

REDESCRIPTION OF *PARACAROPSIS TRAVISI* (BAKER, 1949) (TROMBIDIFORMES: CHEYLETIDAE), WITH RANGE EXPANSION, ADDITIONAL HOST RECORDS, AND REEVALUATION OF CHEYLETID CHAETOTAXY BASED ON THE SEJUGAL FURROW

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ABSTRACT — A lectotype and paralectotype are designated for *Paracaropsis travisi*, which is redescribed and illustrated. Specimens are reported from additional *Laphria* hosts in Michigan and leaf litter in Arkansas. After comparison of Nearctic and Palearctic specimens, the synonymization of *Paracaropsis travisi* (Baker, 1949) and *Paracaropsis strofi* (Samšiniák, 1956) is upheld. We also review the Grandjean System and reevaluate idosomal setal nomenclature in Cheyletidae based on the sejugal furrow.

KEYWORDS — Acari; Acariformes; Prostigmata; Cheyletoidea

INTRODUCTION

Cheyletidae are small (generally 400–700 µm) yellow, orange, or brown mites (Volgin 1969). More than 370 species are known from 74 genera. Many are free-living predators in leaf litter and soil, tree bark, stored food products, and bird, mammal and insect nests, though some are vertebrate and invertebrate parasites or associates (Walter *et al.* 2009). Species found on vegetation or in stored grain can be important predators of crop pests and graminivorous mites (Hughes, 1976; de Moraes *et al.*, 1989).

Volgin (1969) erected *Paracaropsis* for two species, *Acaropsis travisi* Baker, 1949 and *Acaropsis strofi* Samšiniák, 1956, which were collected in Georgia (U.S.A.) and Děčín (Czech Republic) from a spiny lizard (*Sceloporus*) and bee-like robber flies (*Laphria flava*), respectively. Summers and Price

(1970) reillustrated *Paracaropsis travisi* and synonymized *P. strofi* with it without giving explicit reasons.

Previous authors illustrated the dorsum and gnathosoma of *Paracaropsis travisi* only. Improved illustrations of the dorsum and gnathosoma, as well as detailed illustrations of the legs and the first illustration of the venter are provided. Named setae are labeled across all illustrations. In addition, *P. travisi* is reported for the first time from multiple species of *Laphria* (Diptera: Asilidae) in Michigan as well as leaf litter in Arkansas.

MATERIALS AND METHODS

Nearctic, including the lectotype and paralectotype of *Paracaropsis travisi* (Baker, 1949), and Palearctic specimens were examined. The holotype of *P. strofi*

(Samšínák, 1956) could not be located as "[s]ome of Samsinák's slides survive, but many were presumably kept in his private collection. Nobody can trace them now" (Klimov, pers. comm. December 2012). Only Nearctic specimens were measured and reported as future genetic work may resurrect *P. strofi* as a valid species.

All measurements are listed in micrometers: lectotype given, followed by range of Nearctic material in parentheses. Range measurements are composed of the one paralectotype, as well as 19 specimens from Arkansas and Michigan. Palaearctic specimens were excluded from the measurements due to the possibility of *P. strofi* being resurrected in the future. Large stippling indicates unsclerotized arthrodial membrane.

Specimens were mounted in Hoyer's medium and viewed using both phase and differential interference contrast microscopy. Illustrations were made from the lectotype with confirmation of structures on the Arkansas specimen by methods outlined by Fisher and Dowling (2010).

The lectotype and paralectotype are deposited in the National Mite Collection, National Museum of Natural History, Smithsonian Institution, Beltsville, Maryland. The specimen collected in Arkansas is deposited in the Acarology Collection at the University of Arkansas. The specimens collected in Michigan and Russia are deposited in the Museum of Zoology at the University of Michigan.

TERMINOLOGY

An effort was made to implement terminology that is broadly accepted and used across acariform mites, despite conventions among cheyletid workers as some terms used in cheyletid literature are inaccurate or synonymous with other terms used more broadly across acariforms. We therefore follow the suggestions outlined by Fisher *et al.* (2011) and expanded by Skvarla *et al.* (2014), with some modifications, which are outlined below.

Gnathosoma — Infracapitulum and subcapitulum are synonymous (Evans, 1992; Dunlop, 2000; Jesionowska, 2003; Walter, 2005; Smit and Alberti,

2010), with infracapitulum being historically favored by cheyletoid workers (e.g., Swift, 1996; Di Palma *et al.*, 2009; Filimonova, 2010). Although both terms have been applied to a variety of taxa, subcapitulum is not only more common, it is the preferred term in several major mite references (e.g., Kethley, 1990; Walter *et al.*, 2009). Therefore, in support of the recent trend to unite terminology across mite taxa, we implement subcapitulum herein despite the historical use of infracapitulum with Chyletidae.

