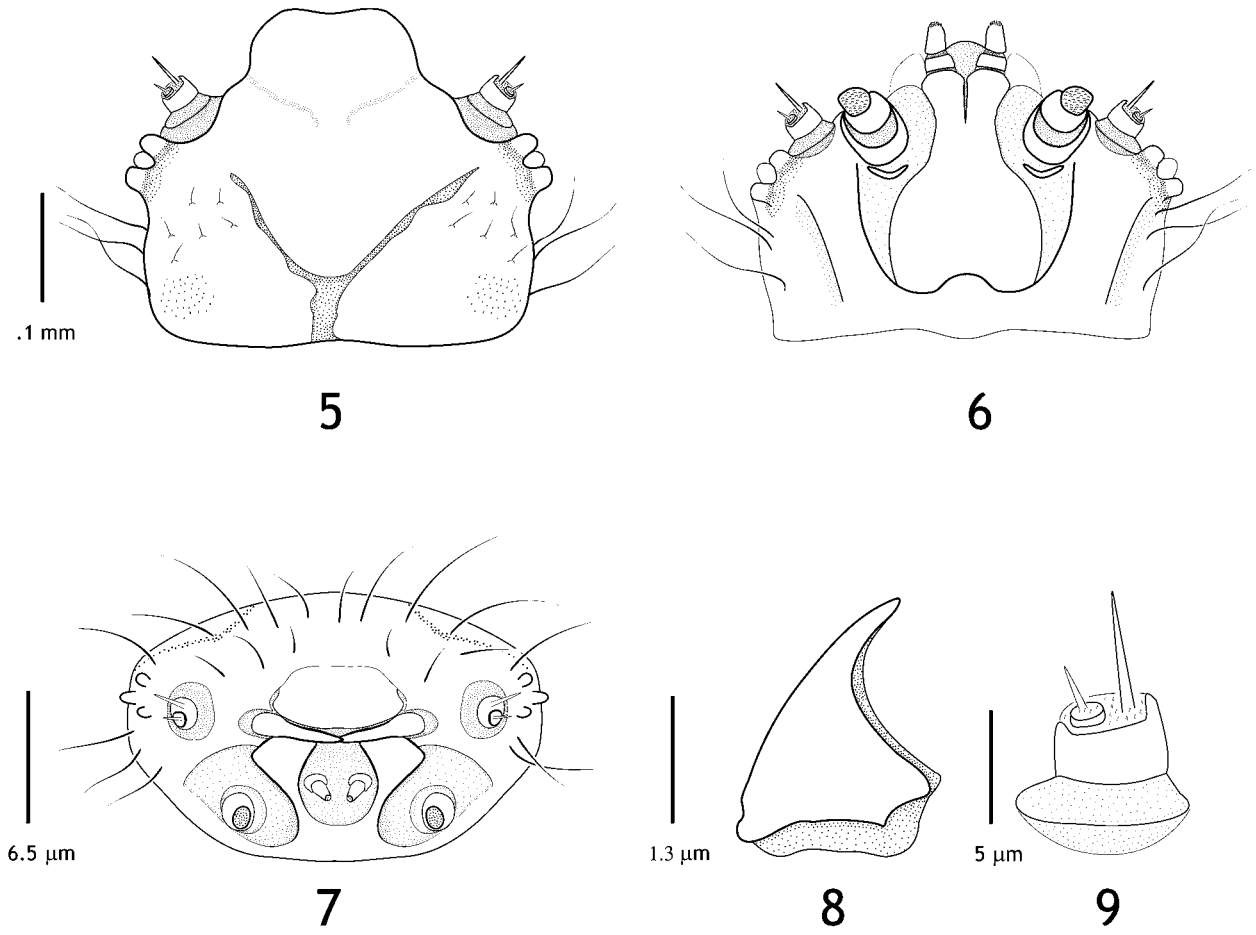
Head (Figs. 5–7) prognathous, darkly pigmented, subquadrate, at least twice as long as wide; dorsal and lateral surfaces with several chalazae; seta-like asperities lateral to frontal arms (Fig. 5). Frontal arms v-shaped; epicranial stem short, about as wide as long; median endocarina absent. Stemmata arranged in triangular pattern, three on each side. Antenna inserted anteromesad to stemmata, 2-segmented (Fig. 9). Antennomere I robust, length ~ 1/3 width; II small, length subequal to width, sensorium longer than antennomere I. Labrum distinct, subrectangular, weakly bilobed apically (Figs. 5, 7). Mandible triangular, enlarged basally, falcate apically (Figs. 7, 8). Maxillolabial complex retracted (Figs. 6, 7). Maxilla with cardo and stipes fused to form solid, sclerotized structure with slender, arm-like extensions passing anteriorly and laterally around labial palpi; maxillary palpomere 2-segmented; I much broader than long; II about as broad as long (Figs. 6, 7). Mala membranous, transverse. Hypopharyngeal bracon present, well-developed.

