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Two new stygobiotic copepod species from the Tibesti area (Northern Chad) and a re-description of *Pilocamptus schroederi* (van Douwe, 1915)

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Abstract

Between 4th and 18th March 2014, an international group of biologists carried out a hydrobiological expedition to the Ounianga-Tibesti area of northern Chad (Africa). The Tibesti is a desert volcanic area, intersected by the beds of ancient rivers which were active in the Tertiary. In deep canyons there are small water bodies (gueltas/aguelmans), fed by rain and spring water. They are rich in zooplankton, benthos, and even fish, but their groundwater fauna has previously been unknown. Groundwater samples collected in the vicinity of one guelta contained Syncarida, Isopoda, and Copepoda. Among the latter, two new species were recognised, *Haplocyclops* (*H.*) *henrii* **sp. nov.** and *Parastenocaris joi* **sp. nov.**, together with a third species, *Pilocamptus schroederi* (van Douwe, 1915), previously known only from the littoral zone and wet mosses of Lake Victoria. The Tibesti area is thus the third known location of *P. schroederi*. All these species have a Gondwanaland distribution and are probably relicts of the Tertiary fauna, formerly widespread in the Sahara. Together with descriptions of two new species, a detailed re-description of *P. schroederi* is presented, along with remarks on their ecology.

Key words: Copepoda, Cyclopoida, desert, ground water, *Haplocyclops*, Harpacticoda, *Parastenocaris*, Sahara

Introduction

The ten Sahara countries (Algeria, Egypt, Libya, Mali, Morocco, Mauretania, Niger, Sudan, Chad and Tunisia), covering about 12.5 million km², are mostly covered with quartz sand or sandstone, intermixed with volcanic plateaus—the Hoggar Mountains and the Ajjer (Algeria), the Azbine (Niger), the Al Hrūj al Aswad (Libya) and the Tibesti Mountains (Chad) (Times Atlas of the World 1990; Trape 2009). Only one small area (< 0.2 million km²) is covered by patchy limestone areas along the Mediterranean and Atlantic coasts (Juberthie & Decu 2001).

The amount of precipitation in the Sahara is small (normally less than 50 mm y⁻¹), and in some areas even lower (around 5 mm y⁻¹ at Ounianga Kebir, 370 m a.s.l.; around 12 mm y⁻¹ at Bardai, 1200 m a.s.l.). At higher elevations however, and especially above 2000 m a.s.l., it can be up to 100–150 mm y⁻¹ (Juberthie & Decu 2001; Guo & Dumont 2014). Although low, these amounts of precipitation in some parts are sufficient to support rare surface water-bodies, called gueltas/aguelmans. These are actually lakelets, usually on the floor of deep canyons and well protected from direct sun. They are fed either by springs or directly by (fossil) groundwater. Some of these lakelets never dry up and support not only a rich community of zooplankton (Guo & Dumont 2014) and benthos (Dumont 2007, 2014), but also rich relict populations of fish (Trape 2009, 2013). The presence of permanent or long-lasting surface water bodies is normally connected with the existence of aquifers of different sizes and with different levels of salinity in sand deposits or fractured rock formations (limestone, sandstone, or even volcanic rocks).

Analyses of sediments of Lake Yoa (NE Chad) have shown that the Sahara drastically dried up relatively recently, between 5600 and 5500 years BP (Krpelin et al. 2008). Thus it is highly reasonable that a groundwater fauna exists, dating back to the Tertiary and able to survive in some local aquifers for the last five or six thousand years.

About 130 stygobionts (obligate groundwater dwellers) have so far been recorded from the Sahara, the majority of which were found in Morocco (61 taxa) and Algeria (42 taxa). They include representatives of several groups, with Isopoda (37 species), Copepoda (16 species), and Amphipoda (12 species) as the most abundant

(Juberthie & Decu 2001). Sampling sites were located in places relatively easy to access, in caves, wells or in sediment deposits along temporary or permanent rivers, mostly at the periphery of the desert and along its Mediterranean fringe.

Most of the stygobiotic Copepoda species from the Sahara are local endemics (Table 1). Nine species have been recorded in Algeria, four in Mali, two in Morocco and one species in Egypt/Sudan; Harpacticoida (13 species) dominating Cyclopoida (three species) (Juberthie & Decu 2001). Only two groundwater Copepoda species were known from the central part of the Sahara: *Parastenocaris ahaggarica* Bozic, 1978 and *Nitocrellopsis ioneli* (Dumont & Decraemer, 1974), both from the Hoggar Mountains in central Algeria.

Between 4th and 18th of March 2014, a small international group of biologists organised a hydrobiological expedition to the Ounianga-Tibesti area in northern Chad, which had been closed to foreigners for several decades—almost since the independence of the country. From many aspects, including biological ones, it is one of the least explored parts of the desert (Dumont 2014). During an approximately 1200 km journey from Faya to the Ounianga area and to northern Tibesti we collected samples for groundwater fauna in several locations. Two of them gave the positive results presented here.

TABLE 1. List of Copepoda species from the Sahara (after Botosaneanu 1986 and Juberthie & Decu 2001); three species from Chad (this study) are included.

| | Habitat | Location | Region | Country |
|---|--------------------|-------------------|-------------------------|---------------------|
| CYCLOPOIDA | | | | |
| <i>Haplocyclops monodi</i> (Kiefer, 1960) | interstitial | river Niger | Tilembaya | Mali |
| <i>Haplocyclops (Haplocyclops) henrii</i> sp. nov. | interstitial | river Uet Duar | Totous, Tibetsi | Chad |
| <i>Megacyclops donaldsoni algericus</i> Kiefer, 1930 | wells | d'Ain Sefra | Naâma | Algeria |
| <i>Microcyclops arenicola</i> Kiefer, 1960 | interstitial | river Niger | Tilembaya | Mali |
| HARPACTICOIDA | | | | |
| <i>Cottarelliaris numidiensis</i> (Rouch, 1987) | spring | Sebdou | Tlemcen | Algeria |
| <i>Elaphoidella algeriensis</i> Rouch, 1987 | spring | Sebdou | Tlemcen | Algeria |
| <i>Nitocrellopsis ionelli</i> (Dumont & Decraemer, 1974) | salt spring; ?? | valley Ziz; ?? | Ksar es Souk; Hoggar | Morocco; Algeria |
| <i>Monodocaris monodi</i> (Chappuis, 1959) | interstitial | river Niger | Tilembaya | Mali |
| <i>Nitocrellopsis petkovskii</i> Rouch, 1987 | spring | Sebdou | Tlemcen | Algeria |
| <i>Paraleptomesochra phreatica</i> Pesce, 1981 | well | Sidi El Aydi | Chaouia | Morocco |
| <i>Parapseudoleptomesochra attieri</i> Dumont, 1984 | well At Tire | Ghor (Khor) | Nubia | Egypt / Sudan |
| <i>Parapseudoleptomesochra minoricae</i> (Chappuis & Rouch, 1959) | interstitial | d'El Omit | Tlemcen | Algeria |
| <i>Parastenocaris ahaggarica</i> Bozic, 1978 | interstitial | l'Oued Tinlalene | Hoggar | Algeria |
| <i>Parastenocaris joi</i> sp. nov. | interstitial | river Uet Duar | Totous, Tibetsi | Chad |
| <i>Parastenocaris kabyla</i> Chappuis, 1953 | interstitial | El Quala | Beni-Saf | Algeria |
| <i>Parastenocaris nigerianus</i> Chappuis, 1959 | interstitial | river Niger | Tilembaya | Mali |
| <i>Pilocamptus schroederi</i> (van Douwe, 1915) | spring | Gonoa | Bardai, Tibetsi | Chad |
| <i>Schizopera jugurtha</i> (Blanchard & Richard, 1891) | spring | Ghazaouet | Tlemcen | Algeria |
| <i>Schizopera subterranea</i> Lang, 1948 | interstitial | El Quala | Beni-Saf | Algeria |

Material and methods

Two locations where we obtained groundwater fauna in northern Chad were a small spring near the wall carvings at Gonoa (Bardai region) (21°18'41" N 16°53'21" E; altitude: 1068 m) and the dry channel of the river Oued Douar near the Totous village (19°26'22" N 17°31'47" E; altitude: 585 m) (Fig. 1). Both locations were in the Tibesti area

that features almost 100,000 km² of Paleozoic sandstone mixed with very large amounts of eruptive rocks (Dumont 2014).

The small spring is located about 50 km NE of the Toussidé Mountain, a dormant volcano. Its discharge is a seepage flow of few ml min⁻¹ from a crack in the quartz sandstone. Immediately after the spring there is a small, shallow pool of a few litres of water. In the pool, apart from a few larvae of mosquitoes, only specimens of *Pilocampus schroederi* (van Douwe, 1915) were observed.

The dry channel of the Oued Douar near the gueltas of Totous is carved into about 30 m high sandstone deposits, positioned on the southernmost part of the Tibesti area (Fig. 1). The walls of the channel are close to vertical and the channel itself is up to 50 m wide. The plateau above the river channel is fractured into many plates, separated by deep cracks filled with wind-drifted sand. Along the riverbed are a series of lakelets or pools, called the “gueltas of Totous” (Guo and Dumont 2014). They are among the classic stations for fish in the Sahara (Lévêque 1990). The sampling point was about 100 m upstream from the right-hand canyon with a series of gueltas, rich in fish. Into the bottom of a dry channel of the river we dug a hole about 1.5 m deep (Karaman-Chappuis method) through gravel deposits with different particle size (from less than 1 mm to about 1 cm in diameter) to reach the groundwater table. Along with representatives of the two new species described in this paper we collected a large number of representatives of Syncarida and Isopoda.

From the outflow of the small spring, water was filtered by means of filtering bottle with a mesh size of 60 µm (Brancelj 2004). A plastic cup was gently swept over the pool's bottom and about 1 L of the mixture of water, mud and organic material was poured into a filtering bottle to remove most of the water. From a hole in the dry channel of the river about 10 liters of water was filtered through a filtering bottle.

Animals were stored immediately in 70% ethanol in 50 ml plastic bottles. They were checked in a laboratory using a dissecting microscope, and specimens of Copepoda and accompanying fauna were sorted out.

Before dissection, specimens were placed in a mixture of glycerol and 70% alcohol (ratio ~1: 10 v/v), which was replaced within half an hour by pure glycerol. They were dissected at 100x magnification under an Olympus SZH 2 stereomicroscope. All appendages and body ornamentation were examined under a magnification of 1000x. Drawings were made at the same magnification with a drawing tube mounted on an Olympus microscope (BHS 40), except for the female/male habitus, at 400x magnification. Final versions of the drawings were made using the CorelDRAW®12 graphic program. For permanent slides, all body parts were placed in a drop of glycerol on one microscope slide, covered with a cover glass and sealed with nail polish.

Locality data and numbers of specimens are given in the type material section of the new species below, and all types are deposited in the in Slovenian Museum of Natural History (Ljubljana).

The following abbreviations are used throughout the text and figures: Enp = endopod; Exp = exopod; Exp/Enp-1 = proximal segment; Exp/Enp-2 = middle segment; Exp/Enp-3 = distal segment; legs = P1–P6. The nomenclature and descriptive terminology follow those of Huys & Boxshall (1991).

Systematics

Order Cyclopoida Rafinesque, 1815

Family Cyclopidae Rafinesque, 1815

Subfamily Cyclopinae Rafinesque, 1815

Genus *Haplocyclops* Kiefer, 1952

Subgenus *Haplocyclops* (*Haplocyclops*) Kiefer, 1952

***Haplocyclops* (*Haplocyclops*) *henrii* sp. nov.**

(Figs. 2–4)

Type locality. Chad, Tibesti area; groundwater in dry channel of river Uet Duar near village Totous, northern Chad; 19°26'22" N 17°31'47" E; altitude: 585 m (Fig. 1).