Hypostome has sometimes been used synonymously with subcapitulum, however it more accurately refers to the area of the subcapitulum anterior to the oral opening and not to the entire structure (Evans, 1992; Krantz, 2009).

Within Cheyletidae, two pairs of relatively long anterior gnathosomal setae have historically been referred to as adoral setae (*ao1-2*) (e.g., Goff, 1982; Bochkov and Klimov, 2005; Xia *et al.*, 2011). Di Palma *et al.* (2009), however, identified two pairs of minute setae at the anterior tip of the gnathosoma as the adoral setae. These minute setae are present in *Paracaropsis travisi* and are therefore identified as adoral setae. The homologies of the setae previously identified as *ao1-2* and the subcapitular setae previously identified as *n* are unknown. We therefore refer to them by position: dorsal subcapitular setae (*ds*, = *ao2* of previous authors), ventral subcapitular setae 1 (*vs1*, = *ao1* of previous authors), and ventral subcapitular setae 2 (*vs2*, = *n* of previous authors).

Idiosoma — Terminology for idiosomal structures (*i.e.*, setae and plates) across Acariformes has been heavily debated and remains contentious. The dominant system used by most acarologists is called the Grandjean System, but this system is contested. In general, we follow Grandjean (1939, 1944) as implemented by Kethley (1990) for dorsal setae, but with significant modifications discussed below.

The Grandjean System — Based upon his studies in comparative arachnology, van der Hammen (1963) hypothesized that the acariform body comprised 14-17 body segments (6 prosomal and 8-11 opisthosomal); he also proposed that the opisthosoma had overgrown the metapodosoma dorsally.

Building upon van der Hammen's ideas, Grandjean (1970) proposed that the propodosoma is also overtaken dorso-anteriorly by an outgrowth of the gnathosoma, which he termed 'aspidosoma'. Under this hypothesis, the opisthosoma contains ten segments and begins immediately posterior to the sejugal furrow with the first segment 'C'. Dorsal setae are named according to their corresponding segment, so that the setae on segment C are named *c1*, *c2*, *c3*, etc. Grandjean especially applied his hypothesis to Oribatida, although it was later adapted to Caeculidae (Coineau, 1974), and currently it has gained popularity across disparate acariform taxa (e.g., Erythraeidae: Makol, 2010; Penthalodidae: Jesionowska, 2010; Tydeidae: Kazmierski, 2008). Weigmann (2001) pointed out that there is no evidence for such overgrowths of the gnathosoma and opisthosoma, and instead argued for reimplementation of Grandjean's previous systems (since 1934) that acknowledged the dorsal appearance of the podosoma and therefore identified the first two segments posterior to the sejugal furrow as metapodosomal. Recent studies by Barnett and Thomas (2012, 2013) investigating the embryology of the oribatid *Archegozetes longisetosus* Aoki, 1965 further call into question the Grandjean System. Those studies demonstrate the opisthosoma of *A. longisetosus* comprises only two segments (not 10), firmly refuting van der Hammen's (1963) segmentation hypothesis and therefore Grandjean's (1970) amendments. Unfortunately, their investigations are as yet unable to determine what happens to the podosoma dorsally during development, and therefore cannot currently address terminology of dorsal setae.

Ultimately, the matter will be resolved only after detailed investigation into the developmental biology of a number of disparately related acariforms. Therefore, it has been suggested (Fisher *et al.*, 2011) that until that point, hypothesis-dependent terminology (*i.e.*, 'aspidosoma' and 'opisthosoma') should be avoided in favor of hypothesis-independent terminology. Thus, Fisher *et al.* (2011) suggested re-implementing the historically favored 'hysterosoma' (body posterior to the sejugal furrow) and proposed increasing the use of

'proterosoma' (body anterior to the sejugal furrow), even though the latter is more inclusive than necessary (*i.e.*, 'proterosoma' includes the gnathosoma). Since then, the sejugal furrow has been recognized as a key synapomorphy uniting acariform mites with camel spiders (Solifugae) into a clade called Poecilophysidea (Dunlop *et al.*, 2012), which is supported by large molecular datasets (Dabert *et al.*, 2010; Pepato *et al.*, 2010) and characteristics of the reproductive system (Alberti 1980a, b, 2000; Alberti and Peretti, 2002; Klann *et al.* 2009). Therefore, as noted by Skvarla *et al.* (2014), terminology focused on the sejugal furrow (*i.e.*, 'proterosoma' and 'hysterosoma') is no longer hypothesis-independent, but is based on well-supported hypotheses about acariform relationships. Therefore, we continue with the suggestion of Fisher *et al.* (2011), with the modified rationale of Skvarla *et al.* (2014), and herein use 'proterosoma' when referring to the dorsal idiosoma anterior to the sejugal furrow and 'hysterosoma' when referring to the dorsal idiosoma posterior to the sejugal furrow.

