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A new species of *Megadiaptomus* Kiefer, 1936 (Copepoda: Calanoida: Diaptomidae) from the Western Ghats of India, with notes on the biogeography and conservation status of the species of the genus

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ABSTRACT

Megadiaptomus montanus **n. sp.** is described based on plankton samples collected from temporary water bodies in the Western Ghats of Maharashtra state, India, a mega-diverse region and biodiversity hotspot in west-central India. This is the third species of *Megadiaptomus* Kiefer, 1936, the other two being *M. hebes* Kiefer, 1936 from Sri Lanka and southern India and *M. pseudohebes* Ranga Reddy,1988 from south-eastern India. All three species are large-sized inhabitants of temporary waters having a rather restricted distribution on the Indian subcontinent, and are presently facing increasing anthropogenic pressures. By IUCN criteria they are assignable to the Critically Endangered category (CR B2). The new species can be easily distinguished from its congeners in that the males have a short, spinous process on the antepenultimate segment of the right antennule; the second exopodal segment of the right leg 5 (P5) has a proximal, quadrate accessory process; and the inner apical spiniform process of the left P5 is greatly transformed, a remarkable apomorphy for the family Diaptomidae Baird, 1850. The urosome has three somites in the female, and the coxal spines of the P5 are large and asymmetrical. The salient characters and their different states in the three species of *Megadiaptomus*, in contrast to those of the other Indian species of Diaptomidae, are briefly discussed. Notes on the biogeography, ecology, and conservation status of the species of *Megadiaptomus* are also given.

Key Words: character states analysis, critically endangered species, taxonomy, temporary ponds

INTRODUCTION

The freshwater copepod genus *Megadiaptomus* Kiefer, 1936 (cf. Kiefer, 1936c) has had until now two nominal species, *M. hebes* Kiefer, 1936 (cf. Kiefer, 1936c) and *M. pseudohebes* Ranga Reddy, 1988, which are rare and have restricted distributions on the Indian subcontinent (Ranga Reddy, 1988; Dussart & Defaye, 2002; Walter, 2015). The type species, *M. hebes*, was described from an unspecified locality in Mysore state (presently Karnataka state), and *M. pseudohebes* from temporary water bodies in Andhra Pradesh state. The morphology of all the postembryonic instars of the latter species reared under laboratory conditions has been described (see Ranga Reddy & Devi, 1985; as *M. hebes*). Overlooking the description of *Megadiaptomus* by Kiefer (1936c), some workers described the two nominal taxa *Heliodiaptomus alikunhii* Sehgal, 1960 from Orissa (now Odisha) state and *Zeylanodiaptomus papillopedis* Fernando & Hanek, 1976 from Sri Lanka. Radhakrishna & Ranga Reddy (1977) and Ranga Reddy (1988) explained that *H. alikunhii*, the description of which is rather sketchy and includes no explicit type designation, is in all probability synonymous with *M. hebes*, and that *Z. papillopedis* is clearly a synonym of *M. hebes*, based on their examination of its type material.

During recent faunistic surveys in the Western Ghats of Maharashtra, also known as the Northern Western Ghats, one of us (MRK) came across several populations of a species of *Megadiaptomus* that was initially mistaken for *M. pseudohebes* (Kulkarni & Pai, 2016a, b). Subsequent examination and comparison with topotypes of *M. pseudohebes*, however, has shown that it is

indeed a new species, *Megadiaptomus montanus* **n. sp.** We provide herein a detailed description of the new species based on material collected from various temporary water bodies in the Northern Western Ghats. The salient characters and their different states within *Megadiaptomus* in comparison with the other Indian species of the family Diaptomidae Baird, 1850, are briefly discussed. Notes on the ecology, biogeography, and conservation status of the species are also given.

MATERIALS AND METHODS

The specimens were isolated from multiple samples collected during a series of visits (2012–2015) to various rocky outcrops in the Northern Western Ghats (leg. MRK and colleagues). Samples were collected using both hand- and tow-nets with mesh size 100 µm and 80 µm, respectively, and preserved in either 4–5% formalin or 90–100% ethanol. Data for some physical and chemical parameters were recorded in the field, using a handheld multi-parameter probe (PCSTestr-35; Eutech, Singapore). Geographical co-ordinates of sites were noted with a handheld GPS unit (ETrex-10, Garmin, Taipei, Taiwan). Specimens were isolated, cleaned, and dissected in glycerol under a stereomicroscope (40× magnification), and permanent slides prepared following Ranga Reddy (2013a). Line drawings were made using a Leica DM 2500 Trinocular Research Microscope (Leica, Wetzlar, Germany), equipped with a UCA condenser, IC objective prism, and 1–2× magnification changer. Digital photographs were taken using Leica EC 3 and Zeiss (Jena, Germany) Axiovision cameras. Images were post-processed using Adobe Photoshop CS3. Some specimens were processed for scanning electron microscopy (SEM) following the chemical drying method (adapted from Nation, 1983) and imaged at 10/20kV using a JEOL-JSM scanning electron microscope (JEOL, Akishima, Japan). Males and females from the following populations were used for morphometry: Tableland, $N = 10$ of each sex; Masai, $N = 10$ of each sex; Medha, $N = 10$ males, 7 females; Kusavade, $N = 9$ of each sex; Mhavshi, $N = 9$ males, 5 females; Jhenda, $N = 5$ males, 10 females). The type material was deposited in the National Zoological Collections of the Zoological Survey of India (ZSI), Western Regional Centre, Pune, India, and also at the Muséum national d'Histoire naturelle (MNHN), Paris, France. Distribution maps were prepared using Diva–GIS (v.7.5) and Area of Occupancy was calculated using GeoCat (Bachman *et al.*, 2011).

The following abbreviations were used: A1 = antennule; A2 = antenna; Enp = endopod (enp1–3 = endopodal segments 1–3); Exp = exopod (exp1–3 = exopodal segments1–3); Md = mandible; Mx = maxilla; Mxl = maxillule; Mxp = maxilliped; P1–P5 =thoracic legs 1–5.