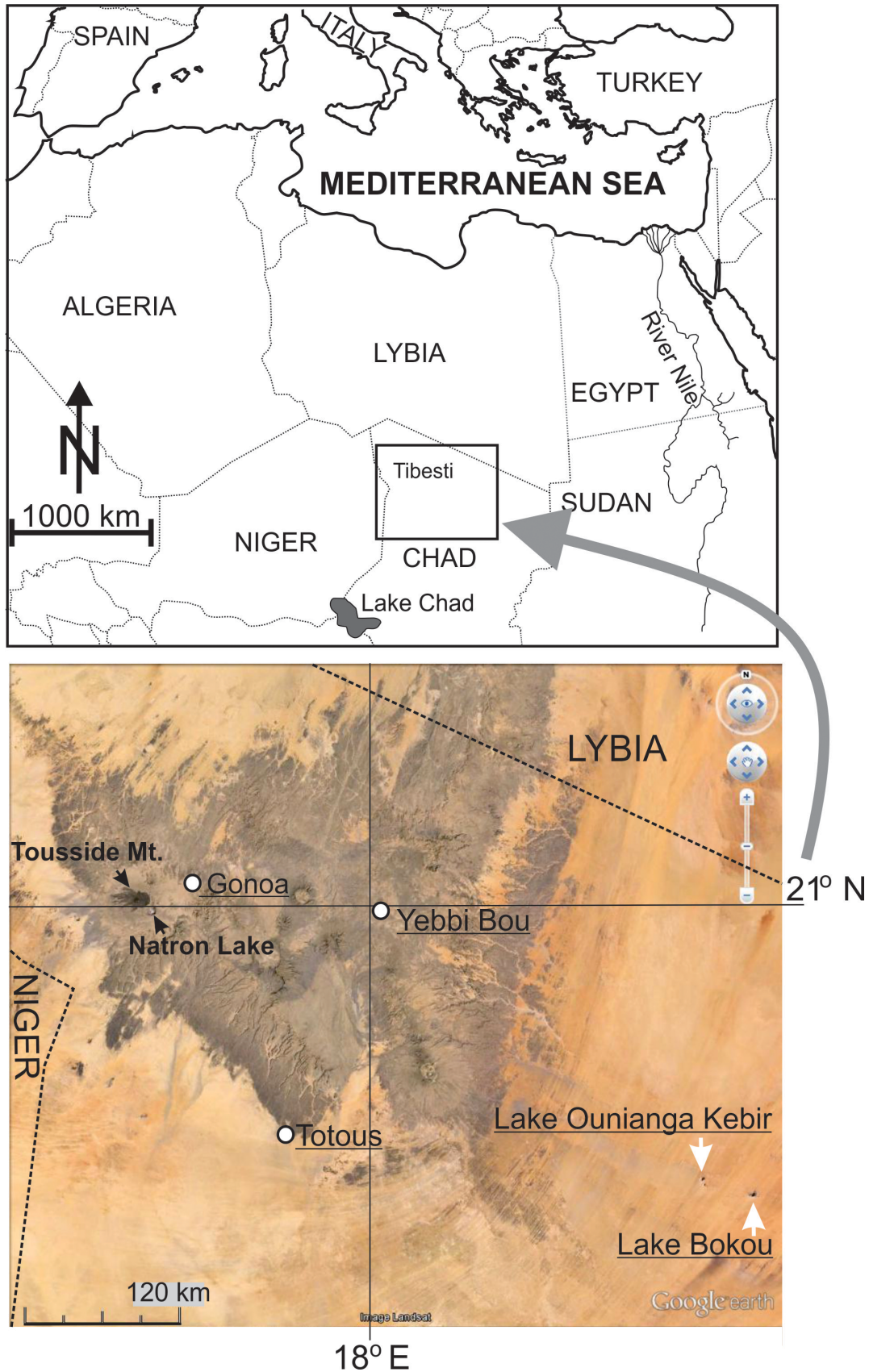


FIGURE 1. Locations for sampling of groundwater fauna in the Ounianga-Tibesti region (northern Chad). White arrows: shore of the lakes Ounianga Kebir and Bokou; white circles: the river bank near the village Yebi Bou, a spring near the village Gonoa and the river bed of the Uet Duar at the village Totous.

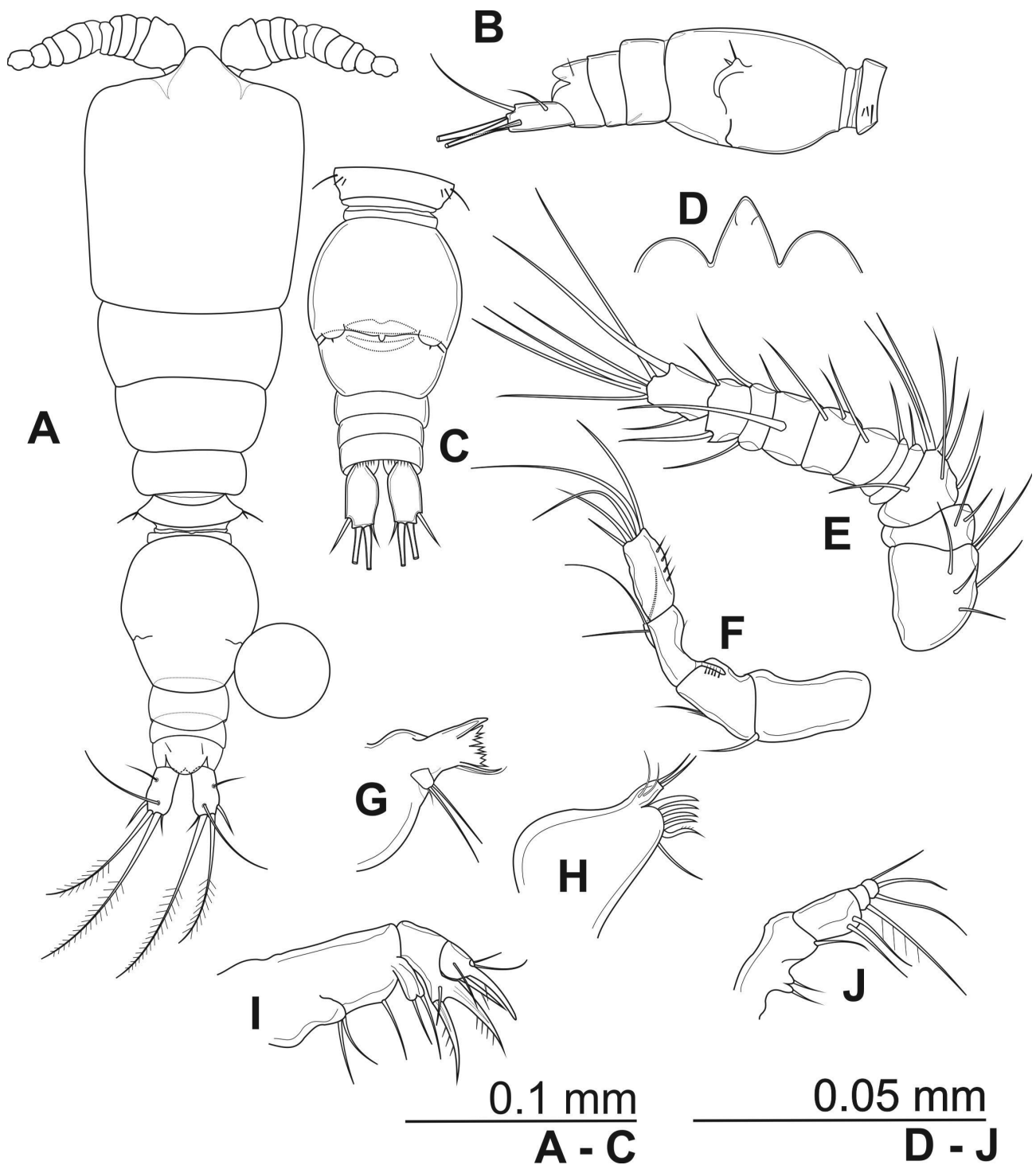


FIGURE 2. *Haplocyclops (Haplocyclops) henrii* sp. nov., holotype female: A, habitus, dorsal view; B, urosome, lateral view; C, urosome, ventral view; D, rostrum; E, antennule; F, antenna; G, mandible; H, maxillule; I, maxilla; J, maxilliped.

Material examined. Holotype: adult female (length 357 μ m), completely dissected, mounted on one slide; collected on 14 March 2014 from ground water on bottom of 1.5 m deep Karaman-Chappuis pit; access No.: PMSL-Copepoda-Brancelj-1356.

Allotype: male completely dissected, mounted on one slide; collected on the same date and same location as holotype; access No.: PMSL-Copepoda-Brancelj-1357.

Paratypes: 13 females, one female with spermatophores, 2 males; stored in 70% alcohol; collected on the same date and same location as holotype and allotype; access No.: PMSL-Copepoda-Brancelj-1358.

Additional material: 2 females, 2 male, 3 juveniles; stored in 70% alcohol in author's collection.

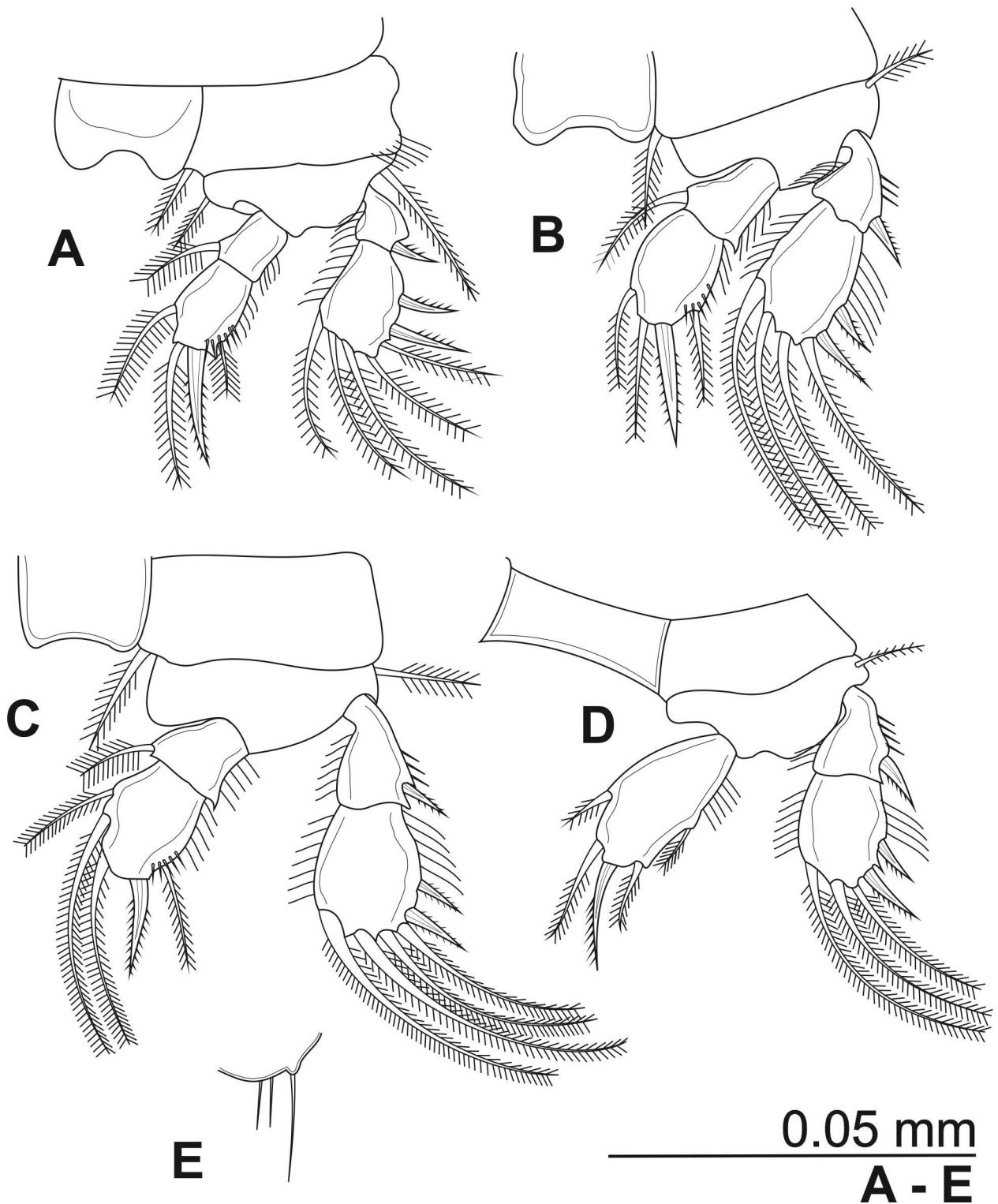


FIGURE 3. *Haplocyclops (Haplocyclops) henrii* sp. nov., holotype female: A, P1; B, P2; C, P3; D, P4; E, P5.

Etymology. The new species is named after Prof. Henri Dumont from the University of Ghent, who is an expert for aquatic fauna of the Sahara.

Description. Female. Body length, measured from tip of rostrum to posterior margin of caudal rami, 321–357 μm (mean body length: 339 μm ; mean prosome length: 207 μm ; mean urosome length: 131 μm ; $n = 8$); preserved specimens colourless. Habitus elongated, almost harpacticoidal; prosomal/urosomal ratio 1.6, greatest width at anterior part of cephalothorax; cephalothorax subrectangular; compressed in dorsoventral direction (Fig. 2A). Naupliar eye not discernible. Rostrum triangular with rounded tip, 2 sensilla at 2/3 of free margins length (Fig. 2D).

