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ARTICLE

A generic key to the known larval Elmidae (Insecta: Coleoptera) of French Guiana

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Abstract. An identification key is provided for 21 larval types of Elmidae (riffle beetles) known to occur in French Guiana. Not all elmid genera known to occur in French Guiana are known in the larval stage. Nor are all the known larval types assigned to known elmid genera.

Key-Words. Biodiversity; Identification; Immatures; Neotropical; Survey.

INTRODUCTION

More and more political units are conducting surveys of their freshwater invertebrate taxa as a way of assessing in-stream water quality. In these assessments, better and better results depend on using the lowest level of accurate identifications. Generic identifications have become the state-of-the-art for many invertebrates, given the keys that are available (*e.g.,* Dominguez & Fernández, 2009; Hamada *et al.,* 2018), especially for immature stages. However, keys for immature stages are often incomplete in the sense that not all genera are known in the immature stages. And many smaller political units do not have a through survey of their invertebrate fauna upon which to base their identifications. So, more survey work needs to be conducted. For many years, freshwater faunal surveys in French Guiana have been conducted by HYDRECO (Laboratoire Environnement de Petit Saut). Among other products, these surveys resulted in a collection of identified specimens. Additional surveys of adult Elmidae were conducted independently by Pierre Queney from 2003 to 2010 which resulted in a list of the 18 elmid genera known from French Guiana and a key for adult identification at the generic level (Queney, 2012).

Work is ongoing to identify the larval elmids of South America. Manzo & Archangelsky (2008) produced a key to all Elmidae larvae known at the generic level by 2008. But their key only accounted for 56% of known South American genera. This has been followed by descriptions of the larvae of *Gyrelmis* Hinton (González-Córdoba *et al.,* 2018b) and *Stenhelmoides* Grouvelle (González-Córdoba *et al.,* 2018a), and the association of adults and larvae of *Hintonelmis* Spangler using barcoding (Fernandes *et al.,* 2013). One of the major challenges is that undescribed elmid genera (as evidenced by adults) keep being found in South America (Barr, 2018). André S. Fernandes *(pers. com.)* reports eight undescribed genera from Brazil alone! And undescribed and unassociated elmid larval types keep being discovered as well. Plus, there is the possibility of intrageneric variation, as has been found in other elmid species (Glaister, 1999; Archangelsky & Brand, 2014), although sometimes what looks like intrageneric variation is a signal of cryptic, undiagnosed genera (Brown, 1977). So there will be much work to be done with South American larval Elmidae for a very long time.

When collecting elmids in the Neotropics, it is common to find larvae that have not yet been associated with an identified adult. This limits information that might be useful for assessing water quality and may give a false impression of elmid diversity. The identification of unknown larvae can sometimes be made by identifying adult genera collected at one site and then matching up known larval identifications with those adults. The remaining adults and larvae can then be associated. This is sometimes hazardous because one cannot always be sure that all adult and larval morphs can be collected at one site. But by doing this at multiple sites, the validity of adult/larval associ-

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ations can be enhanced. Another way larval identifications can be achieved is by rearing larvae to adulthood. Rearing immature stages is useful for establishing both generic and species-level identifications. Final instar larvae can be placed in a sealable plastic container with wet sand and a small stone or piece of wood. If the larva is sufficiently developed, it will burrow under the stone or wood, pupate and transform into an adult within a few weeks. Final instar larvae can be recognized by the presence of spiracular tubercules on the lateral sides of the mesothorax and abdominal segments I-VIII. Alternatively, pupae found in the stream-side environment can be held in the same kind of containers until they transform into adults. The key is to maintain a humid environment so the larvae or pupae do not desiccate. However, it is difficult to find pupae in nature. Specific directions on rearing can be found in White & Jennings (1973), Glaister (1985), and Davis (1986).

A few years ago the first author was asked to produce an identification key for the larval Elmidae of French Guiana, which led to this paper. It is hoped that this key will increase the quality of identifications made by water-quality assessment scientists, and that this key will encourage other workers in French Guiana to pursue further studies with Elmidae. As with other keys, this one should be considered preliminary. It is intended to be used in French Guiana but it might also be useful in neighboring countries.