SYSTEMATICS

Subclass Copepoda H. Milne Edwards, 1840
Order Calanoida Sars, 1903
Infraorder Neocopepoda Huys & Boxshall, 1991
Family Diaptomidae Baird, 1850
Megadiaptomus Kiefer, 1936

***Megadiaptomus montanus* n. sp.**

(Figs. 2–9)

Type material: Holotype adult male (ZSI-C1538-1/1–4) and allotype adult female (ZSI-C1539-1/5–8), dissected on four slides

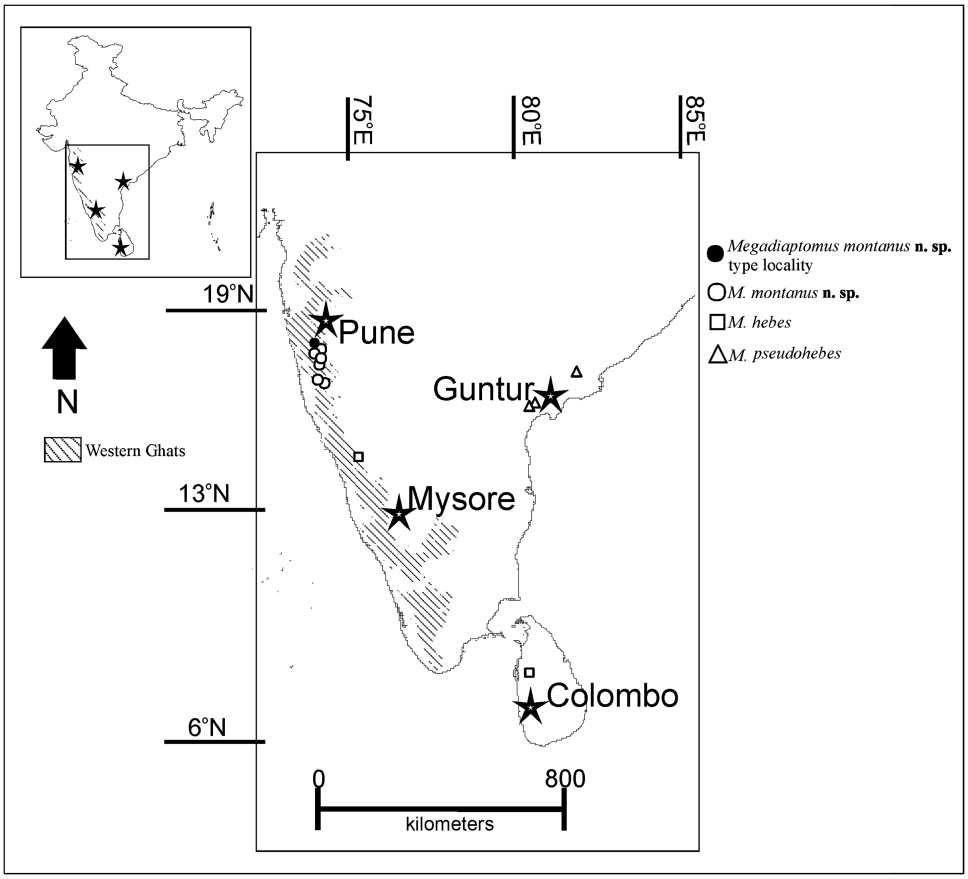

Figure 1. Map showing the distribution of *Megadiaptomus* spp.

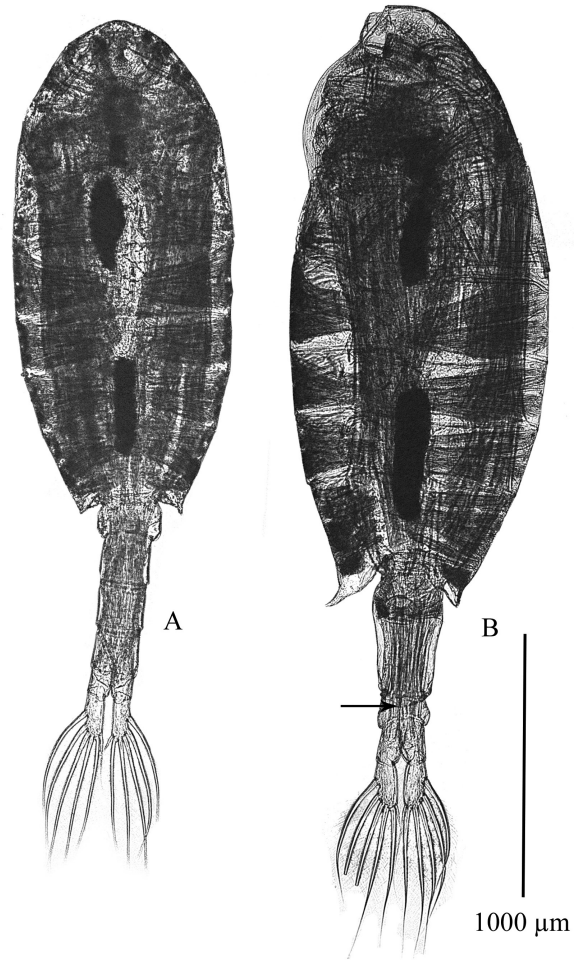

Figure 2. *Megadiaptomus montanus* **n. sp.** holotype male habitus, dorsal view (**A**); allotype female habitus, ventral view (arrow pointing to short mid-distal process) (**B**).

each, and deposited in the National Zoological Collections of the Zoological Survey of India (ZSI), Western Regional Centre, Pune, India, and two male paratypes and two female paratypes (MNHN-IU-2016–2954), preserved whole in 70% alcohol in a vial and deposited at MNHN. All other paratypes (undissected males and females (10 each); dissected males and females (four each)) are in the personal collection of MRK.

Type locality: Tableland (02°10′20″S, 147°19′20″E; elevation 1,250 m) Panchgani, Maharashtra state, India (Fig. 1). This is a large lateritic plateau located in the Northern Western Ghats (NWG), which are part of the Western Ghats biodiversity hotspot. Many shallow (depth 0.5–0.7 m), short-lived (hydroperiod June to early October) pools and ponds are generally formed in monsoons. The pools are typically devoid of vegetation and planktivorous fishes, and have a muddy or rocky substratum. This site has been declared a threatened ecosystem and faces tremendous pressure from tourism.

Other localities: All other localities and the nature of anthropogenic stress on them are as given in Table 2.