Integumental window not discernible. Posterior margins of prosomal and urosomal somites smooth dorsally; free pedigerous somites without expansions in lateral view. Pseudo-somite between fifth pedigerous and genital double-somite not sclerotized. Genital double-somite about 2/3 of urosome length; swollen laterally; about 1.5-times as long as wide (Figs. 2A, C). Genital complex with small copulatory pore, positioned at 2/3 of genital double somite length; seminal receptacle small; anterior part expanded, posterior not discernible. Ovipores situated laterally at 2/3 of somite length, covered with reduced P6 (Figs. 2B, C). Third and fourth urosomites without ornamentation. Anal somite with few spinules ventrally, at base of furcal rami (Fig. 2C); operculum well developed, semicircular, with smooth free margin; reaching end of anal somite; with 2 sensilla at base (Figs. 2A, B).

Caudal rami parallel, with some space between them (Figs. 2A, C); ramus about twice as long as wide; basal part narrower than rest of ramus; no ornamentation observed. Lateral seta (I) reduced. Lateral seta (II) positioned at 1/3 of caudal ramus length, arising almost dorsally, slightly shorter than ramus length. Outermost apical seta (III) positioned subapically at 3/4 of caudal ramus length; spiniform, smooth. Outer apical seta (IV) bipinnate, about 3-times as long as caudal ramus; with no fracture plane. Inner apical seta (V) bipinnate, about 4-times as long as caudal ramus, with no fracture plane. Innermost apical seta (VI) very short, spiniform. Dorsal seta (VII) about 2-times as long as caudal ramus, smooth, uniarticulate at base; positioned close to distal end of caudal ramus on its inner corner (Figs. 2A, B).

Antennule (Fig. 2E) 11-segmented, not reaching middle of cephalothorax length. Segments 4 and 5 weakly chitinised, short. Aesthetascs on third and eleventh segment seta-like; both aesthetascs combined as acrothek (common base of seta and aesthetasc; ae). Setal formula: 6.2.6+ae.1.1.1.2.2.2.2.6+ae. Lateral seta on ultimate segment present. All setae smooth.

Antenna (Fig. 2F) 4 segmented, comprising long coxobasis and 3-segmented endopod. Coxobasis unornamented; one smooth seta on distal inner corner; no seta representing Exp. Short longitudinal row of spinules along inner (caudal) margin of Enp-1; one long and one short smooth seta at mid-inner margin. Enp-2 about 2-times as long as wide, armed with 3 smooth setae (one laterally, one subapically, one apically). Enp-3 2-times as long as wide, row of few spines along inner margin; 5 smooth setae apically; outermost seta on outer margin shortest and spiniform.

Mandible (Fig. 2G) with 1-segmented mandibular palp; 3 smooth setae apically; 2 longest unequal in length, third very short. Ventralmost tooth on gnathobase strong, with blunt tip.

Maxillule (Fig. 2H) composed of well developed praecoxa and 1-segmented palp. Arthrite of praecoxa armed with 5 armature elements along inner margin; proximal-most unipinnate; others smooth. Palp fused with Enp; 2 smooth seta laterally; 2 smooth seta apically, unequal in length.

Maxilla (Fig. 2I) 5-segmented; but praecoxa partly fused with coxa. Proximal endite of praecoxa unarmed, distal with 2 smooth setae. On proximal endite of coxa one smooth seta; on distal endite 2 smooth setae, unequal in length. Basis expanded into strong, sharp-pointed claw; on concave side short row of strong small spinules; next to it robust, unipinnate seta, slightly longer than claw. Enp-1 expanded into blunt-pointed claw; one soft seta laterally, one robust, smooth seta subapically. Enp-2 very reduced; 2 smooth setae on it.

Maxilliped (Fig. 2J) 4-segmented. On proximal endite of syncoxa 2 setae; one seta on distal endite. Basis 1.5-times as long as wide; with 2 smooth setae. Enp-1 short, with long unipinnate seta. Enp-2 almost as large as first one, with 3 setae unequal in length, one subapically, 2 apically.

P1–P3 with 2-segmented Exp and Enp; P4 with 2-segmented Exp, 1-segmented End (Figs. 3A–D). Armature formula of P1–P4 as in Table 2. Second exopodal segment spine formula 2.2.2.2 and setal formula 5.4.4.3.

TABLE 2. Armature formula of P1–P4 of *Haplocyclops (Haplocyclops) henrii* sp. nov. Legend: inner-outer seta/spine; inner-apical-outer; Arabic numerals representing setae, Roman numerals representing spines.

| Leg | Coxa | Basis | Exopod | | Endopod | |
|-----|------|-------|--------|---------|---------|---------|
| | | | 1 | 2 | 1 | 2 |
| P 1 | 1-0 | 1-1 | 0-I | 4-1+I-I | 1-0 | 1-1+I-1 |
| P 2 | 1-0 | 0-1 | 0-I | 3-1+I-I | 1-0 | 1-1+I-1 |
| P 3 | 1-0 | 0-1 | 0-I | 3-1+I-I | 1-0 | 2-I+1-1 |
| P 4 | 0-0 | 0-1 | 0-I | 2-1+I-I | 1-1+I-2 | - |

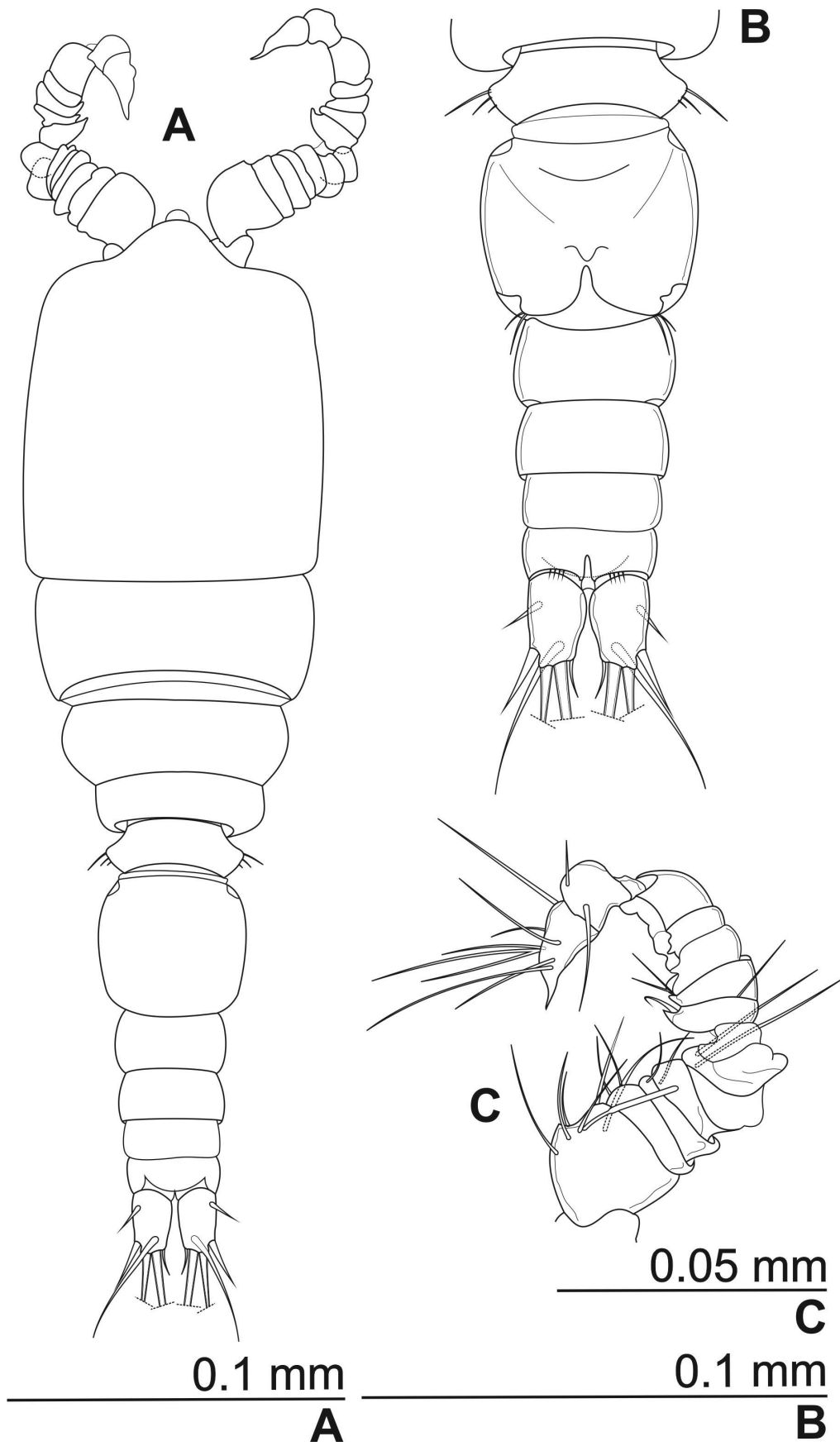


FIGURE 4. *Haplocyclops (Haplocyclops) henrii* sp. nov., allotype male: A, habitus, dorsal view; B, urosome, ventral view; C, antennule.

P1–P4 with intercoxal sclerites; decreasing from well defined rounded distal processes at P1 and complete absence of them at P4. No spinules observed on coxae or bases. Coxae of P1–P3 with seta on inner distal margin, absent in P4. All bases on outer margin with plumose seta, decreasing in strength and length from P1 (robust, long) to P4 (soft, short). Basis of P1 with soft, short plumose seta on inner distal corner. Setae on P1–P3 End and Exp slender, plumosae; P4 End-1 with short setae (Fig. 3D). Spines on P2–P4 Exp-2 shorter than width of segment bearing them. Distal spine on P1 Exp-2 as long as width of segment bearing it.

P5 (Figs. 2B, C, 3E): completely fused to somite, represented by 3 short, slender setae, unequal in length. Remnant of basal segment represented by knob-like elevation, with one long, smooth seta; 2 shorter smooth setae, representing ancestral distal segment; short setae about 0.4-times as long as longer one.

P6 (Figs. 2B, C) distinct small cuticular plate with two elements; one short spiniform seta on ventrolateral side; one soft seta on dorsolateral side, about 2-times as long as short one.

Egg (Fig. 2A): female with one egg attached on right side; in size similar to anterior part of genital segment.

Male. Body length, measured from tip of rostrum to posterior margin of caudal rami, 308–318 μm (mean body length: 315 μm ; mean prosome length: 186 μm ; mean urosome length: 129 μm ; $n = 3$), preserved specimens colourless. Habitus elongated, almost harpacticoidal (Fig. 4A); prosomal/urosomal ratio 1.4; greatest width at the cephalothorax; evenly tapering toward anal segment. Cephalothorax rectangular, width/length ratio 1.3; compressed in dorsoventral direction; rostrum similar as in female. Posterior margins of prosomites and urosomites smooth dorsally and ventrally, similar as in female (Figs. 4A, B). Genital somite as wide as long. At base of furcal rami short row of spinules on ventral side of anal segment. Caudal ramus slightly conical, about 1.5-times as long as wide. Armature and position of setae similar as in female.

Antennule (Fig. 4C) digenicated; 13-segmented. Aesthetascs on segments 1 and 13. Setal formula as follows: 6+ae.2.1.1.2.0.2.2.0.0.0.2.7+ae (but some setae probably overlooked). Antenna, mouth parts (mandible, maxillule, maxilla, maxilliped) as well as P1–P5 similar as in female.

P6 (Fig. 4B) partly fused medially, large cuticular plates; with 2 elements, inner seta about 3-times as long as outer one.

Spermatophore with posterior part widely rounded, anteriorly subconical; drop-like.

Variability. The only variability observed was body length.

Remarks. The genus *Haplocyclops* was erected by Kiefer (1952) to accommodate *H. gudrunae* Kiefer, 1952 from Madagascar. Later, six more species from the genus were described by Kiefer (1955, 1960), Rocha et al. (1998), Fiers (2002) and Karanovic & Ranga Reddy (2005) (Table 3). Fiers (2002) also redescribed the type species and its congeners and gave a detailed discussion on relations between other related/similar genera, particularly *Bryocyclops* Kiefer, *Rybocyclops* Dussart and *Palaeocyclops* Monchenko. In his comparison of similarities/differences he included fine details like refractile points of the integument (present in some *Bryocyclops* species but absent in *Haplocyclops*) and the number and size of seta of male P6 (long in *Bryocyclops* and reduced in *Haplocyclops*). He showed that the two genera are not closely related. In contrast, *Haplocyclops* and *Rybocyclops* are probably the most closely related genera, sharing several characteristics including a large anal operculum, the dorsal position of the antermost lateral seta on the caudal rami, the shape of the seminal receptacle and reduced armament of the legs, especially of P4. The most obvious difference between the characters of the two genera and those of *Rybocyclops* are: a) loss of the subdistal outer elements on the End of P1–P4, b) the absence of the medial spine on the P1, c) the spine formula 2.2.2.2 (all of those characters as apomorphies), and d) the barrel-shaped female genital double-somite with the position of the gonopores in the middle of the somite sides (as a plesiomorphy) (Fiers 2002). In his final remark Fiers stated that “the diagnosis of the genus is 2.3.3.2 (the number of spines on Exp P1–P4), but as the P4 Exp is only 1-segmented, the indication of the formula should be 2.3.3.3”. For practical reasons, however, he suggested to omit it and keep it as 2.3.3.2.