Thoracic segments each with a pair of sclerotized plates; meso-and metathorax each with a pair of lateral strumae; struma bearing many chalazae (Figs. 2–4). Legs long, robust, strongly sclerotized dorsally, semi-membranous and unpigmented ventrally (Figs. 10–12). Coxa transverse (Fig. 3). Femur robust, almost as broad as long (Figs. 3, 10–12). Tibia elongate, ventral surface distally setose; distal setae flat, clavate (Figs. 10–13). Tarsungulus strongly curved, basal tooth well-developed. Abdomen 10-segmented; segments I–IX with 2 pairs of sclerotized tubercles, 1 pair of chalazate strumae, and 1 pair of annular spiracles; X bearing pygopod (Fig. 3).

Pupa. Length 4.5–5.5 mm, width 2.5 – 3.5 mm, exarate (Figs. 14–16). Dorsal habitus elliptical, convex, partially covered in last larval exuvium, attached by cauda to substrate. Color (excluding exuvium) magenta with pale setae (Fig. 15, 16). Dark, stout, bristle-like setae present on dorsal surface of head, pronotum, and humeral angles (Fig. 15).



FIGURES 2–4. *Anovia circumclusa* (Gorham), mature larva. 2. Habitus, dorsal. 3. Habitus, ventral. 4. Habitus, lateral.



FIGURES 5–9. *Anovia circumclusa* (Gorham), larval head and appendages. 5. Head, dorsal. 6. Head, ventral. 7. Head, anterior. 8. Mandible, left, dorsal . 9. Antenna, left, dorsal.

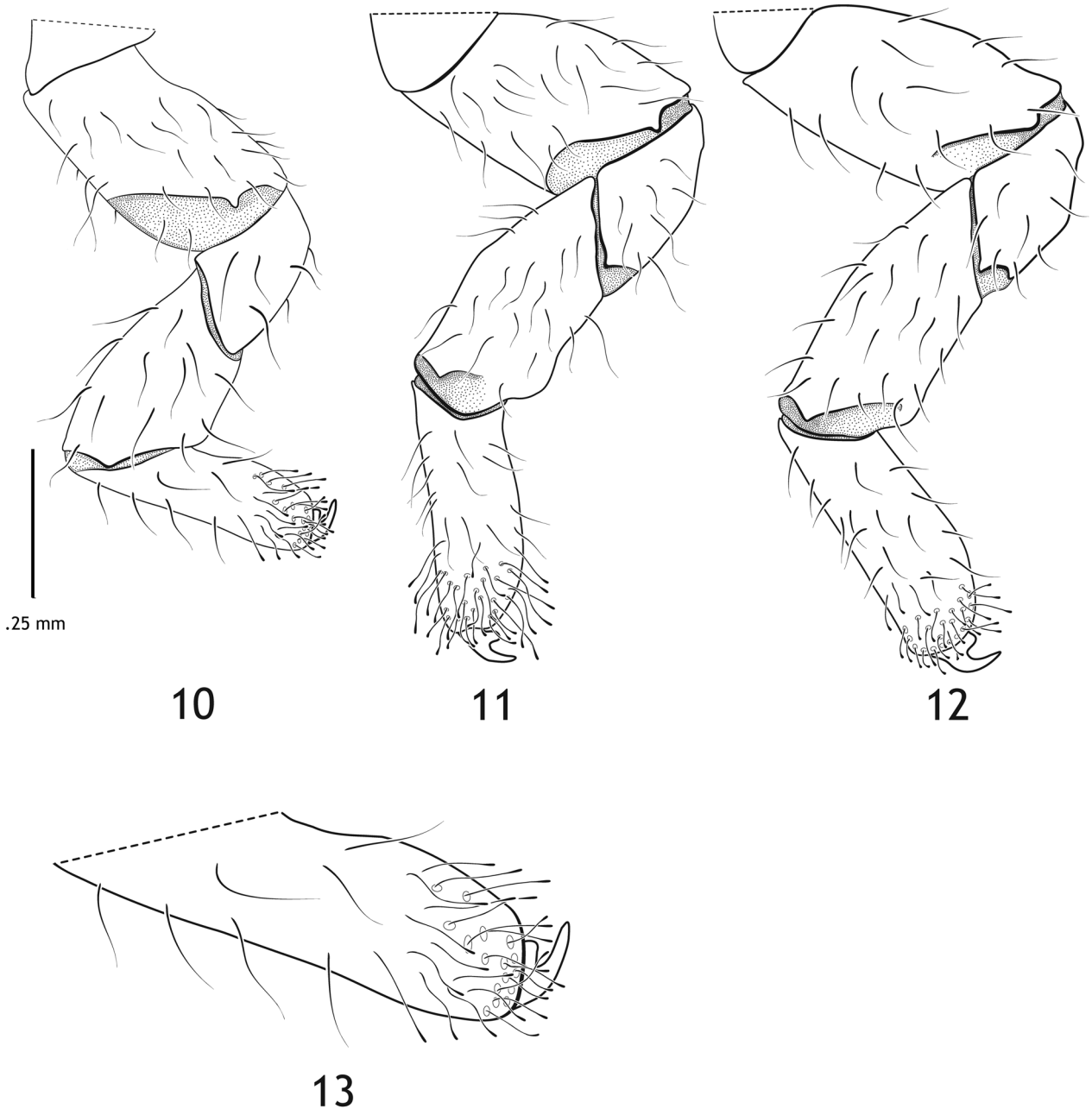
Head length subequal to width. Antenna short, not extending beyond outer margin of eye, club indistinguishable from flagellum. Apical maxillary palpomere strongly securiform (Fig. 16).