Description of holotype (*adult male*): Total body length 2.32 mm excluding caudal setae. Body (Fig. 2A) more slender than female. Prosome nearly twice as long as urosome. Rostrum (Fig. 3C) delineated from frontal margin of cephalic shield by complete suture, with stumpy but acutely pointed, paired asymmetrical filaments; right filament with small process proximally. Fourth, fifth pedigers separated by distinct suture. Postero-lateral wings of fifth pediger small, asymmetrical, with minute apical spine each; right wing relatively large, somewhat produced at distal corner.

Urosome with 5 somites, straight. Genital somite wider than succeeding somites with minute spine on either side at postero-lateral corner; other urosomites normal without ornamentation. Both caudal rami alike; each ramus 2.5 times as long as wide, with hairy inner margin; caudal setae normal.

Left A1 (Fig. 4A) 25-segmented, extending slightly beyond genital somite. Number of setae (s), spines (sp) and aesthetascs (a) of each segment as follows: (1) s + a, (2) 3s + a, (3) s + a, (4) s, (5) s + a, (6) s, (7) s + a, (8) s + sp, (9) 2s + a, (10) s, (11) 2s,(12) s+ sp + a, (13) s, (14) s + a, (15) s, (16) s + a, (17) s, (18) s, (19) s + a, (20) s, (21) s, (22) 2s, (23) 2s, (24) 2s, (25) 4s + a; proximal seta on segment 11 modified as in Fig. 3A,B.

Right A1 (Figs. 4B, C; 6A-C) 22-segmented, with geniculation between segments 18,19; spines present on segments 8, 10–13 and those on segments 11, 13 almost equal in size. Spinous process on segment 20 rather short, knob-like, about 1/4 as long as segment 21, lined with narrow hyaline membrane.

A2 (Fig. 4D) biramous. Coxa with inner seta. Basis with 2 setae at distal inner corner. Exp 7-segmented; segmentation, armature pattern as follows: segment 1 (ancestral segment I) with 1 seta; segment 2 (ancestral segments II–IV) with 3 setae; segments 3–6 (V–VIII, respectively) with 1 seta each; segment 7 (IX–X) with 1 sub-proximal and 3 long distal setae. Enp 2-segmented; segment 1 with 2 setae on sub-distal inner margin and ornamented with oblique row of spinules near outer distal corner; segment 2 bilobed; inner lobe with 8 setae distally; outer lobe with 7 distal setae and spinules at outer distal corner.

Md (Fig. 4E). Gnathobase strongly sclerotized, carrying prominent lobe on distal margin; cutting blade with acute caudal and subcaudal triangular teeth and 1 group of 6 multi-cusped teeth; apical 3 teeth particularly acute; single dorsal seta near apical margin. Palp basis with 1 subproximal seta (opposite to base of Exp), 3 subdistal setae on inner margin. Exp 4-segmented; setal formula: 1, 1, 1, 3. Enp 2-segmented; segment 1 dilated distally, bearing 4 inner setae; segment 2 with 9 apical setae and 2 oblique rows of spinules on anterior margin.

Mxl (Fig. 4F). Praecoxal arthrite with 10 strong marginal, 5 submarginal spiniform setae. Coxal epipodite with 9 setae, 2 proximalmost setae smaller than others. Coxal endite with 4 setae. Basal exite represented by outer seta. Proximal basal endite with 4 distal setae; distal endite fused to basis, with 4 setae. Enp 1-segmented, bilobate, proximal lobe with 3 setae on margin, distal lobe with 5 setae, 1 arched row of spinules on disto-ventral surface (not discernible in Fig.4F). Exp unsegmented, armed with 6 distal setae, ornamented with fine spinules on distal inner margin.

Mx (Fig. 4G). Praecoxa, coxa fused medially, but distinct laterally. Proximal praecoxal endite with 5 setae, 1 small spiniform seta proximally; distal endite with 3 setae. Coxal endites with 3 setae each. Allobasis prominent, with 3 setae. Enp 3-segmented, with setal formula 1, 1, 3.

Mxp (Fig. 4H). Praecoxal endite with 1 seta. Coxa with 3 endites with 2, 3, 4 setae respectively from proximal to distal; distal inner angle produced into subspherical lobe, ornamented with short spinules around margin. Basis with 3 unequal setae on dilated medial margin, ornamented with rows of short spinules, long bristles proximally. Enp 6-segmented; segment 1 reduced in size; setal formula: 2, 3, 2, 2, 1 + 1, 4.

P1–P4 (Figs. 5A-D, 6D). Biramous, rami 3-segmented, except P1with 2-segmented enp. Praecoxa small, somewhat rectangular, unornamented. Intercoxal sclerite, especially in P2–P4, with bulbous antero-lateral corners each ending in short spinous projection. Coxa unornamented, subdistal inner plumose seta large and extending beyond distal margin of enp1 in P1–P3, but only up to distal