A spine formula 2.2.2.2 was suggested by Karanovic & Ranga Reddy (2005) in order to separate subgenus *Haplocyclops* from subgenus *Kiefercyclops* which had been erected to accommodate one new species from India, *H. fiersi* Karanovic & Ranga Reddy, 2005, into genus *Haplocyclops*. *Haplocyclops*(*Kiefercyclops*) *fiersi* shares with other members of the genus characters like large anal operculum, principal apical seta without breaking planes, seventh antennular segment with only 2 setae, Enp of P4 1-segmented, setal formula of Exp-2 P1–P4 5.4.4.3, reduced armature of the male P6; P5 completely fused to somite and represented by three slender setae in both sexes.

There are several characters that place the new species *H. (H.) dumonti* **sp. nov.** into the genus *Haplocyclops*. The most obvious characters of the new species shared with the genus *Haplocyclops*, are, according to Kiefer (1952), a) a genital double-somite with ovipores situated in the posterior half, b) antennule without lateral seta on the ultimate segment, and c) caudal rami with lateral seta inserted in the proximal half of its length.

TABLE 3. Protopodal armament of P1–P4 for all species of *Haplocyclops*, except for *H. neuter* (after Fiers 2002 and Karanovic & Ranga Redy 2005). The new species, *H. (H.) henrii* **sp. nov.** is included. Notation as follows: outer margin-inner margin coxa: outer margin-inner margin basis. Arabic numerals representing spines, Roman numerals indicating setae.

| Taxon | Distribution | Leg 1 | Leg 2 | Leg 3 | Leg 4 |
|--|-----------------------|---------|---------|------------|---------|
| <i>Haplocyclops (Haplocyclops) pauliani</i> Kiefer, 1955 | Madagascar | 0-1:1-I | 0-0:1-0 | 0-0:1-0 | 0-0:1-0 |
| <i>Haplocyclops (Haplocyclops) gudrunae</i> Kiefer, 1952 | Madagascar | 0-1:1-I | 0-1:1-0 | 0-0:1-0 | 0-0:1-0 |
| <i>Haplocyclops (Haplocyclops) monodi</i> Kiefer, 1960 | Niger / Mali | 0-1:1-I | 0-1:1-0 | 0-0(1):1-0 | 0-0:1-0 |
| <i>Haplocyclops (Haplocyclops) neuter</i> Kiefer, 1955 | Madagascar | ? | ? | ? | ? |
| <i>Haplocyclops (Haplocyclops) iranicus</i> Fiers, 2002 | Iran | ? | 0-1:1-0 | 0-0:1-0 | 0-0:1-0 |
| <i>Haplocyclops (Haplocyclops) torresi</i> Rocha, Torres & Maia-Barbosa, 1998 | Brazil | 0-1:1-I | 0-1:1-0 | 0-0:1-0 | 0-0:1-0 |
| <i>Haplocyclops (Haplocyclops) henrii</i> sp. nov. | Chad | 0-1:1-I | 0-1:1-0 | 0-1:1-0 | 0-0:1-0 |
| <i>Haplocyclops (Kiefercyclops) fiersi</i> Karanovic & Ranga Reddy, 2005 | India, Andhra Pradesh | 0-0:1-0 | 0-0:1-0 | 0-0:1-0 | 0-0:1-0 |

According to its protopodal armament of P1–P4, the new species *H. (H.) henrii*, with the presence of inner seta on P1–P3 and its absence on P4, fits into the subgenus *Haplocyclops*, not *Kiefercyclops*. In the subgenus *Haplocyclops*, inner seta is always present on P1–P2, but either present or absent on P3 and always absent on P4. Inner seta on P3 is present in the genus in some specimens of *H. (H.) monodi* as well as in *H. (H.) henrii*. Mandibular palp, which is completely reduced in the subgenus *Kiefercyclops* is present in *Haplocyclops*, including *H. (H.) henrii*. *Kiefercyclops* has 3-segmented maxilliped, which is 4-segmented in all members of the subgenus *Haplocyclops*. All the above mentioned characteristics of the genus are identical with a diagnosis of *H. (H.) henrii*.

Other differential characters between *H. (K.) fiersi*, all six members of the subgenus *Haplocyclops* and the new member *H. (H.) henrii*, are reductions in armature and/or segmentation. According to Fiers (2002), in the subgenus *Haplocyclops* the setal formula of antennule is 7.2.5.2.1.2.2.2+ae.2.2+ae.6+ae while in the subgenus *Kiefercyclops* it is, according to Karanovic & Ranga Reddy (2005), 6.2.3.0.1.1.2.2.1.2.6, with no visible aesthetascs. *Haplocyclops (H.) henrii* has setal formula 6.2.6+ae.1.1.1.2.2.2.2.6+ae, which puts it in an intermediate position between the two subgenera, but closer to the subgenus *Haplocyclops* than *Kiefercyclops*. Antenna has setal formula 1.5.7 in the subgenus *Haplocyclops*, 1.5.6 in the subgenus *Kiefercyclops* and 1.3.5 in *H. (H.) henrii*, which is the most reduced form within the two subgenera.

The most evident characters that differentiate *H. (H.) henrii* from the other members of the genus are: a) subrectangular shape of cephalothorax and b) very short, spiniform innermost (VI) terminal seta. There are certain other characters that are shared with some other species, but are unique in combination with other characters: c) the endopod of the fourth swimming leg, armed apically with one spine and one seta, a character shared with the South American *H. (H.) torresi* Rocha, Torres & Maia-Barbosa, 1998 and the Indian *H. (K.) fiersi*; and d) spine formula 2.2.2.2 shared with *H. (K.) fiersi*, but the species differs in other characters, already listed above.

The new species fits a Gondwanaland distribution, a pattern noted in many other freshwater copepods (Karanovic & Ranga Reddy 2005). All *Haplocyclops* are members of a specialized groundwater fauna which entered a subterranean environment in a distant geological past. As groundwater habitats have rather limited

connectivity (Gilbert 2001; Stoch & Galassi 2010), a specialized fauna living there has limited possibility of geographical dispersion. For that reason, a groundwater fauna is a much better indicator of ancient connections of continents than epigeal fauna.

Adaptation of the new species to a groundwater environment is supported not only by a loss of pigment, absence of eye, elongated, almost vermiform body shape, reduction of appendage segments and armature, but also by reproduction. The large single egg observed in one female indicates K-selection of the species (MacArthur & Wilson 1967), characteristic of a subterranean environment. Further specific adaptations for life in porous aquifers are weakly sclerotized and very short segments 4 and 5 on antennules, indicated also on figures in Fiers (2002) and Karanovic & Ranga Reddy (2005). Such less sclerotized parts are useful in porous aquifers where spaces between grains are small and additional flexibility of appendages enable animals to crawl among particles.

Order Harpacticoida Sars, 1903

Family Canthocamptidae Brady, 1880

Genus *Pilocamptus* Huys, 2009

Pilocampus schroederi (van Douwe, 1915)

(Figs. 5–8)

Synonymy. *Canthocamptus schroederi* van Douwe, 1915: 263–265; Figs. 1–7.

Material examined. 17 ovigerous females, 7 females, 15 males, one pair in copula; collected on 13 March 2014 in the pool next to the small spring near wall carving at Gonoa (Bardai region, northern Chad; 21°18'41" N 16°53'21" E; altitude: 1068 m). One female and one male completely dissected, each of them mounted on one slide; access No.: PMSL-Copepoda-Brancelj-1359 (female), No.: PMSL-Copepoda-Brancelj-1360 (male); 10 ovigerous females, 3 females, one pair in copula, 7 males; stored in 70% alcohol; access No.: PMSL-Copepoda-Brancelj-1361. The remaining material (7 ovigerous females, 3 females, 7 males) collected on the same date and the same location as previous material, deposited in the author's collection.

Description. Female. Body length, measured from tip of rostrum to posterior margin of caudal rami, 548–622 μm (mean body length: 584 μm ; $n = 7$); elongated, width evenly decreased from cephalothorax to last urosomite; preserved specimens colourless (Fig. 5A). Naupliar eye not discernible. Rostrum well developed, protruding forward at angle of 45°; rectangular with rounded free corners; about 2-times as long as wide; 2 sensilla close to tip (Figs. 5B, C).

Integumental window well visible, oval, with narrowing at 1/3 of its length. Cephalothorax smooth, prosomites, urosomites, and anal somite (incl. anal operculum); with several transversal rows of very fine spinules dorsally. Posterior margins of prosomites and urosomites finely serrated dorsally (Figs. 5A, G). Genital double-somite with row of robust spinules at distal margin laterally (Figs. 5A, D, E). Genital complex with single large copulatory pore, sclerotized, copulatory duct bell-shaped. Seminal receptacles small, simple, heavily sclerotized. P6 reduced, represented by fused plate well above seminal receptacles; with one long seta on each side of plate (Fig. 5E).

Row of robust spinules on third urosomite laterally and ventrolaterally; short gap between spinules ventrally; fourth urosomite with continuous row of robust spinules laterally and ventrally, unequal in length; anal somite with short row of robust spinules laterally (Figs. 5A, D).

Anal operculum medium-sized, not overreaching distal end of anal somite; with straight free margin, row of small spinules along it (Figs. 5A, F, G).

Caudal rami slightly conical, diverging, slightly curved; each ramus about twice as long as wide, with weak keel dorsally (Figs. 5A, D, F). Distal half of caudal ramus with oblique row of 6–7 robust spinules, positioned from outer lateral side to ventral side of ramus (Figs. 5F, G). Anterolateral external accessory seta (I) very short, thin; positioned next to seta (II). Anterolateral external seta (II) as long as width of ramus, inserted at 1/4 of its length. Posterolateral seta (III) positioned close to ventral side of ramus, at about 2/3 of its length. Outer apical seta (IV)

spiniform, smooth, as long as caudal ramus. Inner apical seta (V) long, spiniform, with row of small spines on both sides after breaking plane; basal part swollen into hump-like form, with bright dorsal surface. Inner accessory seta (VI) spiniform, as long as seta II, smooth. Dorsal seta (VII) slightly longer than width of caudal ramus; inserted on internal side of it, at about 1/3 of its length.

Antennule (Figs. 5A, 6A) 8-segmented. Aesthetasc on segment 4 cylindrical, with rounded tip; reaching well above tip of segment 8. Second aesthetasc on apical segment about half of length of first one, cylindrical. Both aesthetascs as acrothek (common base of seta and aesthetasc; ae). Setal formula: 1.8.5.2+ae.1.2.1.6+ae.

Antenna (Fig. 6B) with allobasis and robust, 1-segmented Exp and Enp. Allobasis with 2 setae; one short, smooth, near the base; one longer, unipinnate, at about 1/2 of its length. 2 strong spines on outer (anterior) margin of Enp, increasing in length distally; one robust spiniform seta on inner (caudal) margin. Apical armature with one robust inner spine and 4 soft setae; 3 of them geniculate. Exp with 4 spiniform, unipinnate setae; 2 apically, 2 laterally; subequal in length.

Labrum (Fig. 6C) with 2 spiniform setae on outer margins, unequal in length; a row of fine setules apically.

Mandible (Fig. 6D) short, robust; with 3 strongly chitinised teeth on gnathobase. Dorsal seta near gnathobase. Mandibular palp 2-segmented, each segment about as long as wide; distal segment with 3 smooth setae, increasing in length. Group of fine spines and groups of short setules near mandibular palp.

Maxillule (Fig. 6E) with strong, robust spines on praecoxal arthrite. Innermost spine with rounded tip. Spiniform, smooth seta dorsally. Coxa with one strong, chitinised spine with rounded tip and one slim seta. Basis with weak beak-like outgrowth with few spines distally; long smooth seta, slightly longer than beak-like outgrowth. Exp and Enp reduced, with one and 2 smooth setae, respectively.

Maxilla (Fig. 6F) 2-segmented; syncoxa with 2 endites with 3 and 2 elements, respectively. Basis drawn in strong beak-like spine with few distal spinules; Exp and Enp reduced to 4 setae.