'Prosoma' (podosoma + gnathosoma) has been incorrectly used by some cheyletid workers (e.g., Volgin 1969) to refer to the body anterior of the sejugal furrow, thus failing to include the metapodosoma. Therefore, 'prosoma' is not a viable alternative for this discussion.

Cheyletidae chaetotaxy - hysterosoma — Many cheyletid authors have also adopted the Grandjean System for idiosomal setae. However, setae on segment C (*i.e.*, *c1* and *c2*) are consistently identified as anterior to an obvious fold between Leg II and Leg III (e.g., Kethley, 1990; Bochkov *et al.*, 2006; Xia *et al.*, 2011). It is possible that such authors are proposing the dorsal fold is not the sejugal furrow, but we have not found evidence of this discussion. Under the Grandjean System, segment C is defined as the first opisthosomal segment, which is immediately posterior to the sejugal furrow dorsally. This change is additionally supported by evaluation of *h2*, which is a ventral element occurring near cupule *ih* across acariforms. Previous implementation of the Grandjean System within Cheyletidae placed *h2* dorsally and distant from *ih*. By moving the C-setae posteriorly, we propose only *h1* is present dorsally and *h2*

is absent, which is supported by no accompanying seta to cupule *ih*.

Herein, we make the following terminological suggestions with regard to the hysterosoma. First, until hypotheses of cheyletid body organization confirm the presence of a non-sejugal dorsal furrow, we identify the sejugal furrow in Cheyletidae as the primary fold visible dorsally, and therefore reject the use of C-segment terminology anterior to this furrow. Second, given the widespread use of the Grandjean System in Acariformes, regardless of the legitimacy of hypotheses therein, we see no need to implement new terminology for idiosomal setae at this time. Furthermore, we suspect these setae are homologous across acariforms, hence we do not endorse alternate systems such as Fain (1979), and continue with *c1*, *c2*, *d1*, *e1*, etc. In summary, we identify setae immediately posterior to the sejugal furrow as C-setae (instead of D-setae) and rename hysterosomal setae accordingly.

Cheyletidae chaetotaxy - anterior idiosoma — Although proterosomal terminology among acariforms is also much contested, we follow the system implemented Grandjean's (1939, 1944), which identifies verticals (*vi*, *ve*) and scapulars (*sci*, *sce*). These designations are already widely used among cheyletid workers and we continue them herein. However, our reevaluation of C-setae (see above) renders previously named setae on the posterior proterosoma neotrichous. One pair of these neotrichous setae has been previously identified by Fain (1979) as a humeral seta; however, we refer to this seta as *hm* instead of *h* in order to avoid confusion with the *h* setae of the hysterosoma. Additionally, two pairs of setae previously identified as C-setae (*d1* and *d2* in the Fain system) seemingly represent homologous neotrichy across cheyletoids, although correlaries in other acariforms have not been identified. Because of this homology across cheyletoids, we would prefer to be consistent with their terminology (*i.e.*, continue *d1/2*). However, *d1/2* is already used in reference to hysterosomal setae in the Grandjean System. Therefore, we suggest renaming these setae *x1* and *x2* ("x" refers to unknown homology and is used because of disuse in other terminological systems) until homology assessment can be

made across taxa.

Cheyletidae chaetotaxy - legs — We follow Grandjean's system (*e.g.*, 1935, 1942a, b, 1946, 1958, 1961) as reviewed by Norton (1977) for leg setae. Leg solenidia counts are indicated parenthetically next to setal counts.

Paracaropsis VOLGIN 1969

Review — Volgin (1969) erected *Paracaropsis* for two species of *Acaropsis*, viz. *P. travisi* (Baker, 1949) and *P. strofi* (Samšínák, 1956). Summers and Price (1970) redescribed and reillustrated *P. travisi* from the type specimen; they showed that, unlike in the original illustrations, the posterior plate is present and setae *sce*, *c2*, *d1-2*, *e1-2*, and *f1* are on minute platelets. Summers and Price also synonymized *P. strofi* with *P. travisi*; they gave no express reasons for this, though presumably based the synonymization on the presence of the posterior plate and setae on platelets in *P. travisi* and the fact that there were only two species known in the genus.

Paracaropsis travisi (BAKER, 1949) (FIGS. 1-4)

Acaropsis travisi Baker 1949: 313, plate 16, figs. 131-135.

Acaropsis strofi Samšínák 1956: 356, fig. 3.

Paracaropsis strofi (Samšínák) Volgin 1969: 403, fig. 350.

Paracaropsis travisi (Baker) Volgin 1969: 405, figs. 351-353; Summers and Price 1970, 39: fig. 31. Klimov 1997.