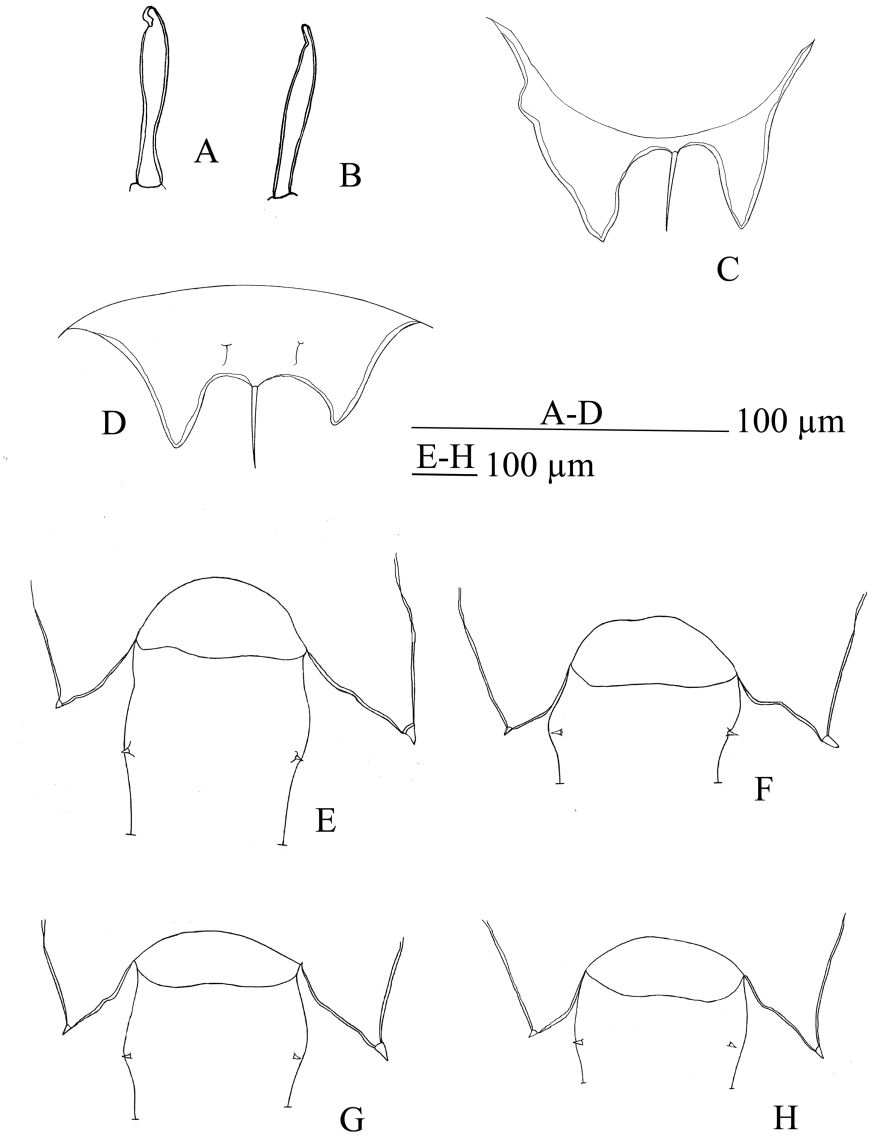

Figure 3. *Megadiaptomus montanus* **n. sp. A–C,** paratypes, male; **D–H**, paratypes, female. left A1, proximal seta on segment 11 (**A, B**); rostrum, ventral view (**C, D**); postero-lateral wings of pediger 5 and proximal part of genital double-somite (to show variation), dorsal view (**E–H**).

margin of basis in P4. Outer margins of exp1-3, inner margins of enp1–3 ornamented only with rows of bristles. Spine on exp1 much smaller than that on exp3 in P1. P4 basis with reduced outer seta on posterior surface. Distal outer spines on exp1–3 of P2–P4 modified into large 'blunt spines' or 'spinose papillae' each 2/3 as long as its respective segment; papillae ornamented with fine spinules on lateral margins. Outer distal element of exp3 of P1–P4, as usual, modified into strong spiniform seta. Full armature formulae as follows (spines, setae denoted by Roman and Arabic numerals, respectively; element or elements on outer margin of any segment given first, separated by hyphen from inner margin element or elements; armature of terminal segment of each ramus with 3 parts separated by hyphens, given in sequence: outer margin, distal margin, and inner margin):

	Coxa	Basis	Exopod	Endopod
P1	0–1	0-0	I-1; 0–1; I-3-2	0–1; 1-2-3
P2	0–1	0-0	I-1; I-1; I-3-3	0–1; 0–2; 2-2-3
P3	0–1	0-0	I-1; I-1; I-3-3	0–1; 0–2; 2-2-3
P4	0–1	1-0	I-1; I-1; I-3-3	0–1; 0–2; 2-2-3

P5 (Figs. 7A–E, 8A, B). Right P5 strongly built. Coxa roughly rectangular, overlapping inner proximal margin of left P5 coxa, armed with moderately strong hyaline spine at outer distal corner of caudal (posterior) surface. Basis roughly rectangular with inner proximal corner produced into broad but short projection, with following structures: chitinous 'ridge' running to about middle of inner margin, with short projection at each end; 1 broadly spatulate lobe lying near outer distal corner, arching over exp1 on posterior surface; usual short seta on outer distal margin. Exp1 much wider than long, with triangular lobe at inner distal angle, bifid lobe at outer distal corner (Fig. 7B). Exp2 about twice as long as wide, with quadrate flap-like structure (accessory process) with rounded postero-lateral corners located near proximal outer corner on posterior surface. Lateral spine nearly straight, acutely pointed, 0.7 times as long as exp2, inserted on sub-distal margin, rather close to end claw. End claw almost twice as long as exp2, thick sub-proximally, doubly curved distally, tip acutely pointed; inner margin except for proximal third ornamented with tiny spinules (Figs.7A, 8A, B). Enp reduced, unsegmented, about as long as posterior inner margin of exp1; apex blunt, with about 10 spinules (Fig. 7B).