MATERIAL AND METHODS

An intense survey for both adult and larval elmids was conducted during February 2016 and March 2019, by WDS, Cheryl Barr and Simon Clavier. Concurrently, Axel Cerdan was conducting stream benthic studies in the same area. Both studies yielded specimens for this work. Additionally, the HYDRECO collections were searched for other elmid larvae. Specimens used in this study are deposited in the collections of HYDRECO and Essig Museum of Entomology, University of California.

Abbreviations used in the text include the following: AB = abdominal segment; I-IX = the individual abdominal segments, from one to nine; HYDRECO = Laboratoire Environnement de Petit Saut, BP 823, 97388 Kourou cedex, French Guiana.

Photographs of elmid larvae produced at the California Academy of Sciences (see Acknowledgments) used a Syncroscopy Auto-Montage system. Photographs produced at the EcoFog lab used a Leica dissecting microscope (Z16APO) fitted with a Leica camera (DC450) and Helicon focus-stacking software. Images were manipulated using Photoshop CC (version 14; Adobe Systems, San Jose, CA). All photographs are of larvae collected in French Guiana. Because the photographs are of actual larvae and the characters vary in size, not all characters show in all photographs.

Larval morphology follows that in Manzo & Archangelsky (2008) and Segura *et al.* (2011). The line drawings in Manzo & Archangelsky are particularly helpful.

RESULTS

Twenty-one types of elmid larvae have been collected as of March, 2019. All are included in the key. Five genera known to occur in French Guiana have not had larvae associated with them. They include: *Amazonopsis* Barr, *Pagelmis* Spangler, *Pilielmis* Hinton, *Portelmis* Sanderson and *Tyletelmis* Hinton. Five larvae have yet to be associated with any genus. They were assigned letters. They include: larva V, larva W, larva X, larva Y and larva Z.

Key to the larval Elmidae known from French Guiana

1. Pleural sclerites on AB I-VIII; body strongly flattened dorsoventrally; lateral margins of thoracic and abdominal segments with narrow, falcate extensions (Fig. 1)..... *Phanocerus* Sharp
1′. Pleural sclerites not as above; body cylindrical, subcylindrical or slightly flattened dorsoventrally; lateral margins of thorax and abdomen without narrow, falcate extension 2
2. AB IX with pleural sutures extending to middle; body cylindrical (Fig. 2) ..... *Cylloepus* Erichson
2′. AB IX lacking pleural sutures; body cylindrical, subcylindrical or slightly flattened..... 3
3. AB IX broad, flat, with denticulate lateral margins, tergum with midline row of about six spines (spines may be broken off) (Fig. 3) ..... Larva V
3′. AB IX not as above 4
4. Sensory appendage of second antennomere very long, equal or exceeding length of second antennomere; AB IX 2.5× as long as wide; a line of flat, wide tubercles on each side of midline on mesonotum to AB IX; posterior margins of pronotum to AB VIII with row of stout tubercles; AB I-VIII with slightly expanded sides (Fig. 4)..... *Austrolimnius* Carter & Zeck
4′. Not with the above combination of characters 5
5. Abdominal terga with two pairs of flanges extending above surface (Fig. 5)..... *Neolimnius* Hinton
5′. Abdominal terga lacking flanges extending above surface..... 6
6. Procoxal cavities open..... 7
6′. Procoxal cavities closed..... 13
7. Mesonotum to AB VIII with dorsal, transverse, broad ridge on posterior border; AB I-VII with posterolateral corners projecting posteriorly; abdominal segments lacking pleurites; AB IX pentagonal in cross section (Fig. 6) ..... Larva W
7′. Mesonotum to AB VIII lacking transverse ridge; AB I-VII lacking posterior projections; some abdominal segments with pleurites; AB IX not pentagonal in cross section 8