Maxilliped (Fig. 6G) comprising syncoxa, basis and 1-segmented Enp. Syncoxa with seta on distal corner. Basis 2-times as long as wide, with 8–10 spinules near palmar margin dorsally, increasing in length distally. Enp drawn out into strong, acutely curved claw; as long as basis, armed with several spinules in distal half; additional armature represented by a short seta.

P1 with 3-segmented Exp and Enp; P2–P4 with 3-segmented Exp and 2-segmented Enp. Exps with rows of strong spinules on lateral and distal margins of segments. Armature formula of P1–P4 as in Table 4.

TABLE 4. Armature formula of P1–P4 of *Pilocamptus schroederi* (van Douwe, 1915). Legend: inner-outer seta/spine; inner-apical-outer; Arabic numerals representing setae, Roman numerals representing spines.

| Leg | Coxa | Basis | Exopod | | | Endopod | | |
|-----|------|-------|--------|-----|-----------|---------|-------|-------|
| | | | 1 | 2 | 3 | 1 | 2 | 3 |
| P 1 | 0-0 | 1-I | 0-I | 1-I | 0-2+I-I | 1-0 | 1-0 | 0-2+I |
| P 2 | 0-0 | 0-I | 0-I | 1-I | 1-1+I-III | 0-0 | 2-2+I | - |
| P 3 | 0-0 | 0-I | 0-I | 1-I | 2-1+I-III | 0-0 | 2-2+I | - |
| P 4 | 0-0 | 0-I | 0-I | 1-I | 2-1+I-III | 0-0 | 2-1+I | - |

Enp of P1 slightly longer than Exp (Fig. 7A). Basis with long, slim spiniform seta on inner margin; stout basal spine on outer margin. Exp-1 with strong outer spine; Exp-2 with one strong external spine and one short, slim and smooth seta on inner distal corner. Exp-3, with one spine subapically, one spine with blunt tip and 2 geniculate setae apically; outer about 2/3 of inner length. Enp-1 with one strong spiniform seta on inner margin. Enp-2 with one slim, smooth seta at distal inner corner. Enp-3 with one spine and one long geniculate seta apically; one soft, smooth seta on inner margin, slightly longer than outer spine.

P2 (Fig. 7B) basis with one spiniform seta on outer margin. Enp almost as long as Exp-1 and Exp-2 combined. Exp-1 as long as wide, with one strong spine at 2/3 of outer margin length. Exp-2 with one strong spine on outer margin; one short, robust seta at distal inner corner. Exp-3 3.5-times as long as wide, with 3 spines along outer margin; 2 elements apically: 1 spiniform seta with spinules unilaterally, one long seta, as long as Exp-3. Inner margin with one long, unilaterally feather-like seta at 1/2 of segment length. Enp-1 short, with no armature. Enp-2 3.5-times as long as wide, with 2 short, robust setae along inner margin at 1/3 and 2/3 of segment length. 3 elements apically: 2 long soft setae, subequal in length; one robust spiniform outer seta, shorter than Enp-2.

P3 (Fig. 7C) with one long, thin seta on outer margin of basis. Enp as long as Exp-1 and Exp-2 combined. Exp-1 and Exp-2 similar to that of P2. Exp-3 3.5-times as long as wide; 3 long spines along outer margin; one relatively weak, long spine apically. Inner margin with one short seta at 1/2 of margin length and one long seta subapically, as long as Exp. Enp-1 and Enp-2 as in P2; Enp-2 about 4-times as long as wide.

P4 (Fig. 7D) Exp similar to that of P3, with less robust armature. Enp-1 small, about half as long as wide, with no armature. Enp-2 with one outer spine and one long seta apically; one slightly shorter seta on inner margin subapically. Additional one long seta at 1/2 of inner margin length.

P5 (Fig. 7E) not fused. Exp and baseoendopod distinctly separated; baseoendopodal lobe well developed, longer than Exp; with 5 elements on endopodal part; one soft, smooth seta on outer margin of basis. Outermost 2 short bipinnate spines unequal in length; one seta apically, about 3-times as long as outer spines. Inner seta subapically; about 0.8 length of apical one, soft; innermost element bipinnate spine, as long as second outer spine. Exp lobe slightly longer than wide, with one short smooth spine at 1/2 of outer margin length; one long, thin outer spine apically; one long, thin inner seta; on inner margin one short spine subapically. Hyaline field not well developed.

P6 (Fig. 5E) fused, small, forming simple plate; each with one thin long seta.

Egg sac with 8-12 eggs.

Male. Body length, measured from tip of rostrum to posterior margin of caudal rami, 471–500 μm ; average: 487 μm ($n = 4$); elongated, widest at distal part of cephalothorax, the rest of the body slightly narrower; evenly tapering toward anal segment; preserved specimens colourless (Figs. 8A, B). Naupliar eye not discernible. Rostrum well developed; as in female. Integumental window not discernible. Cephalothorax smooth; prosomites, urosomites, anal somite with several transversal rows of very fine spinules dorsally. Posterior margins of thoracic and abdominal somites dorsally finely serrated (Fig. 8A). First urosomite with no ventral spinules. Second, third and fourth urosomites with row of robust spinules laterally and ventrally. Anal somite with 2 strong spinules ventrally, at the inner corner of the base of furcal ramus; unequal in length (Fig. 8B). Anal operculum well developed, only slightly rounded, not overreaching distal end of anal somite, with about 20 fine spinules along distal margin (Fig. 8A).

Caudal ramus conical, slightly longer than wide, inner and outer margin slightly convex; weak dorsal keel; rami slightly diverging (Figs. 8A, B). Anterolateral external accessory seta (I) slightly longer than caudal ramus, smooth; anterolateral external seta (II) shorter than seta I, smooth; positioned at the 2/3 of caudal ramus length. Posterolateral seta (III) very short, spiniform. Outer apical seta (IV) spiniform, as long as caudal ramus, unipinnate; no fracture plane. Inner apical seta (V) very long, but shorter than urosome, robust, with strong spinules on distal half; no fracture plane. Inner accessory (VI) very short. Dorsal seta (VII) as long as caudal ramus, inserted medially, at about 1/2 of its length.

Antennule (Fig. 8C) haplocerate, robust, 7-segmented, strongly chitinised. Genuiculated articulation between fifth and sixth segment. Aesthetasc on fifth segment cylindrical, extending over distal segment; aesthetasc on seventh segment half of length of previous one. Setal formula: 0.7.5.2.5.1.7.

Antenna, mandible, maxillule, maxilla, maxilliped, P1 similar to those in female.

P2 (Fig. 8D): Exp similar to those in female. Enp 2 segmented. Enp as long as Exp-1 and Exp-2 combined. Enp-1 0.75-times as long as wide, with no seta on inner distal corner. Enp-2 3-times as long as wide, with setae along inner margin at 1/3 and 2/3 of segment length; 2 soft setae apically, equal in length, about twice as long as segment bearing them; outer margin with several strong spinules.

P3 (Fig. 8E): Exp similar to that in female. Enp 3-segmented, as long as Exp-1 and Exp-2 combined. Enp-1 half as long as wide, with no armature. Enp-2 with long apophysis with spear-like tip; reaching distal margin of Exp-3. Enp-3 about 3-times as long as wide, with 2 relatively long setae apically.

P4 (Fig. 8F): 3-segmented Exp and 2-segmented Enp. Enp expanding over middle of Exp-2. Exp in armature similar to female's but less robust; with feather-like inner seta subapically. Enp-1 half as wide as long, with small inner seta. Enp-2 with one blunt outer spine apically, as long as segment bearing it; one soft inner seta, twice as long as spine. One blunt spine along inner margin subapically, about 1.5-times as long as outer spine.

P5 (Fig. 8B) fused. Exp and baseoendopod well separated; baseoendopod well developed, with strong bipinnate spine. Exp longer than baseoendopod, slightly longer as wide, with 4 elements: one outermost seta spiniform, accompanied by short spinule; next to it one short seta, about 4-times as long as outermost spiniform seta; one long seta apically, about twice as long as outer soft seta; inner margin with one robust spine with few long setules unilaterally, spine as long as Exp.

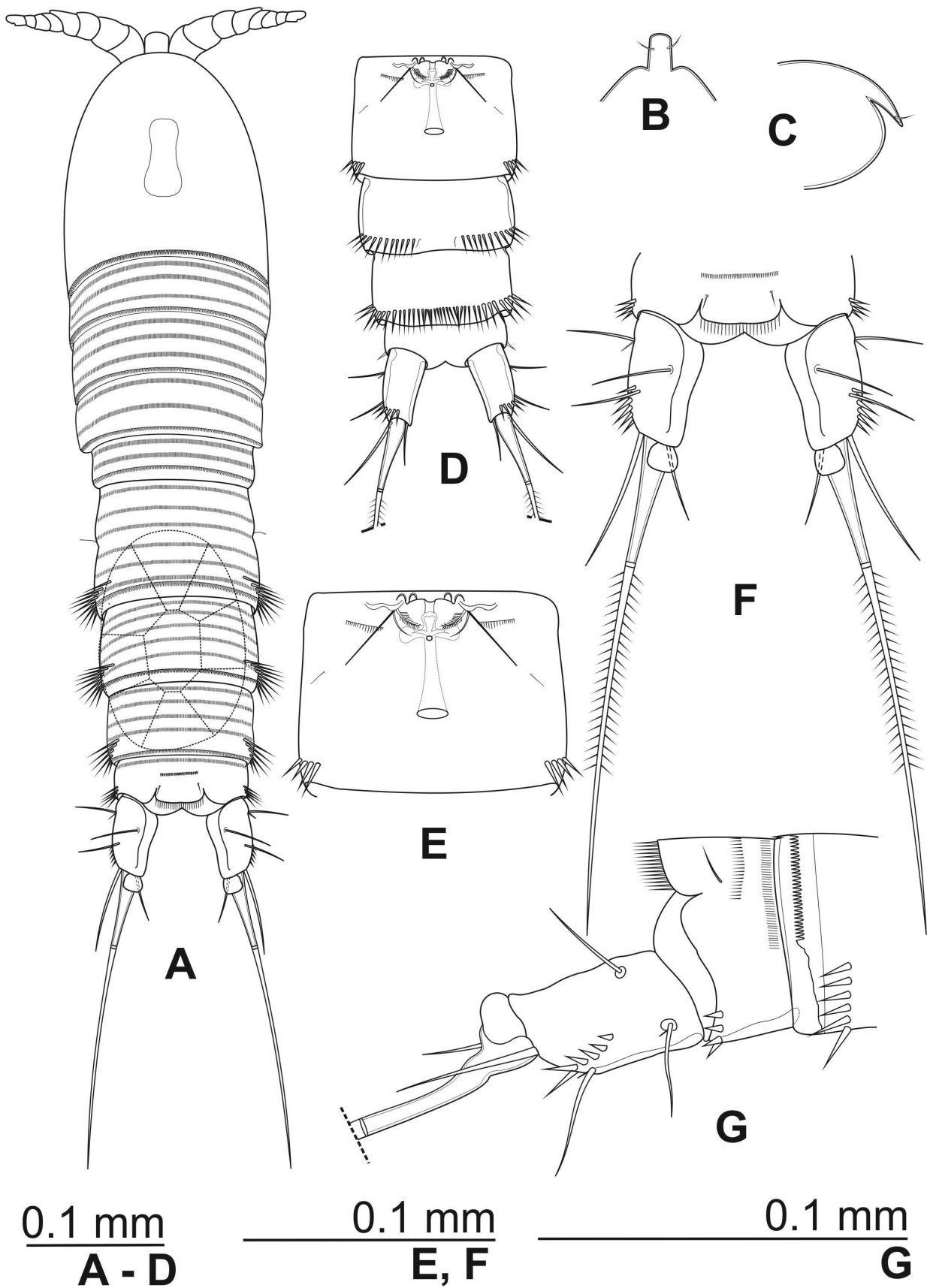


FIGURE 5. *Pilocamptus schroederi* (van Douve, 1915), female: A, habitus, dorsal view; B, rostrum, frontal view; C, rostrum, lateral view; D, urosome, ventral view; E, genital double-somite; F, anal somite and furcal rami, dorsal view; G, 4th urosomal and anal somite with furcal ramus, lateral view