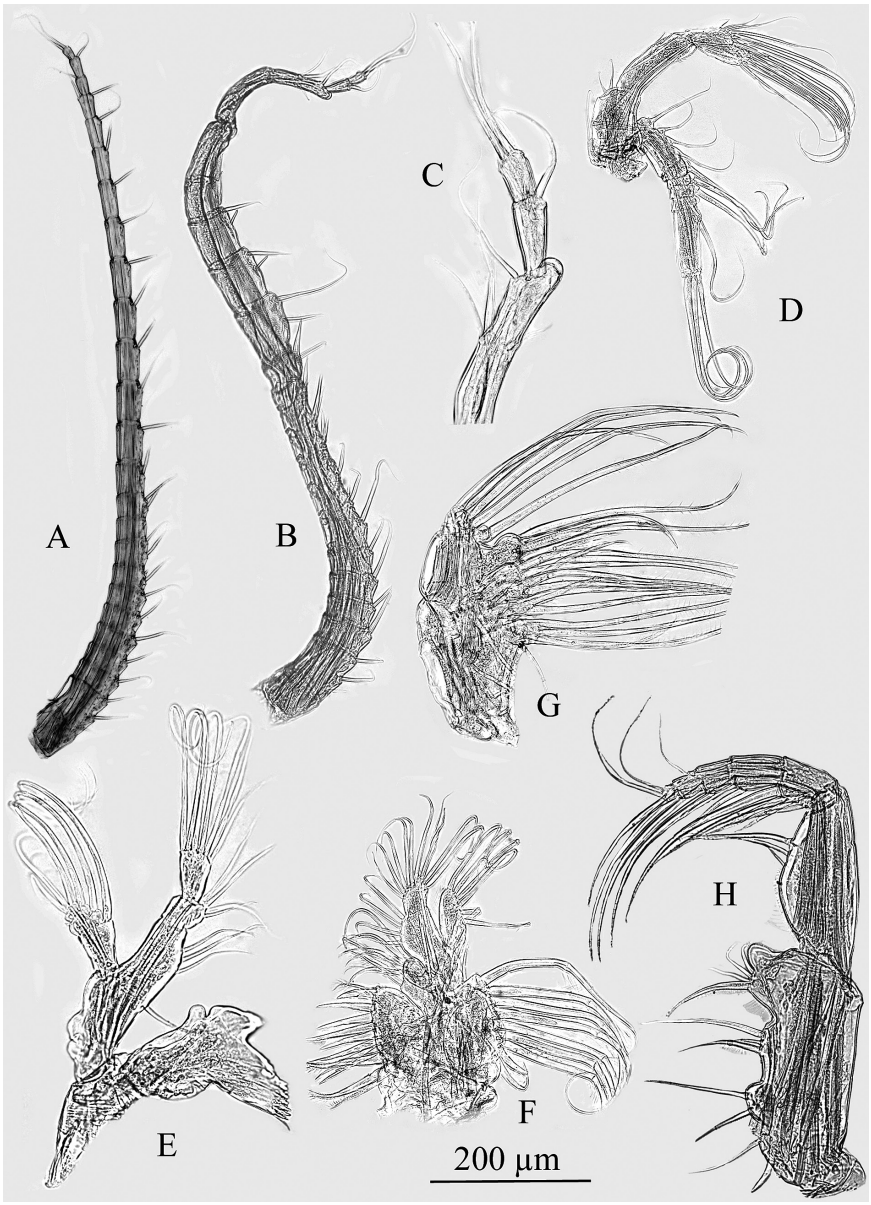

Figure 4. *Megadiaptomus montanus* **n. sp.** holotype male: left A1 (**A**); right A1 (**B**); same, segments 20–22 (**C**); A2 (**D**); Md (**E**); Mxl (**F**); Mx (**G**); Mxp (**H**).

Left P5 sturdily built, reaching about mid-length of right P5 exp2. Coxa over half as long as basis, having small hyaline spine near inner distal corner. Basis squarish, with convex outer margin; inner margin lacking hyaline lobe but with indented distal half; small sensory seta near distal outer corner. Exp1 oval, almost as long as basis (Fig. 7A), with sensory pad of fine hairs on distal inner margin. Exp2 short, bulbous, deeply bent inwards, bearing 2 apical structures: short, thumb-like outer process with smooth outer margin, finely serrulate inner margin, blunt apex; and inner setiform process modified into massive, horn-shaped structure, with bulbous proximal region drawn out distally into acute setiform structure, both parts ornamented with several rows of short spinules as in Figs. 7D, 8A. Enp somewhat bottle-shaped (Fig. 8A), slightly shorter than exp1; apex with transverse row of about 10 spinules.

Description of allotype (*adult female*): Total body length excluding caudal setae 2.64 mm. Prosome robust, widest at first pedigerous somite, about 3 times as long as urosome (Fig. 2B). Rostrum (Fig. 3D) with stumpy but acutely pointed, paired symmetrical filaments, delineated from frontal margin of cephalic shield by complete suture, 2 sensillae adjacent to suture. Pedigerous somites 4, 5 perfectly fused together, lacking ornamentation between them. Pedigerous somite 5 with somewhat asymmetrical postero-lateral wings; right wing larger, with proximal half relatively wide, but distal part narrow, triangular; left wing apically produced into digitiform process; each wing bearing 2 small hyaline spines, 1 on inner margin and 1 apically.

Urosome with 3 somites. Genital double-somite slightly longer than other somites and caudal rami combined, nearly symmetrical, with sub-proximal left margin a bit dilated and mid-distal margin produced into short ventral process (Fig. 2B, arrowed); 1 tiny hyaline spine present on either side of somite sub-proximally. Genital area located centrally on ventral surface of proximal half of genital-double somite; genital operculum crescentic, with flat postero-lateral margins (Fig. 9E). Second urosomite with