Diagnosis — Palp claw with 7-9 teeth. Palp tarsus with 1 comb, 2 sickle-shaped setae; comb with ca. 14 teeth. Eyes present. Proterosomal shield extending onto hysterosoma, capturing *c* seta. Plate bearing no setae present between *d1* and *e1*. Plate bearing *h1-3* present. Dorsal body setae (except *c2*) short, slightly serrate. Setae *c2* long, smooth.

Female (n=21, all Nearctic specimens). Idiosoma 310 (320) long, 160 (210) wide.

Gnathosoma (Figure 1) — Subcapitulum less than half length of idiosoma, 130 (108-133). Surface smooth with ridge-like striations around base

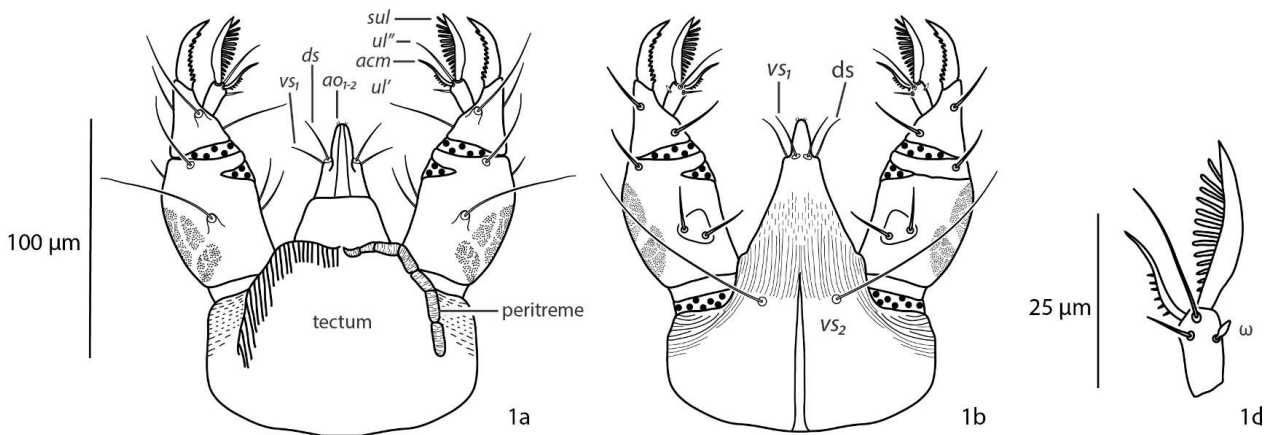


FIGURE 1: *Paracaropsis travisi*, gnathosoma. 1a. Dorsal aspect. Left side illustrates the striations and extent of the tegmen, right side illustrates the peritremes under the tegmen. 1b. Ventral aspect. 1c. Pedipalpal tarsus, ventral. 1a and 1b to same scale.

of palp. Two pairs of minute adoral setae (*ao1-2*), one pair of dorsal setae (*ds*) and two pairs of ventral setae (*vs1-2*) present. Peritremes arched, each branch with 7 segments. **Palp** 113 (95–113) long (excluding claw). Palp femora and genua fused dorsally. Palp femora with patches of sculpturing dorso- and ventrolaterally. Palp femora and genua with 5 filiform setae, 2 dorsal and 3 ventral. Palp tibiae with 3 filiform setae. Palp tibial claw with 7–9 teeth. Palp tarsi longer than wide, with 2 filiform setae, 2 comb-like setae (*sul*, *acm*), and 1 ω solenidion. Setae *sul* 26 long with about 14 teeth, *acm* 22 long with 6 minute teeth. Solenidia flame-shaped. Chelicerae highly modified, styliform.

Dorsum (Figure 2) — Eyes present. Proterosomal shield present, smooth with fine, widely spaced striae. Five pairs of setae (*vi*, *ve*, *sci*, *x1*, *x2*) present on shield; all approximately same length, 18–25. Setae *sce* and *hm* present adjacent to shield on minute platelets in soft integument, 23 (23–28) and 108 (95–125), respectively. Hysterosomal shield present, smooth and not complemented with setae. Setae *c1*, *c2*, *d1*, *d2*, and *e1* present on minute platelets in soft integument, 18 (15–20), 20 (18–23), 15 (15–23), 18 (15–23), and 18 (18–23), respectively. Setae *f1-2* and *h1* present on posterior plate, 20 (20–28), 15 (13–28), and 25 (15–38), respectively. Lyrifissures *ia* and *im* present. Integument striated.

Venter (Figure 3) — Coxal plates I and II separate, but closely approximated; coxal plates III and

IV fused, but retaining part of a dark line indicating a suture. Coxal plates smooth. Coxae I–IV setal formula 2-1-2-2. Setae *1a*, *3a*, *4a*, and three pairs of aggenital setae (*ag1-3*) located on small platelets in soft integument between or slightly posterior to coxae. Two pairs of genital setae (*g1-2*) and three pairs of pseudanal (*ps1-3*) setae present. Lyrifissures *ih* present.