8. Only AB I with pleurites 9
8′. AB I-VI or I-VII with pleurites 10
9. Lateral sides of AB I-VI extended as quadrate projections; projections laterally denticulate; surfaces not heavily tuberculate; anterior of head lacking blunt, stout setae (Fig. 7) ..... Larva Z
9′. Lateral sides of AB I-VI lacking quadrate projections; all surfaces heavily tuberculate; meso- and metasternite with heavily tuberculate triangular projection between coxae; body cylindrical; anterior of head with numerous blunt, stout setae (Figs. 8-9) ..... *Stenhelmoides* Grouvelle
10. Pleural sclerites present on AB I-VII 11
10′. Pleural sclerites present on AB I-VI 12
11. Body wide, heavily sclerotized, densely pubescent; AB IX, 2.2× as long as wide (Fig. 10) ..... *Potamophilops* Grouvelle
11′. Body slender, not heavily sclerotized, not densely pubescent; AB IX, 5× as long as wide (Fig. 11) ..... *Elachistelmis* Maier
12. Ventral region of prothorax with four sclerites (one anterior pair and one posterolateral pair); body usually curved in "C"; margin of body lacking many stout spines (Fig. 12) ..... *Xenelmis* Hinton
12′. Ventral region of prothorax with seven sclerites (one anterolateral pair, two lateral pair and one central sclerite); body not "C" shaped; margin of body with many stout spines (Fig. 13) ..... *Stegoelmis* Grouvelle
13. Lateral margins of prothorax to AB I overhanging venter of those segments; all surfaces smooth, not tuberculate; body wide anteriorly and tapering posteriorly (Fig. 14) ..... *Gyrelmis* Hinton
13′. Lateral margins of prothorax to AB I not overhanging those segments; surfaces tuberculate; body not wider anteriorly 14
14. AB IX 4× longer than wide 15
14′. AB IX less than 4× longer than wide 16
15. Thorax and abdomen dorsally with tubercles arranged in rows (Fig. 15) ..... *Hexacylloepus* Hinton
15′. Thorax and abdomen with tubercles randomly arranged (Fig. 16) ..... *Neoelmis* Musgrave
16. Dorsum with tubercles; venter of prothorax with several separate sclerites 17
16′. Dorsum lacking tubercles; venter of prothorax with one large sclerite (Fig. 17) 20
17. AB IX with one lateral row of spines on each side (Fig. 17) ..... *Heterelmis* Sharp
17′. AB IX without a lateral row of spines on each side 18
18. Midline of dorsum with a longitudinal row of yellow spots at intersegmental joints; anterior margin of head lacking large tooth between bases of antennae and clypeus (Fig. 18) ..... *Microcylloepus* Hinton
18′. Midline of body lacking dorsal longitudinal row of yellow spots; anterior margin of head with a large tooth on each side, between bases of antennae and clypeus 19
19. Body flattened in cross section; mesothorax and metathorax with 2 pleurites; prothorax with distinct suture between coxal cavities and notum (Fig. 19) ..... *Macrelmis* Motschulsky
19′. Body semicylindrical in cross section; mesothorax and metathorax with 3 pleurites; prothorax lacking suture between coxal cavity and notum (Fig. 20) ..... *Hintonelmis* Spangler
20. Prothorax venter with one large sclerite (Fig. 21) ..... Larva Y
20′. Prothorax with pentagonal prosternum; two pleurites, anterior pleurites meeting at midline, posterior pleurites wrapping around coxal cavities (Fig. 22) ..... Larva X

Characteristics of elmid larvae not associated with a known genus

Larva V (Fig. 3)

Length 3.9 mm. Body semicylindrical; dark brown, with lighter yellow-brown spots beside ecdysal suture, apex of AB IX yellow; surface covered with white tubercles. Head globular, transverse line of long white setae on frons; frontoclypeal apex with short yellow setae. Antennae with sensory appendage of second antennomere equal to length of third antennomere. Labial and maxillary palpi very short. Labrum shiny and smooth. No teeth on margin of head medial to antennae. Ecdysal suture extending from pronotum through AB I. Pronotum in basal half with oval smooth area devoid of tubercles on each side of ecdysal suture; anterior border and anterolateral corners with long white setae; lateral margins serrate. Pronotum to AB VIII with posterior margins with long setae. Mesonotum to AB IX with basal ⅓ to ½ narrower than apical ½ to ⅔, capable of telescoping into preceding segment; lacking white tubercles. Prothorax with three ventral sclerites on each side (1 broad anterior sclerite, 1 very elongate triangular lateral sclerite, 1 posterolateral subtriangulalr sclerite); procoxal cavities open. Meso- and metasternite broad and flat; each with two linear pleurites on each side; meso- and metacoxal cavities open. AB I-V with anterolateral corners with linear sclerotized ridge that meets tooth from preceding segments; posterolateral corners with short tooth. AB I with narrow, linear pleurite. AB II-IX lacking pleurites or pleural sutures. AB IX broad, flat; with spinose lateral ridges; mid-dorsal line of about 6 erect spines (easily broken off); ventral operculum subpentagonal, not reaching sides of segment.