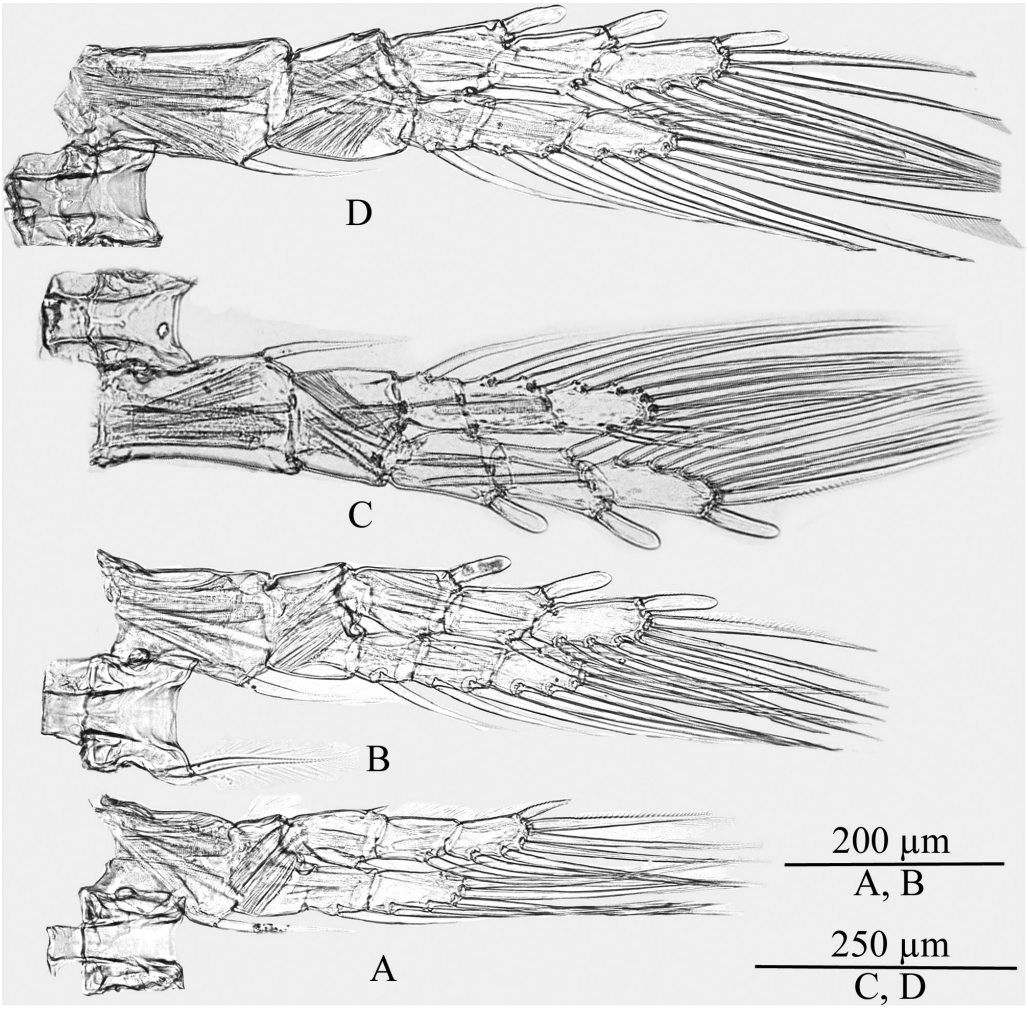

Figure 5. *Megadiaptomus montanus* **n. sp.** holotype male: P1–P4(**A–D**).

dilated postero-lateral margins. Anal somite partly telescoped into second urosomite and with straight lateral margins. Caudal rami symmetrical, parallel, about 3 times as long as wide; both rami with fine hairs along inner margins. All principal caudal setae normal; lateral seta of each ramus arching over neighbouring seta; dorsal jointed setae of both rami equal, 2/3 as long as principal setae.

A1. Twenty-five segmented, not extending beyond lateral wings of fifth pedigerous somite; other details as in male left A1. Other cephalic appendages and P1–P4 also as in male.

P5 (Fig. 9A-D). Both legs strong, nearly symmetrical. Coxa subrectangular, with strong spine arising from lobed structure located at disto-outer corner of caudal surface; right coxal spine larger than left one. Basis roughly trapezoidal, with convex inner margin, outer sensory seta short. Exp1 over twice as long as wide, with nearly straight inner margin, slightly curved outer margin. Exp2 tapering off into moderately strong claw, bearing spinules on lateral margins (Fig. 9C), short lateral spine at base of exp3. Exp3 short, quadrate, not defined at base, having 2 unequal spines: smooth outer spine, about 1/3 as long as inner spine with fine spinules on lateral margins; inner setiform spine about 2/3 as long as end claw. Enp 1-segmented (distinct lateral notch at mid-length, probably representing partial segmentation), slightly shorter than exp1, proximal 1/3 with dilated inner margin; apex obliquely truncate, bearing about 10 closely-set spinules.

Colouration in life: Both males and females pale bluish-white with deep reddish-violet antennules and caudal setae.

Egg sac: Quadrate, containing about 15–26 eggs ($N = 6$).

Variation: Body length ranges from 2.00 to 2.52 mm, mean 2.28 mm ($N = 54$), in males, and from 2.25 to 3.00 mm, mean 2.64 mm ($N = 53$), in females. The urosome is posteriorly bent to the right in some males. The spatulate hyaline lobe on the right P5 basis varies in size within and between populations, sometimes short (Fig. 7A), but often reaching the base of the accessory process of exp2 (Fig. 7B). The lobes on exp1 of right P5 are somewhat variable and in some preserved specimens the end claw of the right P5 is bent sharply backward over exp2 (not figured). The postero-lateral wings of females, especially the right wing, of the fifth pedigerous somite vary in size and form (Fig. 3F-I), and sometimes the right enp is slightly longer than the left enp on the P5 (not figured).

Ecology: *Megadiaptomus montanus* **n. sp.** appears to be restricted to high altitude (> 900 m), temporary, shallow, fishless pools and ponds on lateritic outcrops in the NWG.

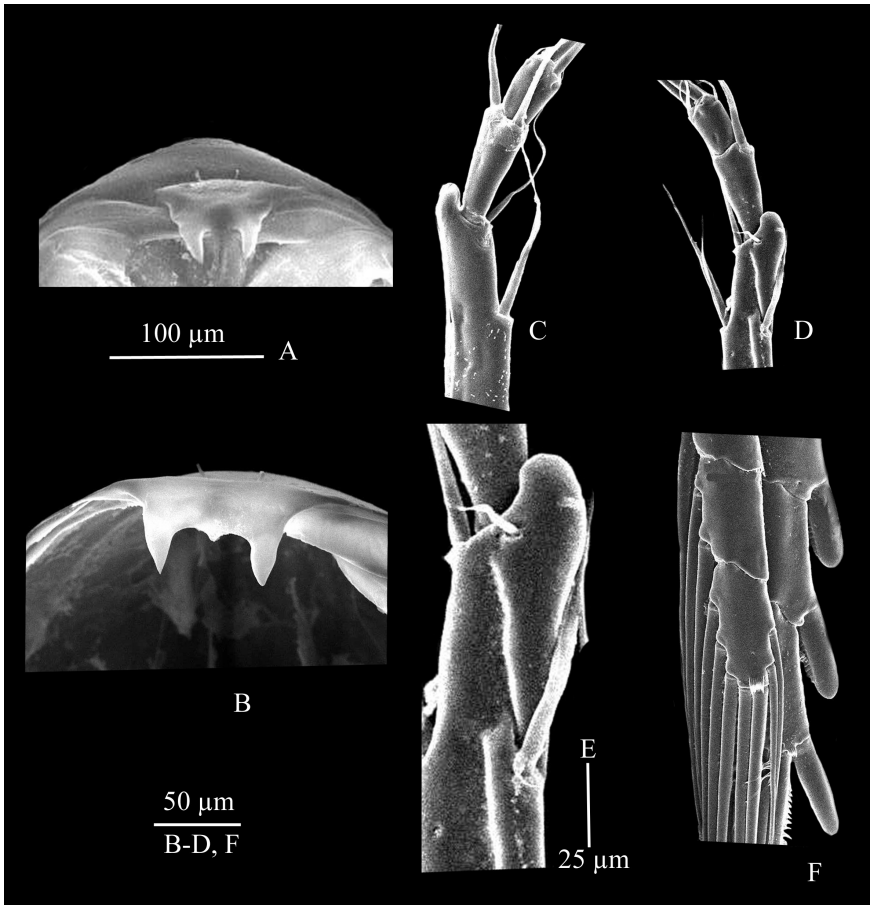

Figure 6. *Megadiaptomus montanus* **n. sp.**, SEM photographs, paratypes: male (**A, C–E)**; female (**B**, **F**). rostral filaments, ventral view (**A**, **B**); right A1, segments 20–22 (**C**, **D**); same, segment 20 (**E**); P4, exp and enp (part) (**F**).