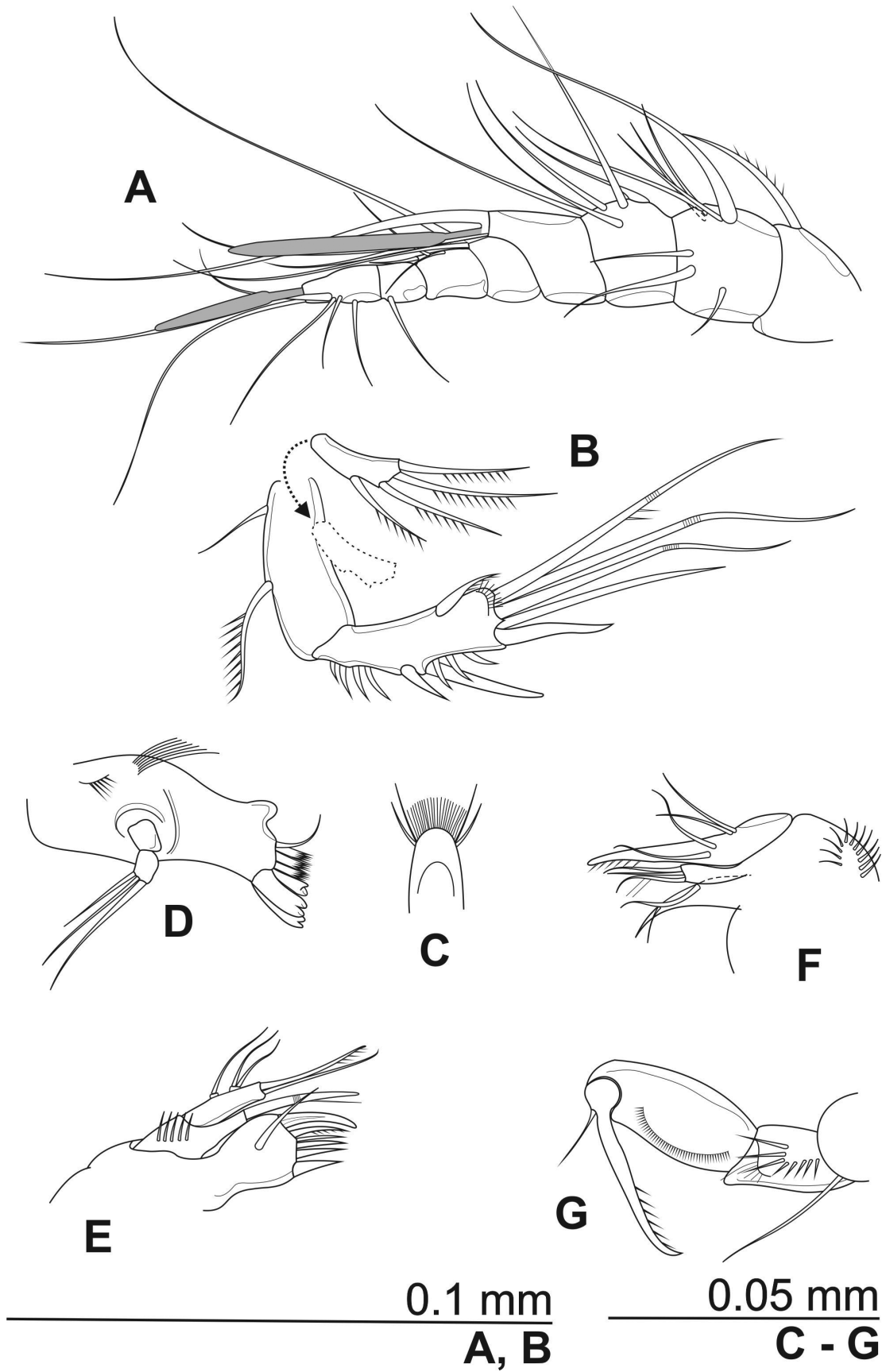


FIGURE 6. *Pilocamptus schroederi* (van Douve, 1915), female: A, antennule; B, antenna; C, labrum; D, mandible; E, maxillule; F, maxilla; G, maxilliped.

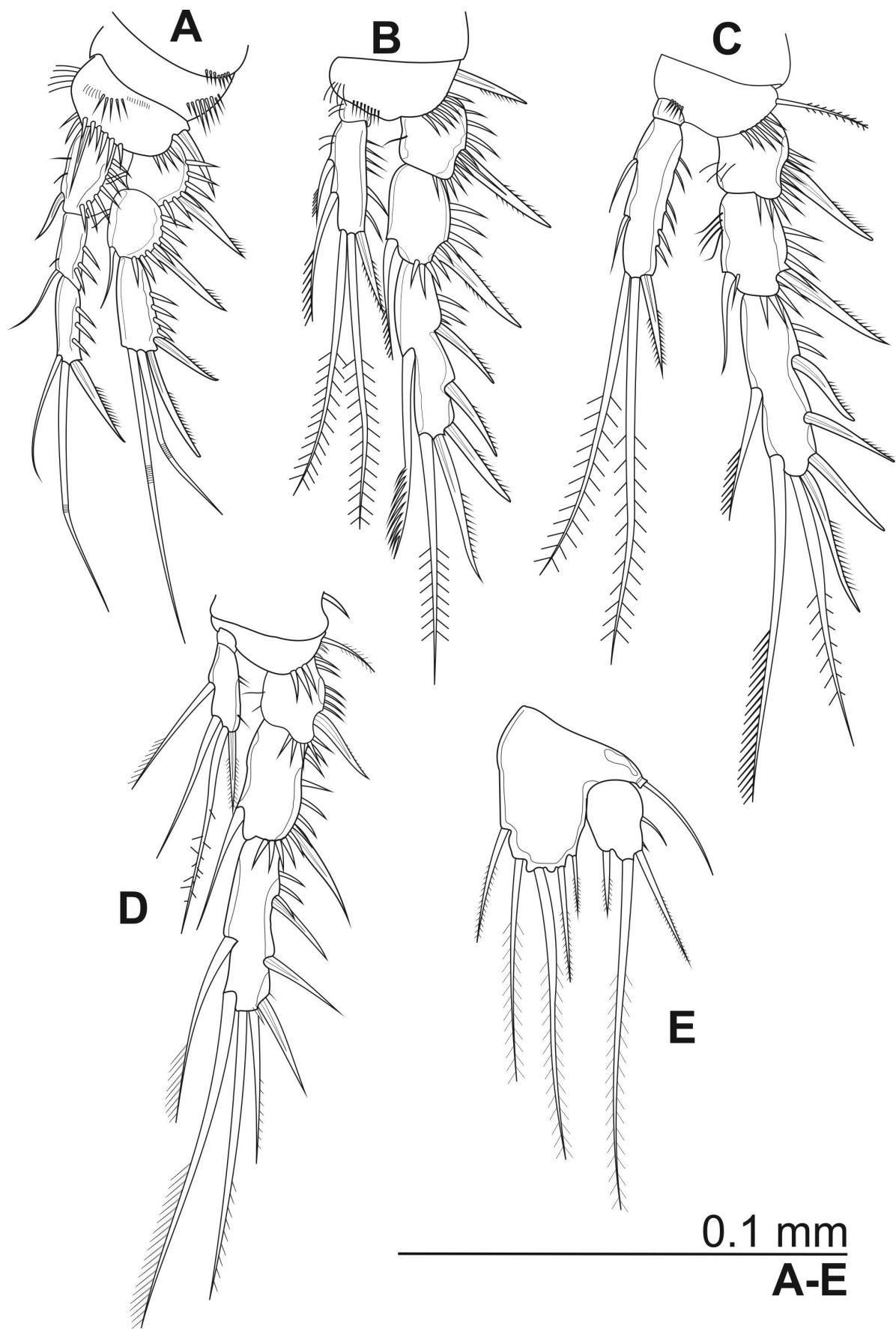


FIGURE 7. *Pilocamptus schroederi* (van Douve, 1915), female: A, P1; B, P2; C, P3; D, P4, E, P5.

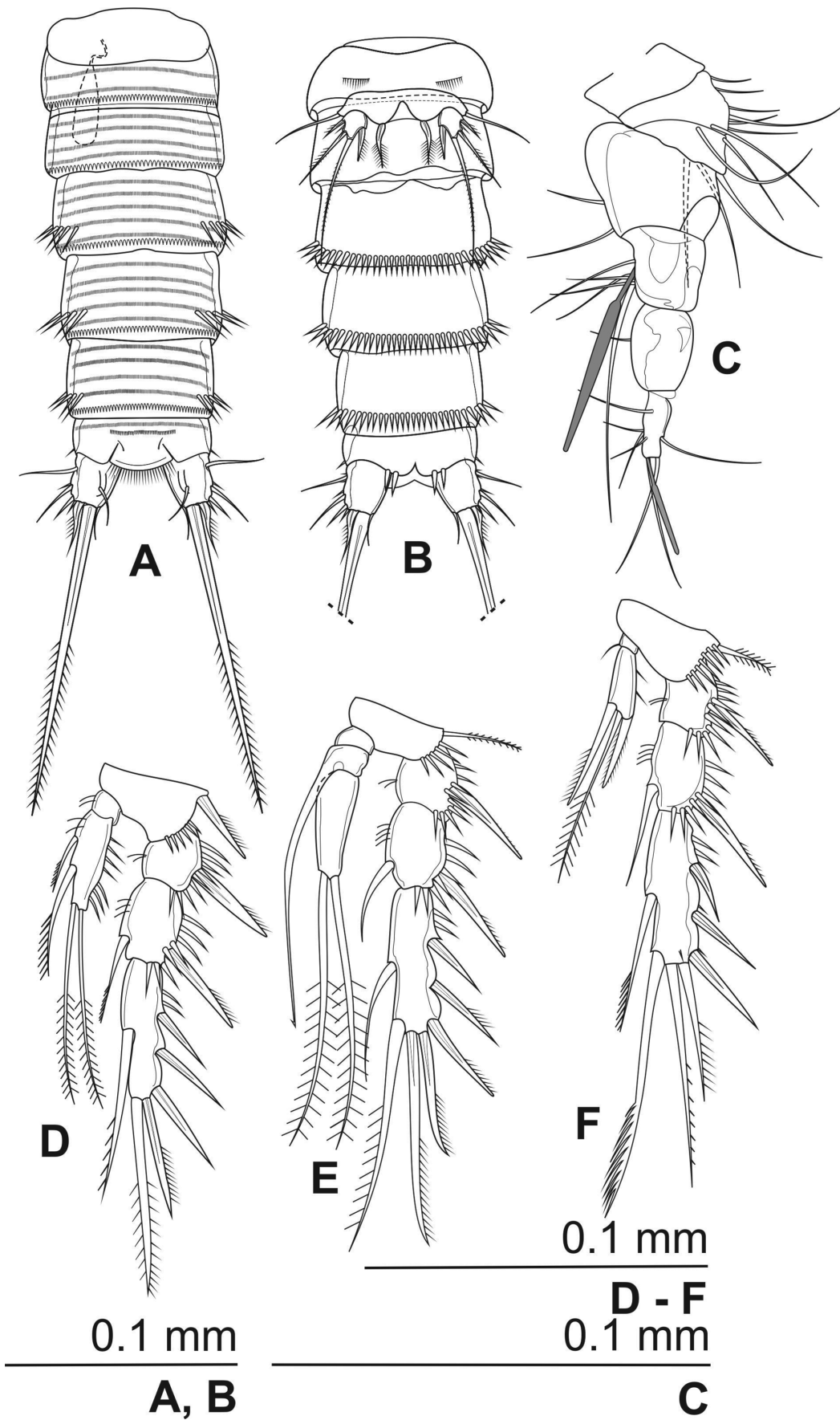


FIGURE 8. *Pilocamptus schroederi* (van Douve, 1915), male: A, urosome, dorsal view; B, urosome, ventral view; C, antennule; D, P2; E, P3; F, P4.

P6 (Fig. 8B) fused, small, forming simple plate; with no armature.

Variability. Minor variation in the number of spinules on abdominal somites and legs in both sexes.

Remarks. The genus *Pilocamptus* contains fourteen species according to Wells (2007), Pesce (2014) and the World Register of Marine Species (WoRMS) by Gaviria-Melo & Walter (2014) (Table 5) but 13 according to Defaye & Dussart (2011), who considered *P. georgevitchi* (Chappuis, 1923) a synonym of *P. pilosus*.

The genus covers a wide geographical area (either *sensu* WoRMS register or Pesce/Wells), spanning from central Europe (*P. pilosus* and *P. georgevitchi*) to sub-Saharan Africa and Madagascar, inhabiting predominantly surface water bodies (Table 5).