Larva W (Fig. 6)

Length 4.5 mm (mature larva). Body brown; comma-shaped after fixation; well sclerotized, heavily granulate; widest in pronotum and mesonotum. Head with frons flattened and well sclerotized, fitting flush into pronotal opening; remainder of head lightly sclerotized. Antennae with short sensory appendage on second an-

tennomere. Pronotum on each side with five depressions (one broad basal depression, one depression to side of middle area, one depression near anterolateral corner, one elongate depression on anterolateral corners, one small depression on posterolateral corner); middle area broadly raised; posterior border arcuate. Mesonotum with posterior half raised in broad, rounded ridge extending between posterolateral corners; posterolateral

Figures 1-6. Larval habitus (dorsal, lateral, ventral). (1) *Phanocerus* Sharp; (2) *Cylloepus* Erichson; (3) Larva V; (4) *Austrolimnius* Carter & Zeck; (5) *Neolimnius* Hinton; (6) Larva W. Scale bars = 1 mm.

corners of ridge raised into a bump. Metanotum similar except ridge more distinct; slight notch at midline; posterolateral corners slightly produced posteriorly, with serrate margin. AB I-VIII dorsally similar to metanotum except posterolateral corners more strongly produced and extending ventrally; corners with several spines. AB IX 3× as long as wide; with middorsal ridge, two lateral ridges and two ventrolateral ridges, pentagonal in cross sec-

Figures 7-13. Larval habitus. (7) Larva Z, dorsal, lateral, ventral; (8) *Stenhelmoides* Grouvelle, dorsal, lateral, ventral; (9) *Stenhelmoides* Grouvelle, head and thorax, dorsal; (10) *Potamophilops* Grouvelle, dorsal, ventral; (11) *Elachistelmis* Maier, dorsal, lateral; (12) *Xenelmis* Hinton, dorsal, lateral, ventral; (13) *Stegoelmis* Hinton, dorsal, lateral, ventral. Scale bars = 1 mm.

tion. Prosternum with anterior pleurites serrate anteriorly, broadly meeting at midline; lateral pleurite very elongate, on inside of heavy tergopleural ridge; coxal cavities open. Intersegmental area with very short but wide, sclerotized fold extending from side to side. Mesosternum short, very broad; very small, tooth-like projection between coxae; coxal cavities open. Intersegmental sclerotized fold present. AB I sternum broadly rectangular;

Figures 14-19. Larval habitus (dorsal, lateral, ventral). (14) *Gyrelmis* Hinton; (15) *Hexacylloepus* Hinton; (16) *Neoelmis* Musgrave; (17) *Heterelmis* Sharp; (18) *Microcylloepus* Hinton; (19) *Macrelmis* Motschulsky. Scale bars = 1 mm.

carina on midline; posterolateral corners produced into ventrally and posteriorly directed tooth, tooth well sclerotized, with serrate margin. AB II-VIII sterna similar except with no carina on midline. AB IX with ventrolateral ridges serrate; short, ventral operculum. Abdominal segments without pleurites.

Figures 20-22. Larval habitus (dorsal, lateral, ventral). (20) *Hintonelmis* Spangler; (21) Larva Y; (22) Larva X. Scale bars = 1 mm.