Legs (Figures 4a–d) — I–IV shorter than idiosoma: 200, 1423, 163, and 150, respectively (only lectotype measured). All legs with well-developed claws and empodia. Setal and solenidia count of legs I–IV: trochanters 1-1-2-1, femora 2-2-2-1, genua 2 (1)-2-2-2, tibiae 4(1)-4(1)-4-4, tarsi 9(1)-7(1)-7-7; Trochanteral setae *vTrI*, *vTrII*, *l'TrIII* and *vTrIII* lightly barbed, while *vTrIV* smooth. Femoral setae *dFI*, *dFII*, *dFIII*, *vFIII*, *dFIV* lightly barbed, while *vFI*, and *l'FI* smooth. Genual setae *dGIII*, *vGIII* lightly barbed, while *dFI*, *l'GI*, *dGII*, *l'GII*, *dGIV*, and *vGIV* smooth. Tibial setae *v'TiI*, *v'TiII*, (*v*)*TiIII*, and (*v*)*TiIV* lightly barbed, while *dTiI*, *l''TiI*, *v''TiI*, *dTiII*, *l'TiII*, *v''TiII*, (*l*)*TiIII*, and (*l*)*TiIV* smooth. Tarsal setae *v'TaI*, (*a*)*TaII*, *v'TaII*, (*a*)*TaIII*, *v'TaIII*, (*a*)*TaIV*, and *v'TaIV* lightly barbed, while (*tc*)*TaI*, *itTaI*, (*p*)*TaI*, *a'TaI*, *u'TaI*, (*tc*)*TaII*, (*it*)*TaII*, (*tc*)*TaIII*, (*it*)*TaIII*, (*tc*)*TaIV*, and (*it*)*TaIV* smooth; setae *iTI*, *u'TI*, *a'TI*, (*p*)*TII*, (*u*)*TII*, (*p*)*TIII*, (*u*)*TIII*, (*p*)*TIV*, (*u*)*TIV* absent. We do not identify which iter on tarsus I is present and which is absent as the seta that is present is found on the midline of the segment. We also identify se-