TABLE 5. Species of the genus *Pilocamptus* Huys, 2009 (previously part of *Echinocamptus* Chappuis, 1928) and their distribution Worldwide (see Borutzky 1964; Wells 2007; Pesce 2014).

| Genus: <i>Pilocamptus</i> | Distribution |
|--|---|
| <i>P. pilosus</i> (van Douwe, 1910) | Europe, Asia; fresh waters; mountain regions of W Europe (incl. <i>Elaphoidella unica</i> Kiefer, 1931) |
| <i>P. schroederi</i> (van Douwe, 1915) | Africa, Tanzania; lakes |
| <i>P. georgevitchi</i> (Chappuis, 1923) ^{+,#} | Europe, Asia; ground waters |
| <i>P. kamerunensis</i> (Kiefer, 1928) [*] | Africa, Camerun; lakes |
| <i>P. africanus</i> (Chappuis, 1932) | Africa; fresh waters |
| <i>P. trichotus</i> (Chappuis, 1932) | Africa; fresh waters |
| <i>P. alluaudi</i> Chappuis, 1932) | Africa; fresh waters |
| <i>P. vulgaris</i> (Chappuis, 1935) | Africa; fresh waters |
| <i>P. jeanneli</i> (Chappuis, 1935) | Africa, Kenya; fresh waters |
| <i>P. verrucosus</i> (Chappuis, 1935) | Africa; fresh waters |
| <i>P. monticola</i> (Chappuis, 1935) | Africa; fresh waters |
| <i>P. pauliani</i> (Chappuis, 1956) | Madagascar; moss |
| <i>P. monodi</i> (Dussart, 1974) | Africa; fresh waters |
| <i>P. hypophyllus</i> (Defaye & Heymer, 1996) | Africa, Zaire (= DR of Kongo) leaf litters |

*Incl.: *P. k. kamerunensis* (Kiefer, 1928) and *P. k. villosus* (Chappuis, 1932)

⁺ Questionable species (after Pesce 2014); [#] synonym of *P. pilosus* (after Defaye & Dussart 2011)

Specimens collected from the far north of the Chad fit the description of *P. schroederi* which was provided by van Douwe as *Canthocamptus schröderi* (see van Douwe 1915). That description was based on three females collected from Lake Victoria/Nyanza (Mwanza?). A male was described one year later by Menzel (1916), who collected a sample containing seven females and one male from wet moss (in about 1 ml of water) from “East Africa”. Both authors mentioned the half-ball shaped base of the inner terminal (V) seta, well visible from a lateral view, and also an oblique row of short, robust spines along the distal outer margin of the furcal ramus in the female. Both characters are also well visible in specimens recently collected from Chad. The most evident difference between specimens from Lake Victoria and the spring in Chad is the much more elongated segments on P1–P4 of females from the lake (van Douwe 1915). There are also some differences in body length of females between specimens described by van Douwe (1915) (0.8 mm) and Menzel (1916) (0.5 mm), while specimens from Chad range from 0.548 to 0.622 mm, which is an intermediate position.

The location from Chad provides the third known locality of the species. Unfortunately Menzel (1916) did not give a more detailed location of his material than “East Africa”. So far, three samples have been collected in different habitats. In East Africa specimens were collected from the littoral zone of a lake (van Douwe 1915) and from wet moss beds (Menzel 1916) while, in Chad, they were found in a small spring in the Sahara. The listed locations are about 3000 km apart, almost in a north–south direction and with contrasting climates. The location in Chad is isolated on the northern slopes of an ancient volcano at an elevation of about 1070 m where there is no additional surface water. The population depends on the small amount of seepage water fed from an aquifer in porous material.

The minor differences in ornamentation and their similar body sizes support the idea that populations have not been in contact since the Holocene wet climate interval (i.e. about 6000 years ago; Kröpelin et al. 2008).

Family Parastenocarididae Chappuis, 1940

Genus *Parastenocaris* Kessler, 1913

Parastenocaris joi sp. nov.

(Figs. 9–10)

Type locality. Chad, Tibetsi area; groundwater in dry channel of river Uet Duar near village Totous, northern Chad; 19°26'22" N 17°31'47" E; altitude: 585 m (Fig. 1).

Material examined. Holotype: adult female (length 390 µm), completely dissected, mounted on one slide; collected on 14 March 2014 from ground water on the bottom of 1.5 m deep Karaman-Chappuis pit; access No.: PMSL-Copepoda-Brancelj-1362.

Paratypes: 4 adult females stored in 70% alcohol; collected on the same date and location as holotype; access No.: PMSL-Copepoda-Brancelj-1363.

Etymology. The new species is named after Jo Vermeir, a member of the Chad expedition. I dedicate this species to him in a honour of our long-lasting friendship and his reliability during many expeditions in remote places.

Description. Female, body length, measured from tip of rostrum to posterior margin of caudal rami, 384–409 µm (mean: 388 µm; n = 5); elongated, slightly compressed in dorsoventral direction; largest body width on fourth pedigerous somite; preserved specimens colourless (Figs. 9A, B). Naupliar eye not discernible. Rostrum very small, triangular; no sensilla observed. Integumental window not discernible on any somite. Posterior margins of prosomites and urosomites smooth dorsally (Figs. 9A, B). Genital double-somite as long as wide. Genital complex with single copulatory pore, poorly sclerotized, broadly rounded; seminal receptacles small, simple. Fused plate with reduced P6 positioned well above seminal receptacles (Fig. 10E). Anal segment on ventral side with 2 groups of minute spinules mediolaterally (Figs. 9 B, C). Anal operculum large; 2 sensilla positioned anteriorly; free margin almost straight, not reaching distal end of anal somite (Figs. 9A, B, C).

Caudal rami slightly conical, slightly curved, diverging; each ramus about 3.5-times as long as wide, with few small spines at the distal inner corner (Fig. 9C). Anterolateral external accessory seta (I) slightly shorter than width of furcal ramus, inserted at about 2/3 of its length. Anterolateral external accessory seta (II) about 1.5-times longer than seta I, positioned close to it. Posterolateral seta (III) positioned close to seta II, about twice as long as seta I. Outer apical seta (IV), about 0.5 length of caudal ramus, spiniform, smooth. Inner apical seta (V) straight, with several minute spines on both sides, about 5-times as long as caudal ramus. Inner accessory seta (VI) as long as outer apical seta, soft, smooth. Dorsal seta (VII) slightly longer than caudal ramus, inserted on internal side of it, at about 2/3 of its length (Figs. 9A, B, C).

Antennule (Fig. 9D) as long as cephalothorax, 7-segmented. Aesthetasc (ae) on fourth segment cylindrical, with rounded tip, overreaching tip of seventh segment. Setal formula: 0.4.3.2+ae.1.1. 8+ae.

Antenna (Fig. 9E) with allobasis; small, 1-segmented Exp; robust 1-segmented Enp. Exp with one seta apically. 3 strong spines on outer margin of Enp, increasing in length distally; apical armature consisting of one short and one long robust spine on outermost locations; 3 geniculate setae between both spines.

Mandible (Fig. 9F) short, robust, with 3 strongly chitinised teeth on cutting edge. Dorsal seta near gnathobase. Mandibular palp relatively long, 1-segmented; apically 2 long setae, similar in length.

Maxillule (Fig. 9G) with 3 strong, long spines on praecoxal arthrite. Coxa with 2 setae unequal in length. Basis with one seta.

Maxilla (Fig. 9H) 2-segmented; syncoxa with 2 endites, each with 2 elements apically. Basis with strong beak-like outgrowth. Enp small, with 2 setae unequal in length.

Maxilliped (Fig. 9I) comprising syncoxa, basis, 1-segmented Enp. Syncoxa with no seta distally. Basis 5-times as long as wide. Enp drawn out into strong, acutely curved claw; about half of basis length; additional armature represented by a short seta.

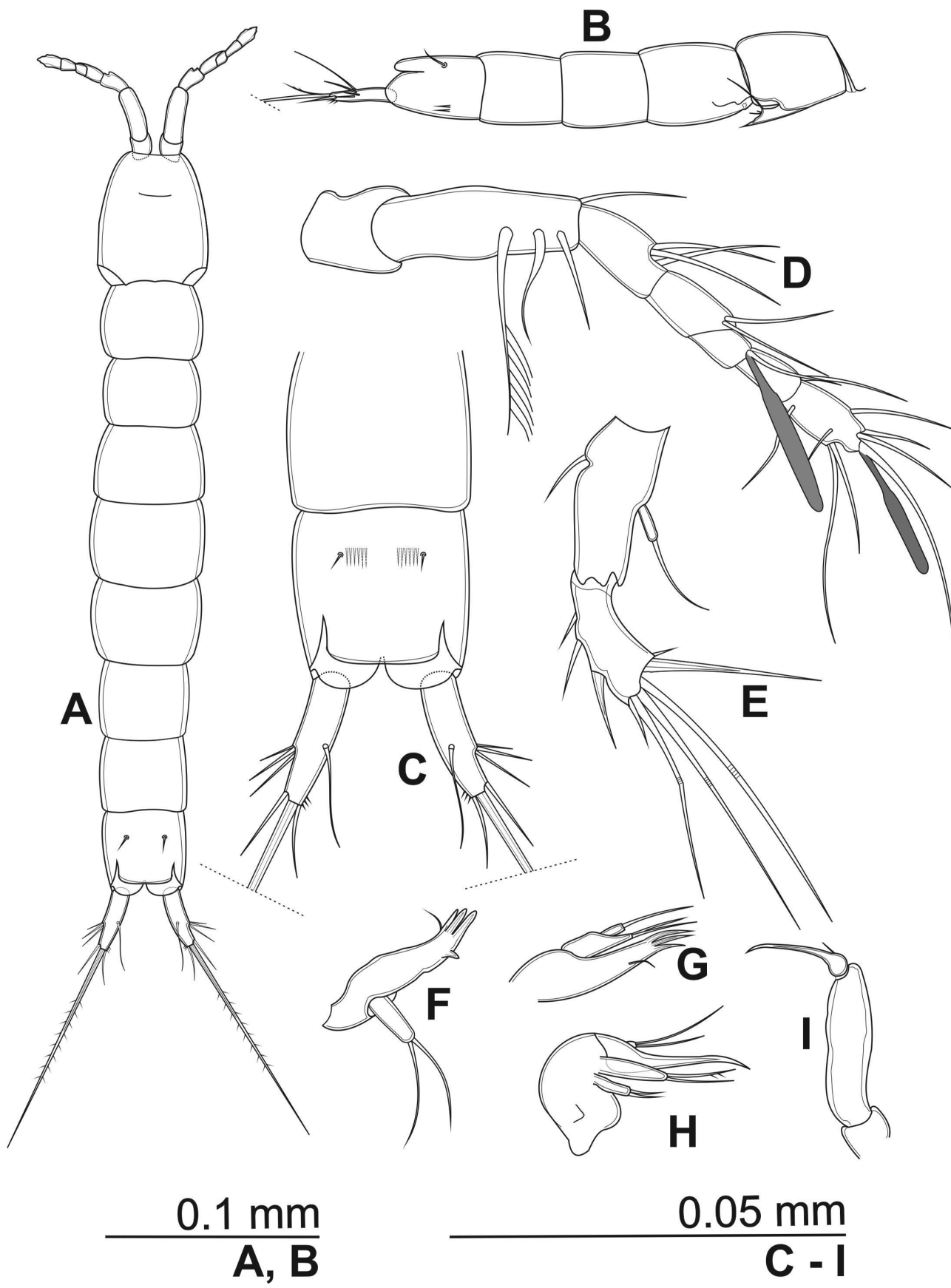


FIGURE 9. *Parastenocaris joi* sp. nov., holotype female: A, habitus dorsal view; B, urosome, lateral view; C, 5th urosomal and anal somite with furcal rami, dorsal view; D, antennule; E, antenna; F, mandible; G, maxillule; H, maxilla; I, maxilliped.