Larva X (Fig. 22)

Length 3.8 mm; width 0.4 mm. Body color yellow; prothorax to AB VIII with basal brown ring; AB IX brown apically. Body semicylindrical; dorsum lacking tubercles. AB IX twice as long as wide; widest just after base; apex with two very small blunt spines with wide flat border between spines; equilaterally triangular in cross-section; well-developed flat-topped middorsal ridge. Prothorax with broadly pentagonal prosternum; two pleurites, anterior pleurite extending to middle of prothorax; posterior pleurite wrapping around posterior coxal cavity, suture between pleurites angling anteriorly from lateral edge of coxal cavity; procoxal cavities closed. Meso- and metasternite broad, rounded on sides; short triangular projection; two pleurites present; meso- and metacoxal cavities open. Metasternum and AB I with median longitudinal carina in basal ½. AB I-VII with pleurites; pleurite VII triangular.

Larva Y (Fig. 21)

Length of mature larva 4.7 mm; width 1.0 mm. Body flat, tan; head and apical ⅓ of AB IX brown; each side of segments with 1-3 brown spots. Antennae with antennomere 2 sensory appendage equal in length to antennomere 3. Dorsal midline suture from prothorax to AB VII. Tubercles absent on all surfaces. Pronotum widest basally, sides broadly arcuate; anterior and posterior borders straight; anterior and posterior angles rounded. Posterolateral corners of prothorax to AB VIII denticulate. Meso- and metanotum with straight transverse carina at basal ¼; sides arcuate; posterior corners right-angled. AB I-IV similar to metanotum. AB V-VIII similar to AB IV but narrower and posterolateral corners spine-like. AB IX widest at basal ⅙ then converging apically; apex with two acute sines and a broad straight margin between spines. Prothorax venter fused into one sclerite; median suture in posterior ⅔, extending between coxae; procoxal cavities closed; median carina from base to apical ⅓. Meso- and metasternum twice as wide as long; anterior border straight; posterior border V-shaped, extending around coxae and projecting posteriorly; two broad, quadrate pleurites on each side; coxal cavities open. Pleurites on AB I-VII; AB VII triangular, others quadrate. All legs with coxae as long as femura; coxae twice as long as wide; single tarsal claw long and thin.

Larva Z (Fig. 7)

Length 3.7 mm. Body semicylindrical in cross section; brown. Head withdrawn into prothorax; labrum shiny brown; antennae with globular first antennomere, elongate second and third antennomeres, sensory appendage of second antennomere longer than third antennomere. Pro-, meso- and metanota with bare spot on each side of midline; AB I-VIII with dark median spot. Pronotum

to AB VII with lateral margin with line of stout tubercles. Ecdysal suture on pronotum to AB I. Mesonotum to AB VII dorsum with anterior half transversely striate, posterior half tuberculate; lateral edges produced forming quadrate flanges. Mesonotum to AB VI with posterolateral corner spinulate. Lateral margins of body with long silky setae. Prosternum with 2 pleurites on each side, anterior pleurites broad, meeting at midline; lateral pleurites elongate, circling around lateral part of coxae; no prosternum. Meso- and metasternum on each side with 2 pleurites, anterior pleurite longer than posterior pleurite; sternum broad, three times as wide as long. AB I with small triangular pleurite on each side.

DISCUSSION

This study covers 21 larval types of elmid larvae (16 identified to genus and five not) known to occur in French Guiana as of March, 2019. Undoubtedly more types will be discovered, especially as more collecting is done in the southern part of the country and on and around the inselbergs.

Additionally, increased collecting will likely disclose elmid genera that currently are not known to occur in French Guiana but do occur in neighboring countries. Thus the key provided here will be modified and expanded in the future as more collecting is done and barcoding of adults and larvae is accomplished. It should go without saying that just about any identification key for South American elmids (adults or larvae) is preliminary until the elmid fauna is known better (see "Limitations" in Benetti *et al.,* 2018). Also, anyone attempting to identify South American elmids should not make identifications using keys for North American elmids. Doing so will lead to many misidentifications (Sonderman, 2013).

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AUTHOR CONTRIBUTIONS

William D. Shepard collected specimens in the field, identified larvae and wrote the text.

Simon Clavier suggested the topic, arranged collecting expeditions, collected specimens in the field, identified specimens and produced many of the photographs.

Axel Cerdan collected specimens in the field, identified specimens and produced many of the photographs.

DISCLOSURE STATEMENT

No potential conflicts of interest are reported by the authors.

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