The water parameters of its habitats (individual pools in the entire distributional range) were as follows: pH 6.25–8.7, water temperature 19.9–33.4°C, electrical conductivity 25.1–240 µS, total dissolved solutes 17.8–169 ppm, and salinity 15.5–129 ppm. The depth of habitats ranged from 0.5–1.5 m, with only a few habitats having a depth >1.5 m. The substratum of most habitats was rocky, covered by a layer of fine sediment. The water was very turbid in most habitats, but clear in some, usually in the late hydroperiod. Emergent vegetation and algae were observed only in some of the habitats sampled. The co-occurring fauna included ostracods (see Shinde *et al.*, 2014), large branchiopods (see Padhye & Dahanukar, 2015), cladocerans (see Padhye & Victor, 2015), and calanoid and cyclopoid copepods (see Kulkarni & Pai, 2016 a, b). The emergence of nauplii was observed about a month after the onset of the monsoon, and adults were observed for about 4–6 months afterwards, a shorter time if the habitat dried up. Each of these sites continues be under different types of anthropogenic stress such as heavy tourism, grazing by cattle and horses, organic and inorganic pollution, and mining (Table 2).

Etymology: The specific epithet *montanus* is a Latin adjective, meaning 'pertaining to or growing on mountains, montane.' The name agrees in gender with the masculine generic name.

Nomenclatural statement: A life science identifier (LSID) number was obtained for the new species: urn:lsid:zoobank.org:pub:4CC8DF14-9F80-462C-BAE7-CA01C1755C62.

DISCUSSION

Taxonomy and character states analysis

Kiefer (1936c), with his uncanny comprehension of diaptomid taxonomy, erected *Megadiaptomus* on the basis of a single but remarkable morphological feature, the presence of blunt spines (*stumpfen Dornen*) on the exopodal segments of P2–P4, although he referred to, without describing, the special features of the male right A1 and P5. He even coined the specific epithet of the type species, *M. hebes*, from the 'blunt' nature of the said spines (Latin *hebes* for 'blunt'). Subsequently, Fernando & Hanek (1976) and Ranga Reddy (1988) described these blunt and broad spines as 'spinose papillae.' While describing *M. pseudohebes* and redescribing *M. hebes*, Ranga Reddy (1988) provided a formal definition of *Megadiaptomus*, which holds true for *M. montanus* **n. sp.**, despite the autapomorphic state of its inner apical spiniform process on the male left P5 as already described.

In light of certain novelties presented by *M. montanus* **n. sp.**, we briefly review the chief morpho-taxonomic characters and their different states in the three species of *Megadiaptomus* in contrast to those of other Indian species of Diaptomidae.

Body size

It is axiomatic that body size is a decisive factor in governing habitat preference among diaptomid copepods. Among the Indian diaptomids, the species of *Megadiaptomus* are the largest, the body