Abdomen with 9 ventrites, I and II reduced and hidden beneath metacoxae; dorsal surface of abdomen with paired transverse tubercles on segments I–VIII; anterolateral angles with annular spiracles; IX with bipartite urogomphi.

Adult. Length 4–4.5 mm. Dorsal habitus hemispherical, laterally arcuate, convex; head strongly deflexed, not visible from above; color variable (Figs. 17–22). Vestiture pale, short, moderately dense, posteriorly-directed.

Head width about twice head length; dorsal surface with evenly spaced, small, shallow punctures; ventral surface narrower; postoccipital margin sinuate (Figs. 23, 24). Eyes large, covered entirely by pale, suberect setae. Antennal insertion exposed, anteromesad to inner eye margin. Antenna with 8 articles; antennomere I asymmetrical, laterally expanded; II subglobose; III–V subequal in length and width; VI–VIII forming loose club, VI–VII asymmetrical, expanded medially; VI about as long as IV + V, VII shorter, VIII broadly tapered apically (Fig. 25). Clypeus small, fused to frons (Figs. 23, 24). Frontoclypeal suture absent. Labrum (Fig. 26) emarginate medially, expanded beyond clypeus laterally. Mandible apically bidentate, teeth sickle-shaped, not in same plane, ventral tooth longer than dorsal one; prosthecal fringe well-developed (Fig. 27). Lacinia slender, elongate, apically setose (Fig. 28). Galea broad, elongate, truncate and apically setose. Maxillary palp 3-segmented, palpifer well-developed; palpomere I elongate, about three times as long as basal width, broadest apically, membranous surface exposed; II apically divergent, mesal edge short, membranous surface exposed; III with distal edge almost twice the length of proximal edge, lateral edge twice the length of mesal

one (Fig. 28). Labium narrow, labial palp 2-segmented; palpomeres I and II subequal in size, palpomere II gradually narrowed distally to apical sensory area (Fig. 29).



FIGURES 10–13. *Anovia circumclusa* (Gorham), larval legs. 10. Prothoracic leg, left, dorsal. 11. Mesothoracic leg, left, anterior. 12. Metathoracic leg, left, anterior. 13. Prothoracic tibia, left, anterior.

Pronotum with dorsal surface punctate, moderately setose; anterior angles extending forward just beyond lower margin of eye (Figs. 18, 20, 22); anterior edge horizontal just behind head capsule; posterior edge markedly sinuate, slightly notched at scutellum (Fig. 30). Prosternum narrow; prosternal process abruptly raised, rectangular with margins entire; procoxal cavities slightly transverse, closed internally (Fig. 31).

Scutellum triangular. Meso- and metathorax ventrally flattened, pubescent (Fig. 35). Mesoventrite short, narrowest posteriorly. Metaventrite wider than long, finely punctate. Legs (Figs. 32–34) flattened, broad and stout. Femur deeply grooved ventrally for reception of tibia; groove bicarinate, sharply defined, extending almost entire length of femur. Profemur with anterior groove expanded prior to apex. Tibia slightly widened at

mid-length, ventral surface broader than dorsal, deeply grooved for reception of tarsus; groove bicarinate. Tarsal formula 3-3-3; tarsomeres I and II elongate, lobed ventrally with spongy pubescence; III elongate, cylindrical; male tarsal claw bifid; female tarsal claw with long triangular tooth (Fig. 38).

FIGURES 14–16. *Anovia circumclusa* (Gorham), pupa. 14. Habitus, dorsal, clothed in last larval skin. 15. Habitus, dorsal, last larval skin removed. 16. Habitus, ventral, last larval skin removed.