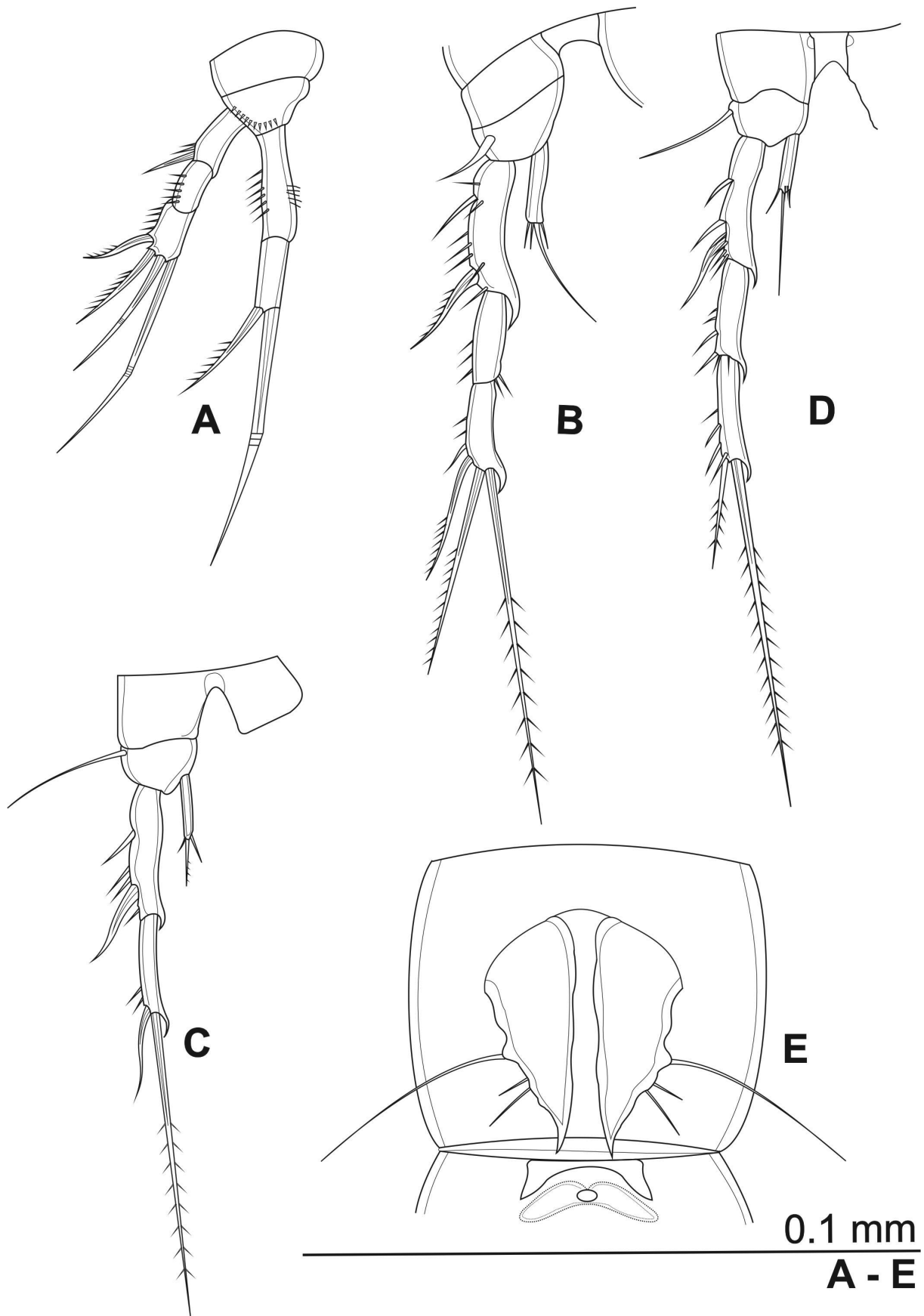


FIGURE 10. *Parastenocaris joi* sp. nov., holotype female: A, P1; B, P2; C, P3; D, P4; E, P5 & P6 and genital field.

P1 (Fig. 10A): basis with row of spinules on anterior margin distally. 3-segmented Exp, 2-segmented Enp; equal in length. Exp-1 with one strong outer spine; Exp-2 with no spine or seta; Exp-3 with one strong spine subapically; 3 setae apically, increasing in length, longer 2 geniculate. Longest geniculate seta longer than Exp. Enp-1 with no seta or spine; row of spines along outer margin. Enp-2 with 2 setae apically, longer one geniculate and longer than End.

P2 (Fig. 10B): basis with one spiniform outer seta. 3-segmented Exp, 1-segmented Enp. Enp about 1/2 length of Exp-1. Exp-1 about 4-times as long as wide, with 2 spines along outer margin. Proximal spine smooth, at 1/4 of Exp-1 length; distal one with small spinules, at the distal corner. Exp-2 about 3-times as long as wide, with few spinules along outer margin. Exp-3 as long as Exp-2, with 2 outer spines; proximal very short, distal about 1/3 longer than Exp-3; 2 spiniform setae apically; shorter one with spinules unilaterally, longer one bipinnate. Enp-1 4.5- times as long as wide; with 4 elements apically: 3 short spiniform setae, one long smooth seta, about 1.5-times longer than Enp-1.

P3 (Fig. 10C): basis with one long, thin, smooth seta on outer margin. 2-segmented Exp, 1-segmented Enp. Enp about 0.5 length of Exp-1. Exp-1 similar to Exp-1 of P2. Exp-2 with one long spine subapically, one long spiniform seta apically. Enp-1 about 6-times as long as wide; with 3 spines unequal in length apically; one very short, the longest about 0.5 length of Enp-1.

P4 (Fig. 10D): basis with one long, thin, smooth seta on outer margin. 3-segmented Exp, 1-segmented Enp. Enp about 1/2 length of Exp-1. Exp-1 with 3 spines, increasing in length; proximal shortest, distal longest; proximal spine at 1/3 of outer margin length; middle spine at 2/3 of margin length; distal one subapically. Exp-2 with 2 small spines; one at 2/3 of margin length, second one subapically. Exp-3 4.5-times as long as wide, with 2 relatively weak spines on outer margin; proximal at 3/4 of margin length, distal one subapically; two elements apically: one spiniform seta as long as Exp-3, one about 3-times longer than Exp-3. Enp-1 5-times as wide as long, about 0.5-times length of Exp-1. 3 elements apically: 2 very short spines, one spiniform seta about 1.5-length of Enp.

P5 (Fig. 10E) well separated, each half triangular in shape, with sharply pointed tip. Outer margin with 2 short spines distally, one long smooth seta proximally. Inner margin smooth.

P6 (Fig. 10E) reduced to small, fused plate, with pointed tip on each side.

Male. Not known.

Variability. Except slight differences in body length, no variability was observed.

Remarks. Since only females were collected, it is not possible to allocate the new species accurately to any of the many new genera recently described or resurrected (Karanovic & Lee 2012). For that reason this species should be provisionally included into the genus *Parastenocaris* Kessler, 1913, *sensu lato*, until males are found enabling precise allocation of the species into its definitive genus status.

So far only five species of parastenocaridids have been recorded from the Sahara (Table 1). From Mali, Chappuis (1959) reported *Parastenocaris nigerianus* Chappuis, 1959 and *Monodicaris monodi* (Chappuis, 1959). A further three species have been reported from Algeria: *Parastenocaris kabyla* Chappuis, 1954; *Parastenocaris ahaggarica* Božić, 1978; and *Cotarellicaris numidiensis* (Rouch, 1987) (see Chappuis 1954; Božić 1978; Rouch 1987).

More detailed analysis of possible differences between those five species and the new species is difficult as the previous descriptions were frequently incomplete. In fact, there are no figures for *P. kabyla*, which was collected close to the coast, and only males were found. Chappuis (1954) reported that P4 and P5 of the male of *P. kabyla* are similar to those in *P. fontinalis* Schnitter & Chappuis, 1915. As figured in Janetzky et al. (1996), P5 in the female of *P. fontinalis* is quite different from those in *P. joi* **sp. nov.**

For *P. nigerianus* and *M. monodi*, only figures of males are presented and there are not enough details in the text to make any concise conclusions on taxonomic relations between those two species and the new one. However, the shape and armature of furcal ramus in males, and especially the position of lateral and dorsal setae, are quite different from those observed in the female of the new species. In *M. monodi* furcal ramus is longer, straight, conical, with width/length ratio of about 1:6 (about 1: 3.5 in the new species) and with only one external lateral seta (anterolateral external accessory seta (II)?) vs. three relatively long setae (I-III) in the new species. Outer apical seta (IV) in *M. monodi* looks long and soft, but short and spiniform in the new species. Only insertion of dorsal seta (VII) at 1/2 of inner margin length is similar to those in *P. joi*.

In *P. nigerianus* width/length of furca is about 1:4; divergent and slightly curved outward, like in the new species. In *P. numidiensis* one single external seta is figured (anterolateral external accessory seta (II)?) at about 1/3 of external margin length, compared to three setae in the new species: anterolateral external accessory seta (I), anterolateral external accessory seta (II) and posterolateral seta (III); all inserted at about 2/3 of external margin length (Fig. 9C). Shape and position of outer apical seta (IV) is similar in both species. Insertion of dorsal seta (VII) in *P. nigerianus* is at the distal middle part of furcal rami, while in the new species is at internal side of it, at about 2/3 of its length.

For two species enough detailed description exists to make more firm conclusions on taxonomic relations between them and the new species. In *P. ahaggarica* End P2–P4 of the female have one apical element each and thus are different from those in *P. joi*, with 3 or 4 elements of different lengths on each End. Also P5 in both species differ in shape and number of elements. P5 in *P. joi* has three elements laterally and a pointed distal end while *P. ahaggarica* has four elements; two of them apically and with no distinct tip.

There are some similarities between *P. numidiensis* and *P. joi* in the armatures of P2 and P4, but not of P3. End P3 of *P. joi* has three elements apically, while in *P. numidiensis*, the distal part of End ends with a sharp point. The distal end of P5 in both species ends with a sharp point, but on the outer margin there are 3 elements in *P. joi* and four in *P. numidiensis*. In *P. numidiensis* there is a very obvious incision in the middle of the outer margin, just next to the longest seta on P5, while in *P. joi* there is only slight depression. There are also differences on the anal operculum, which is short, and with straight free margin in *P. joi*, but longer and semicircular in *P. numidiensis*. The two species also differ considerably in the shape of the furcal rami and their armature. In *P. numidiensis* the furcal ramus is curved inward, while in *P. joi* it is curved outward. The lateral setae and dorsal seta in *P. joi* are positioned at 2/3 of caudal ramus length, while in *P. numidiensis* they are positioned at about 3/4 of the caudal ramus length. The inner apical seta (V) is swollen at the base in *P. numidiensis*, while in *P. joi* it tapers evenly from its base to tip.

On consideration of the above listed differences between the six species from the Sahara it is evident that the collected specimens belong to the new species, *P. joi*. At the same time the existence of several characters in common between *P. numidiensis* and the new species also indicates that the new species belongs to the genus *Parastenocaris* Kessler, 1913, *sensu stricto*.

Discussion

In the Sahara 130 stygobionts belonging to different taxonomic groups, ranging from Turbellaria to Crustacea, have so far been found (Botosaneanu 1986; Juberthie & Decu 2001). Most of them were collected at the periphery of the desert or in some spots relatively easy to access (i.e. the Tamanrasset, Algeria). The majority of sampled habitats are karstic caves and springs and the interstitium along the rivers or the wells.

Recent sampling of various groundwater habitats in the northern Chad has shown that there are not many possibilities of collecting interstitial fauna in wind-drifted sand deposits (dunes) along the lakes in the Ounianga area. The particle size of drifted sand is uniform, less than 1 mm in diameter, in the range of the size of interstitial fauna and providing no living space for groundwater organisms.

Much better conditions for existence of groundwater fauna are in the valleys of ancient rivers connected with gueltas/aguelmans. There, the sediments are diverse in size, from pebbles several cm in diameter to fine sand (mm in diameter) or even mud (less than a tenth of a mm in diameter). They were transported by rivers and, depending on flow velocity, deposited at random along their course. The differences in sediment size make enough living space for diverse meiofauna, both in taxonomic composition as well as in body size.

At the same time, we found that the wells along travel routes or within villages can be contaminated with epigeal fauna, mainly Cladocera and Copepoda. This results from contamination by residual water from water bags/containers re-filled with water from the wells. Travellers frequently empty their containers into the wells before re-filling them. To avoid samples contaminated with such epigeal fauna, the Karaman-Chappuis method of digging a hole into the river bed, where water table is close enough to surface, is a better choice than direct sampling of wells.

The fauna in the valleys of ancient rivers expresses stygobiotic adaptations that are not a result of rapid and brief evolution in the last 6000 years, when the Sahara turned from a savannah into dry land (Kröpelin et al. 2008). Their adaptations, loss of pigmentation, eyes and reduction of segments have resulted from a much longer

existence and evolution in subterranean environment. Groundwater fauna was affected during the transformation into a dry landscape, but probably less so than the epigeal aquatic fauna which only managed to survive in a few surface water bodies. However, even the epigeal fauna still reflects the rich and diverse aquatic fauna existing before the drastic changes in hydrological regimes started (Lévêque 1990; Dumont 2007, 2014; Kröpelin et al. 2008; Trape 2009, 2013).

The high altitude plateaus with deep ancient river valleys and wide alluvial plains, distributed in remote and almost inaccessible mountain parts of the Sahara, are connected with aquifers which appear at the surface locally as permanent or temporary gueltas/aguelmans. These are places where stygobionts with ancestors from the Tertiary are relatively easily accessible through temporary wells dug in shallow sand deposits. Sampling such locations could provide a stygobiotic fauna comparable with that in Europe (Deharveng et al. 2009), if appropriate sampling methods were employed. However, special attention must be given to mesh size (i.e. about 60 µm) and to techniques that enable the sampling of small volumes of interstitial water. The most common groups expected there would be Copepoda, Isopoda, Syncarida and Amphipoda, according to the list of stygobionts already known from the Sahara (Juberthie & Decu 2001). The list from the Sahara has a similar proportion of representatives of the main groups as that recorded during PASCALIS project in Europe (Stoch et al. 2009).

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