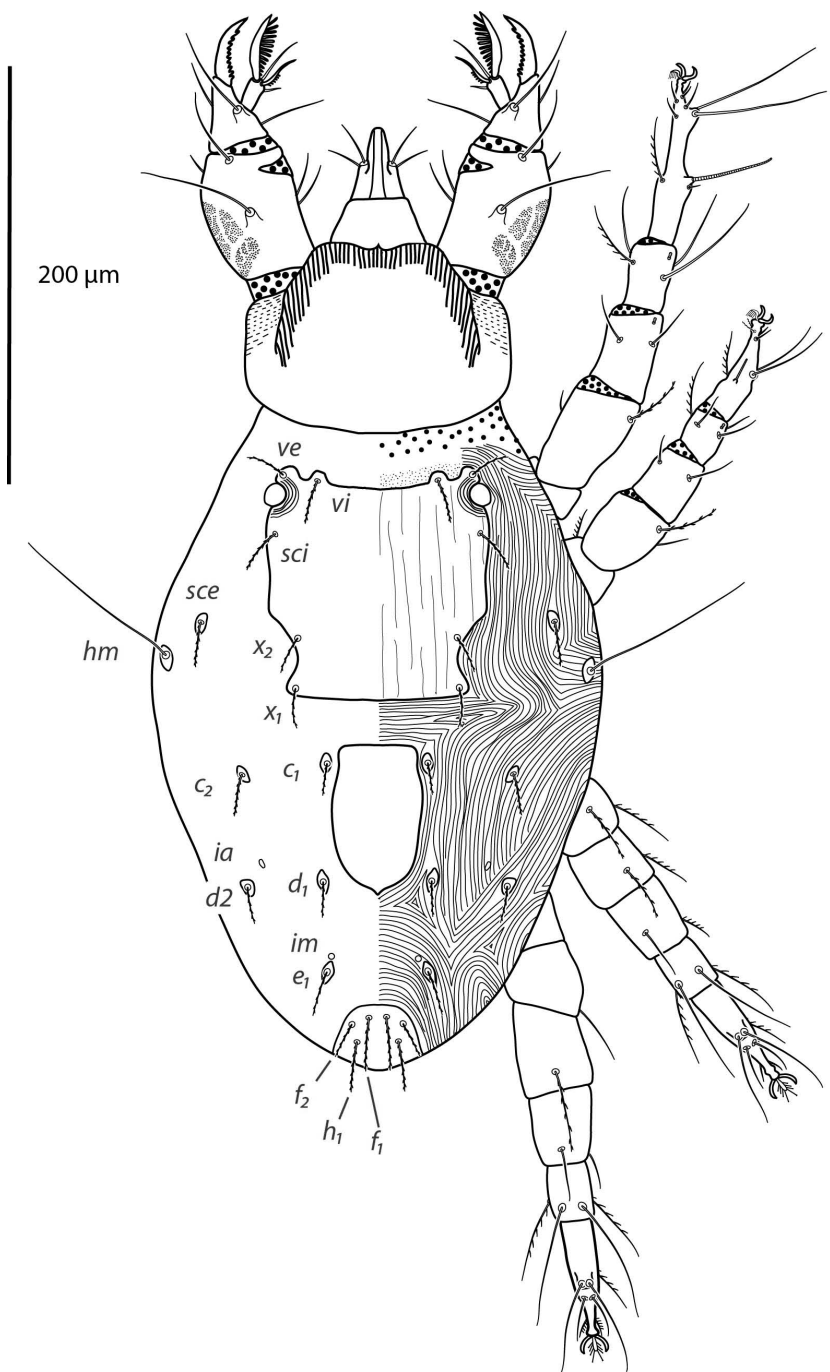


FIGURE 2: *Paracaropsis travisi*, idiosoma, dorsal.

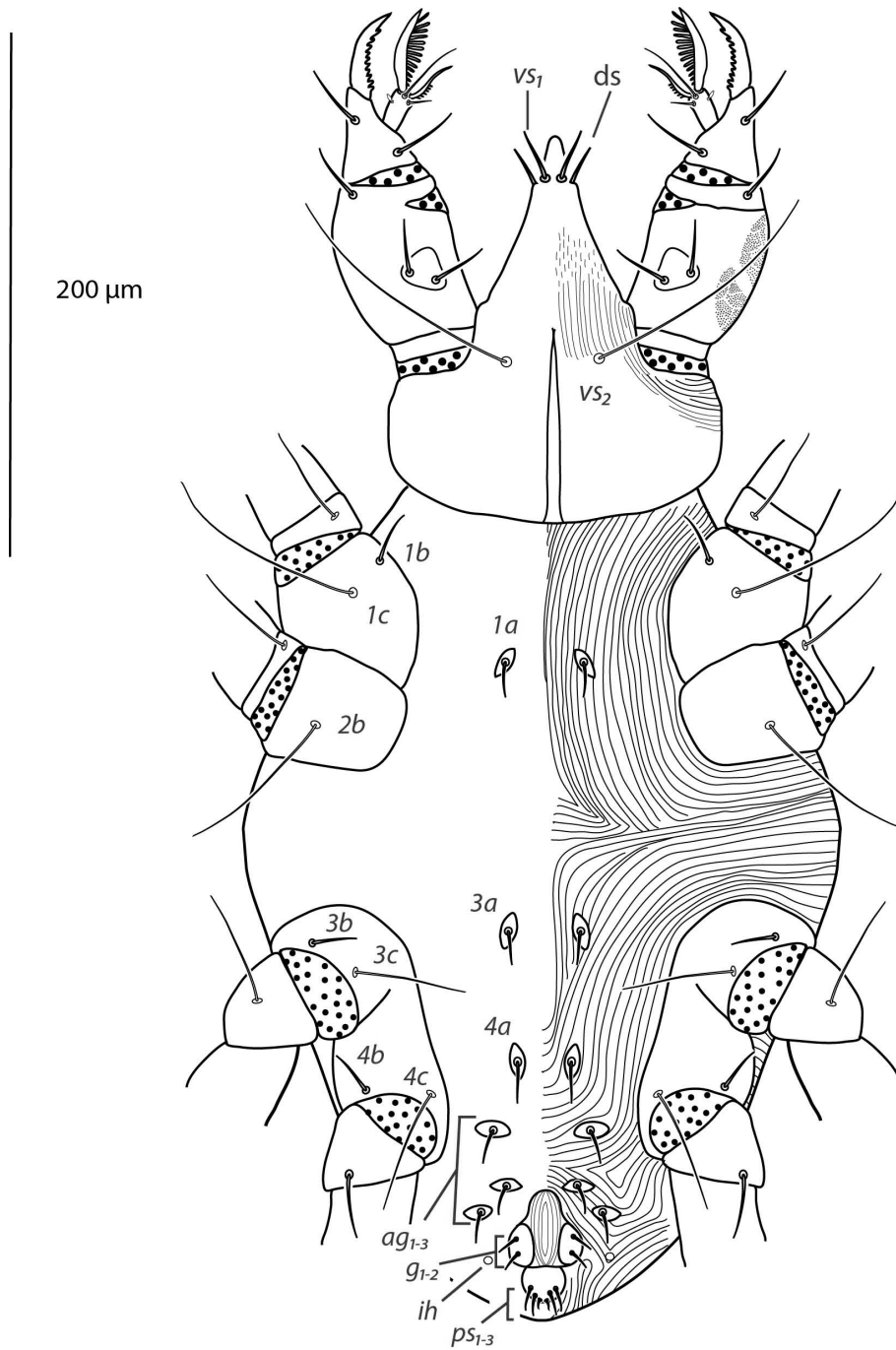


FIGURE 3: *Paracaropsis travisi*, idiosoma, ventral.