Elytron subhemispherical to hemispherical, laterally arcuate, finely punctate, non-striate; epipleuron complete to posterior margin, ventral surface moderately rugose. Wing with reduced cantharoid venation, absent in distal half, with strong medial and cubital veins, one anal vein, jugal lobe present. Abdomen with broad, slightly cleft intercoxal process; postcoxal line incomplete to lateral margin; 6 ventrites; I–V rectangular, progressively narrower in width posteriorly; VI narrower, tapering slightly to rounded apex; male with emarginate apex (Fig. 37), female with apex entire. Pygidium subrectangular, setose, broadly rounded apically (Fig. 36).

Male genitalia with phallobase widest anteriorly; basal lobe slender, not extended laterally beyond internal margin of parameres (Figs. 39–41). Sipho as in Fig. 41.

Material examined: see Table 2.

Discussion

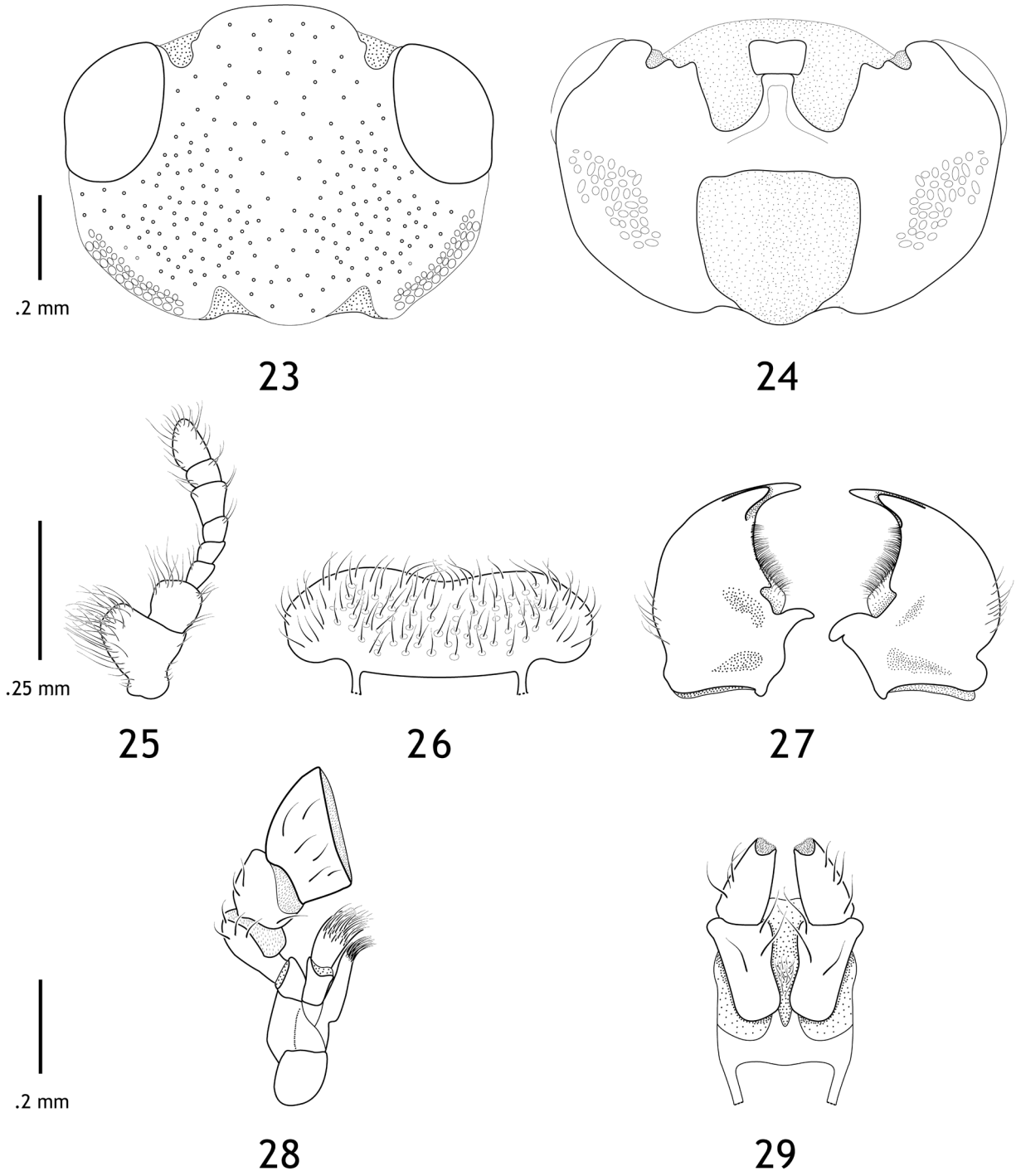
One of the most significant taxonomic questions surrounding Noviini is whether or not the included genera are valid. Gordon (1972; 1985) hinted that *Rodolia* and *Anovia* should be synonymized because they are virtually impossible to separate on the basis of adult morphological characters, and he cited the larval study by Rees (1947) as the only evidence supporting the recognition of two separate genera. Rees's (1947) study was the first and only attempt to define noviine genera based on larval morphology, but unfortunately only one species of *Anovia* was examined. The brief description of *A. virginalis* in that study was used to characterize the larvae for the entire genus. As a result, subsequent authors continued to recognize *Rodolia* and *Anovia* as distinct genera based entirely on the presence (*Rodolia*) or absence (*Anovia*) of larval antennomere II (Gordon 1972; Gordon 1985; Rees *et al.* 1994). Examination of the larva, pupa, and adult of *A. circumclusa* supports its inclusion in Noviini. The larva has the cardo and stipes fused to form slender arms that encompass the

labial palpi, and each abdominal tergum bears two pairs of sclerotized tubercles (Rees 1947, Rees *et al.* 1994). The pupa has dense, fine, pale setae on the apex of the hind wing and bipartite urogomphi on abdominal tergum IX (Phuoc & Stehr 1974). The species is native to South America and the adult has an incomplete postcoxal line: a taxonomic feature that Gordon (1972, 1985) used to differentiate *Anovia* from *Rodolia*. Examination of over 1500 specimens of Noviini by the senior author has demonstrated that this character is not sufficient to separate the genera. The postcoxal line in Noviini is variable, though; some *Rodolia* species also have an incomplete postcoxal line. Furthermore, the larva of *A. circumclusa* lacks the critical feature that Rees (1949) proposed to diagnose the genus, i.e, the two-segmented larval antenna. Thus, given the extreme morphological similarity of both genera, the validity of *Anovia* is more questionable than ever. A phylogenetic analysis, ideally one including both adult and larval characters, is needed to resolve this issue.

TABLE 2. Material examined.

Label 1	Label 2	Label 3	Label 4	#, gender	Depository
La Celba Honduras June 28	Chnodes sp.	FJ Dyer coll.	Anovia circumclusa (Gorham) det. R. Gordon	1, male	USNM
Tampico Mex 612	EA Schwarz Collector		Anovia circumclusa (Gorham) det. R. Gordon	2, male	USNM
Tampico Mex 2212	EA Schwarz Collector		Anovia circumclusa (Gorham) det. R. Gordon	1, female	USNM
Tampico Mex 1412	EA Schwarz Collector		Anovia circumclusa (Gorham) det. R. Gordon	1, female	USNM
Tegucigalpa Hond	June 23, 18	FJ Dyer coll.	Anovia circumclusa (Gorham) det. R. Gordon	1, male	USNM
Tegucigalpa Honduras VI. 12. 18	F. J. Dyer, Col. No. 40425	Anovia circumclusa (Gorham) det. R. Gordon		1, male	USNM
Tegucigalpa Honduras IV. 27. 18	F. J. Dyer, Col. No. 41319 41430	Anovia circumclusa (Gorham) det. R. Gordon		1, male 1, female	USNM
FLORIDA: Miami-Dade Co.	Miami S30 T53 R42	13-IX-2007 coll. O. Garcia	on *Quercus virginiana* [Fagaceae]. A *Diomus roseicollis* was in the same collection]	1, male	FSCA
Port Everglades, Fort Lauderdale, on leguminous weeds infested with *Icerya genistae*				1, male	USNM

FIGURES 17–22. *Anovia circumclusa* (Gorham), adult. 17. Habitus, dorsal. 18. Habitus, lateral. 19. Habitus, dorsal. 20. Habitus, lateral. 21. Habitus, dorsal. 22. Habitus, lateral.