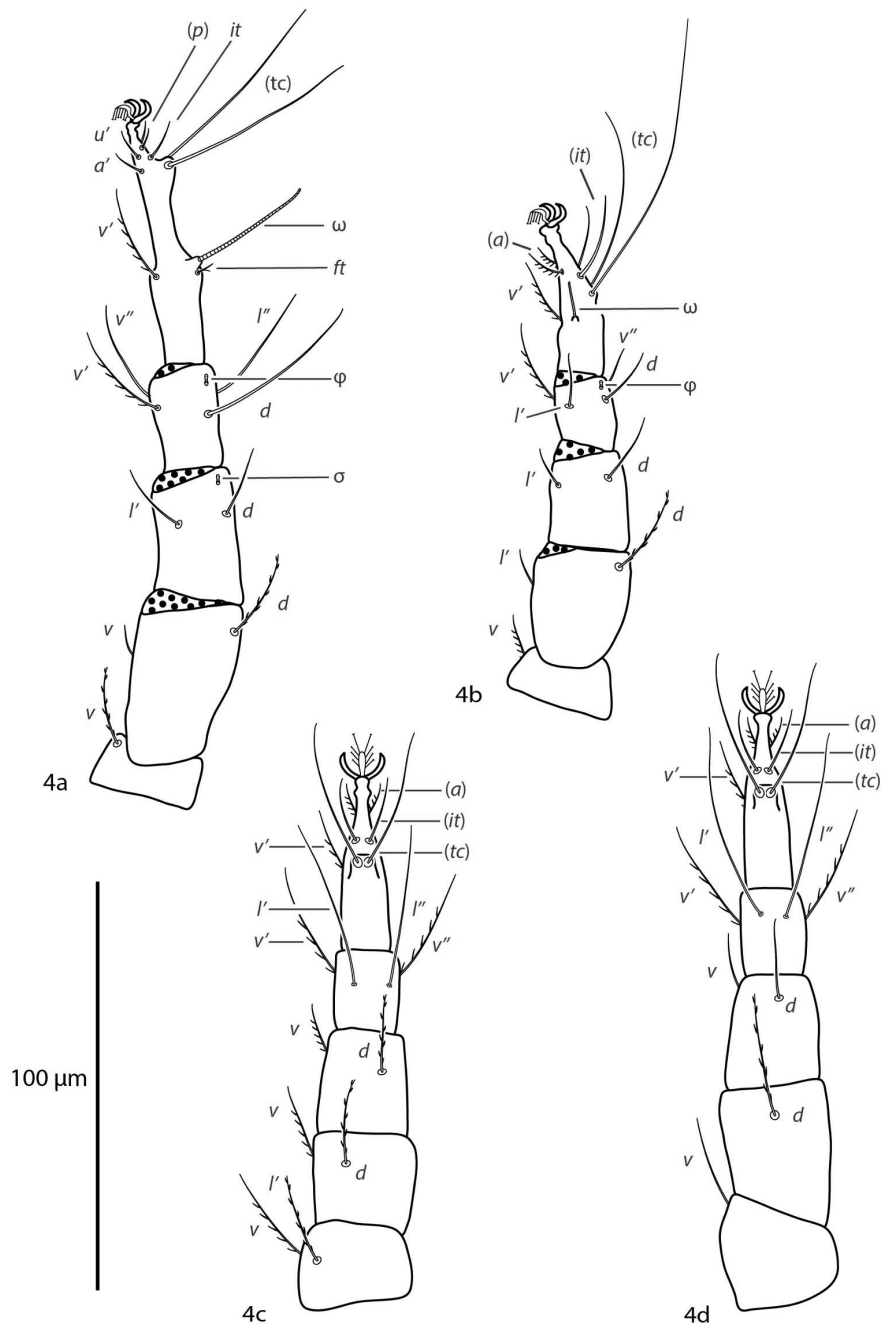


FIGURE 4: *Paracaropsis travisi*, legs. 4a. Leg I, lateral. 4b. Leg II, lateral. 4c. Leg III, dorsal. 4d. Leg IV, dorsal.

tae on legs II–IV as prorals and anterolaterals based on the fact that they occur closer to the tectals than to the tarsal claws; however, it is also possible that they are prorals and unguinals that have moved posteriorly after the loss of the prorals and anterolaterals. Genua solenidia σ I and tibial solenidia φ I and φ II short (3, 5, 4, respectively), tarsal solenidia ω I long (30), and tarsal solenidia ω II of medium length (12); all solenidia dorsal, except tarsal solenidia ω II, which is lateral towards the midline. Empodia with tenent hairs in two parallel rows.