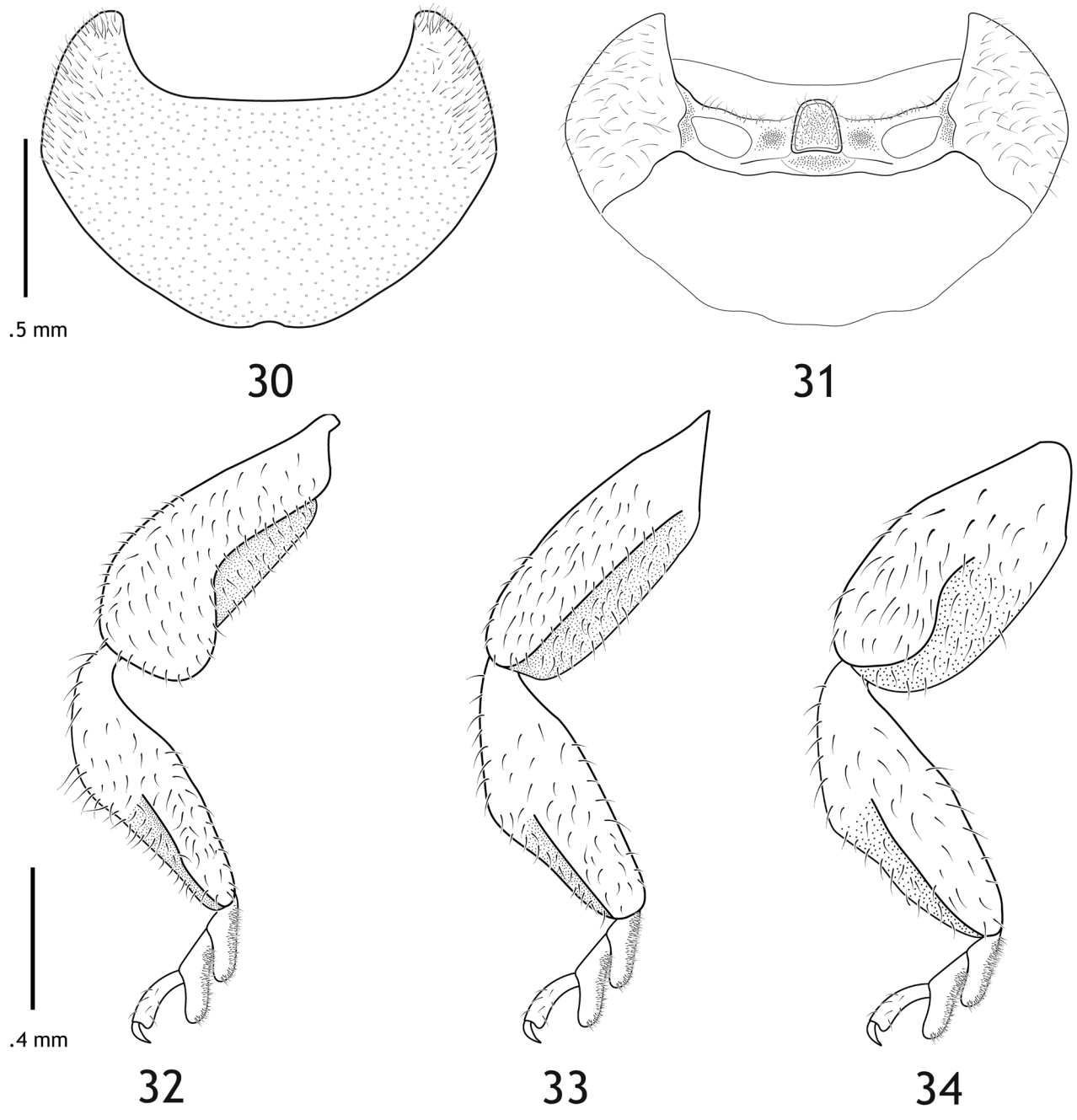


FIGURES 23–29. *Anovia circumclusa* (Gorham), adult head and appendages. (Note: setae and eye facets omitted for clarity.) 23. Head, dorsal. 24. Head, ventral. 25. Antenna, left, dorsal. 26. Labrum, dorsal. 27. Mandibles, dorsal. 28. Maxilla, left, dorsal. 29. Labium, ventral.

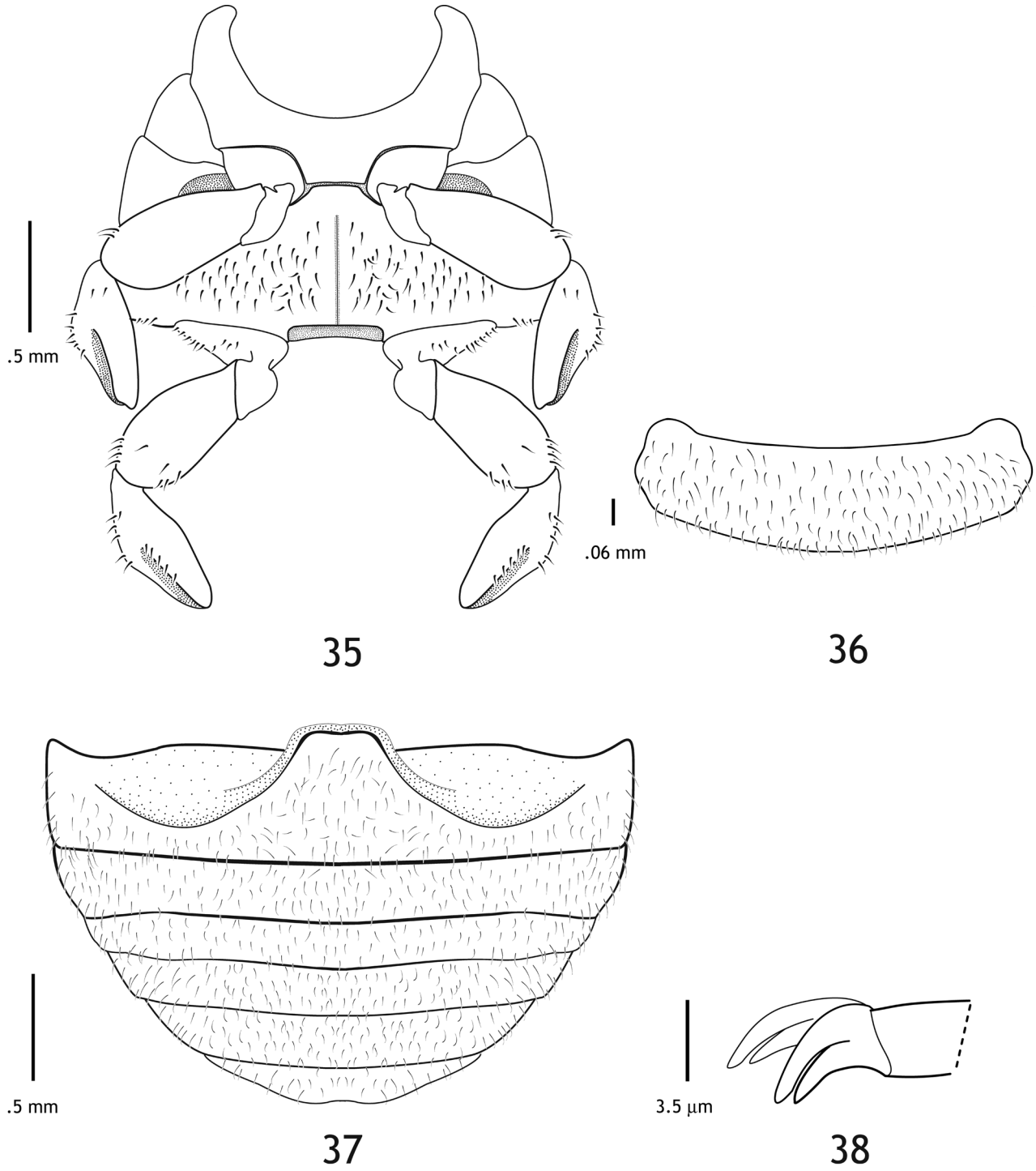
Noviine larvae are very difficult to identify in the field. Besides their overall similarity, all noviine larvae are covered with powdery, granular wax that obscures most aspects of their anatomy (Figs. 2–4). The wax threads apparently are secreted from the bases of hollow, pointed spicules on the dorsal surface of the larval body; the spicules are used for support as the wax thread is secreted upward (Pope 1979).

Another taxonomic problem encountered with adult noviines, and coccinellids in general, is intraspecific

color variation. Gordon (1972) noted extensive elytral pattern variation within *Anovia* species, but identification keys for the genus still rely heavily on color patterns. Examination of the majority of the world's holdings of Noviini by the senior author confirmed that coloration is not a reliable feature for diagnosing any species in the tribe, including members of *Anovia*. When representatives of *A. circumclusa* are viewed dorsally side-by-side, a smooth coloration gradient becomes apparent. The elytral pattern ranges from carmine red with a discrete black ring (Figs. 17, 18) to almost entirely black (Figs. 21, 22). Intermediate forms have orange elytra with a broad, vaguely defined dark area laterally and posteriorly (Figs. 19, 20). A similar gradation in elytral color patterns occurs in *A. punica.*