Male and immature stages. Unknown.

DISCUSSION

The holotype and paratype specimens were mounted under the same cover slip, which was not ringed. This resulted in the mounting medium drying and cracking to the point that the specimens were nearly impossible to see. In addition, it was not possible to determine which specimen Baker intended to be the holotype or paratype. The authors have thus remounted the specimens on separate slides and designated the lectotype and paralectotype.

Klimov (1997) stated Palaearctic and Nearctic specimens of *Paracaropsis travisi* sensu Summers & Price, 1970 (= *travisi*+*strofi*) differ by the relative position of the *c* setae: in Palaearctic specimens the distance between these setae is subequal to the length of the setae, while in Nearctic specimens the distance is shorter than the length of the setae. This is true for the holotype of *P. travisi* and examples of Palaearctic *P. travisi* examined; however, additional Nearctic specimens examined exhibit this range of variation within a population collected at a single field site. We therefore recognize the synonymization of *P. strofi* with *P. travisi*.

Paracaropsis travisi has previously been reported from a Palaearctic bee-like robber fly, *Laphria flava*. The records reported here expand the known hosts to five other *Laphria* species, viz. *L. postica*, *L. index*, *L. royalensis*, *L. janus*, and *L. flavicollis*, demonstrating *P. travisi* utilizes a wide range of *Laphria*. Klimov (pers. comm., Feb. 2013) indicated that "*Paracarop-*

sis can be found between the midcoxae of *Laphria*" and that "they are pretty common".

The lectotype and paralectotype may have been collected from *Sceloporus woodi*, a phrynosomatid lizard, in the Nearctic. This is questionable given the prevalence *Paracaropsis* on *Laphria* and because the original slide label has a question mark after *Sceloporus woodi*, suggesting Baker was unsure of some aspect of the information. Additionally, *S. woodi* is not known from Georgia; if the *Paracaropsis* were indeed collected from a spiny lizard, it was likely *S. undulates*, not *S. woodi*. However, given the length of time since the original collection and lack of additional information, until further collections reveal otherwise, definitive conclusions cannot be made.

Finally, one specimen was extracted from leaf litter in Arkansas by the authors using Berlese extraction. Additional specimens have not been found after processing more than 400 gallons of leaf litter from the same and similar localities. Why that specimen was in leaf litter is unknown. However, several species of *Laphria* are abundant at that site (Devil's Den State Park, Ark.), which at least does not refute the hypothesis of an association with *Laphria*. Further investigations into the association of *Paracaropsis* and *Laphria*, including how the mites find their hosts, may shed light onto this.

Material Examined (33 individuals on slides). Female lectotype, USA, Newton Co, Georgia, "on *Sceloporus woodi* ?", Bish. No. 26102, Lot 37 – 24446. 1 September 1937, coll. B. V. Travis • Female paralectotype, same data • 2 females (BMOC #85-0829-8), USA, Michigan, Marquette Co, Huron Mountain Club, "ex Hymenoptera in Malaise trap", 9 July 1985, coll. D. C. L. Gosling • 2 females (BMOC #85-0829-3), same locality, "ex Hymenoptera in Malaise trap", 14 July 1985, coll. D. C. L. Gosling • 2 females (BMOC #86-0622-12), same locality, ex *Laphria postica*, 22 June 1986, coll. B. M. O'Connor • 1 female (BMOC #86-0622-14), same locality, ex malaise trap, 22 June 1986, coll. B. M. O'Connor • 4 females (BMOC #86-0623-7), same locality, ex *Laphria postica*, 23 June 1986, coll. B. M. O'Connor • 2 females (BMOC #86-0623-8), same locality, ex *Laphria postica*, 23 June 1986, coll. B. M. O'Connor • 1 female (BMOC

#86-0623-9), same locality, ex *Laphria index*, coll. B. M. OConnor • 1 female (BMOC #86-0625-3), same locality, ex *Laphria royalensis*, 25 June 1986, coll. B. M. OConnor • 2 females (BMOC #86-0626-28), same locality, ex *Laphria janus*, coll. B. M. OConnor • 1 female (BMOC #86-0626-29), same locality, ex *Laphria flavicollis*, coll. B. M. OConnor • 1 female (APGD 10-0604-001), USA, Arkansas, Washington Co., Devil's Den State Park, ex. leaf litter. 4 June 2010, coll. J. R. Fisher and M. J. Skvarla • 12 females, Russia, Primorskiy Kray, Pavlovka River, South of Shumnyy, ex *Laphria flava* L. (Diptera: Asilidae) between coxae of legs II, 22 July 1987, coll. P. Ler

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