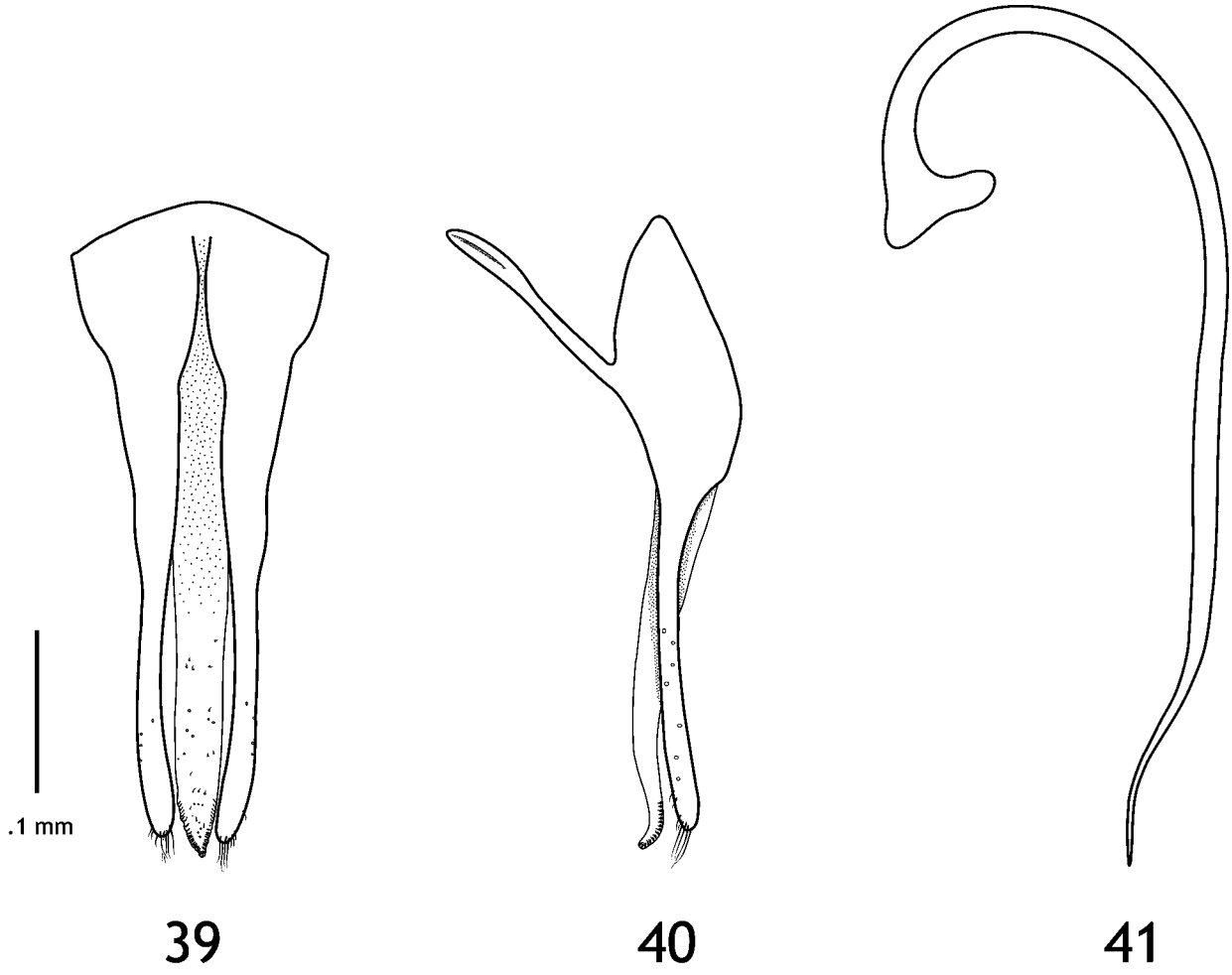
FIGURES 30–34. *Anovia circumclusa* (Gorham), adult prothorax and appendages. 30. Pronotum, dorsal. 31. Prosternum, ventral. 32. Prothoracic leg, left, anterior. 33. Mesothoracic leg, left, anterior. 34. Metathoracic leg, left, anterior.



FIGURES 35–38. *Anovia circumclusa* (Gorham), adult pterothorax, abdomen, and appendages. 35. Pterothorax, ventral. 36. Pygidium, dorsal. 37. Abdomen, ventral. 38. .Metathoracic tarsal claw of female, left, posterior.

A number of factors contribute to the wide array of elytral color patterns associated with Coccinellidae. Much of the variation (number of spots, spot position, spot size and shape) is genetic; however, there are other factors that are known to affect coloration (Majerus 1994; Honěk 1996). Honěk (1996) provided a review of temporal and geographic variability in lady beetles, noting that light-colored populations tend to occur in arid regions while darker pigmentation is more common in humid areas. Gordon (1972) noted that in the neotropical *Zenoria*, elytral pattern differences can sometimes be linked to specimen maturity; however, neither habitat nor age seems correlated with the color variation observed in Noviini. The familiar aposematic

colors of many coccinellids often advertise chemical defenses (Bezzerides *et al*. 2007; King & Meinwald 1996), but it is unknown whether this is true for Noviini.



FIGURES 39–41. *Anovia circumclusa* (Gorham), adult male genitalia, redrawn with permission from *Zootaxa* 1720: 66–68 (Forrester & Vandenberg 2008). 39. Aedeagus, dorsal. 40. Aedeagus, lateral. 41. Sipho, lateral.

Acknowledgments

We thank Divina Amalin and Amy Roda, USDA, APHIS, Plant Protection and Quarantine, and Michael Thomas, FSCA, for kindly sending Florida-collected specimens of *A. circumclusa*. We especially thank Divina Amalin for sending laboratory-reared eggs, pupae, and additional adult specimens. We thank Nathan P. Lord (University of New Mexico) for the ESEM image of the egg. The senior author is grateful to Ralph Holzenthal (University of Minnesota) for valuable instruction in digital illustration. We also thank Dave Nickle (SEL), Al Norrbom (SEL), Adam Ślipiński (CSIRO), and Wioletta Tomaszewska (Muzeum i Instytut Zoologii PAN) for providing thorough reviews of this manuscript. Darren Pollock (ENMU) and an anonymous reviewer also provided helpful comments. This work was supported by Hatch Project GEO 00787 (to J.V. McHugh) and N.S.F. PEET grant DEB-0329115 (to J.V. McHugh, M. F. Whiting, and K. Miller).

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