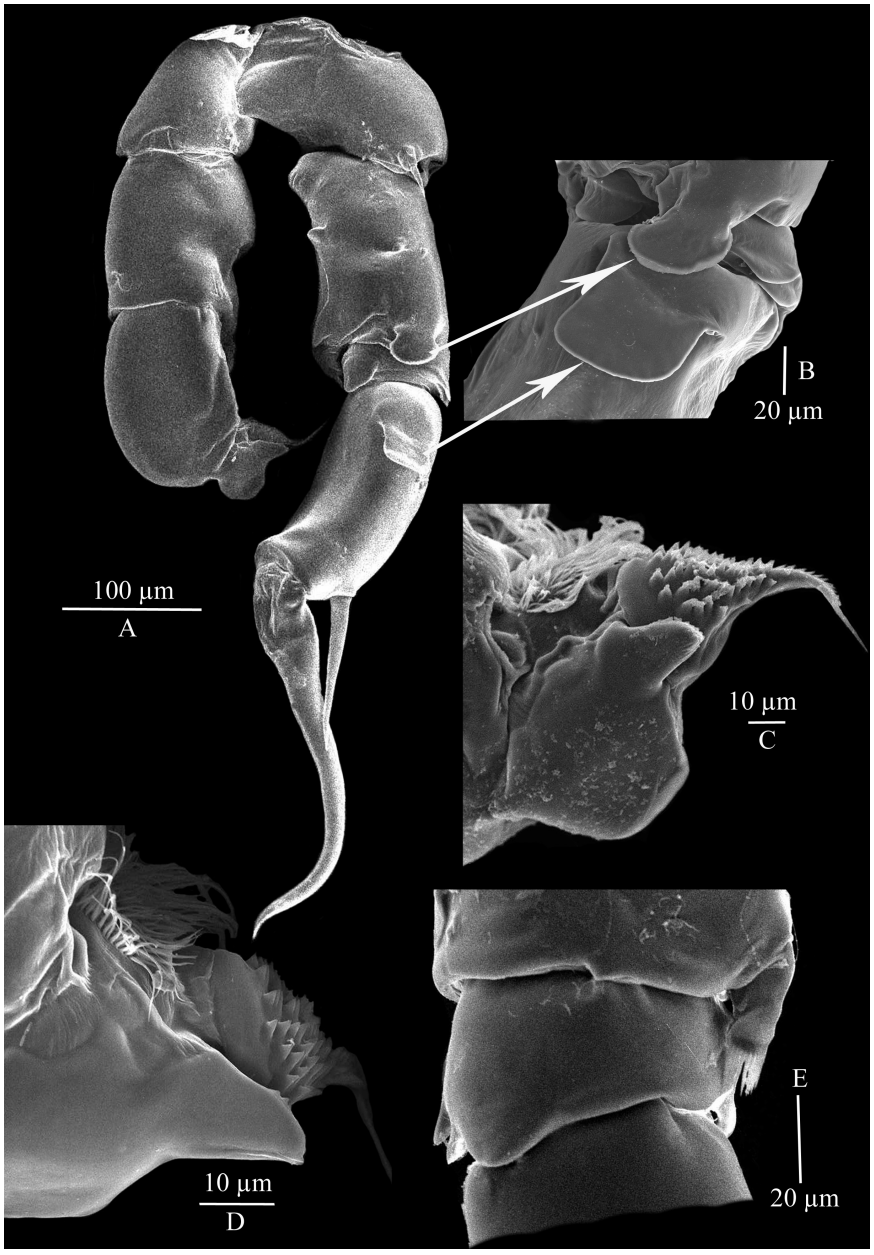

Figure 7. *Megadiaptomus montanus* **n. sp.**, SEM photographs, paratype male: P5, posterior view (**A**); same, right P5 (part), lateral view (**B**); left P5, exp2 and terminal processes, lateral view (**C**); same, terminal processes (**D**); right P5, basis (part), exp1 and exp2 (proximal part), and Enp, anterior view (**E**).

length of both males and females being always more than 2 mm (some females slightly exceeding 3 mm). All three congeners form a homogeneous group so far as the body size is concerned. *Spicodiaptomus chelospinus* Rajendran, 1979, has a mean length of 2 mm (maximum of female topotypes 2.69 mm) (see Ranga Reddy, 1985). A body length of 2 mm is rarely attained by the females of certain other species such as *Heliodiaptomus viduus* (Gurney, 1916), *Tropodiaptomus orientalis* (Brady, 1886), and *Arctodiaptomus* (*Haplodiaptomus*) *parvispineus* Kiefer, 1935. All other diaptomid species are about 1 mm long. A minimum body size of 0.8 mm has been observed in the males of *Allodiaptomus raoi* Kiefer, 1936 (cf. Kiefer, 1936a) and *Eodiaptomus shihi* Ranga Reddy, 1992, which are slender and predominantly occur in lotic habitats (Ranga Reddy, 1987, 1992). All the species measuring over 1.5 mm in body length are confined to small, seasonal, generally turbid fishless pools and ponds. Species of *Hemidiaptomus* Sars, 1903 of Palaearctic inland waters are among the largest diaptomid copepods in the world.

Postero-lateral wings of fifth pedigerous somite

These wing-like structures are generally well developed and asymmetrical in Diaptomidae, especially in females, as in the case for certain species of *Allodiaptomus* Kiefer, 1936 (cf. Kiefer, 1936a) and *Phyllodiaptomus* Kiefer, 1936 (cf. Kiefer, 1936b), among others, and often aid in species identification. In *Megadiaptomus*, however, their size and asymmetry, as well as their spines, are greatly reduced; the spines are barely discernible on the inner margins of the wings in the new species. On the whole, diaptomid copepods exhibit a negative relationship between body size and asymmetry of the wings.

Urosome

The urosome generally consists of three somites in the females of all Indian diaptomids except *Paradiaptomus greeni* (Gurney, 1906), *Neodiaptomus meggitti* Kiefer, 1932, and all species of *Tropodiaptomus*

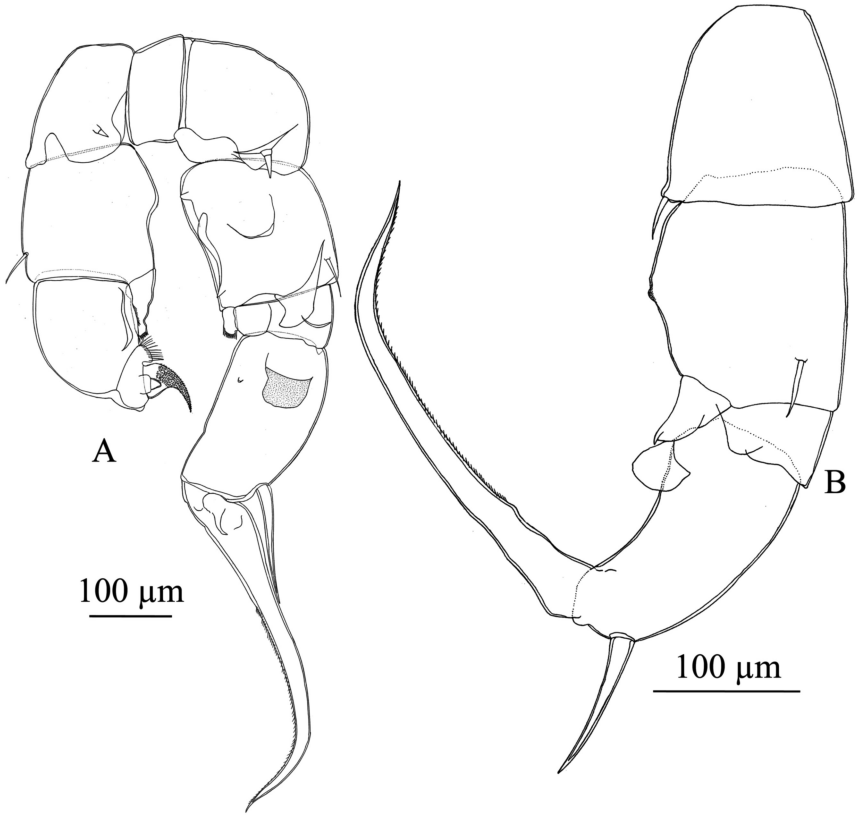

Figure 8. *Megadiaptomus montanus* **n. sp.**, paratype male: P5, posterior view (**A**); right P5, lateral view (**B**).

Kiefer, 1932, all of which have two somites. The urosome has two somites in *M. hebes* and *M. pseudohebes*, but the plesiomorphic state of three somites is shown by *M. montanus* **n. sp.** The genital double-somite is almost twice as long as the rest of the urosome including the caudal rami in *M. hebes* and *M. pseudohebes*, but only slightly longer in the new species. It is usually at least as long as the rest of the urosome in the other Indian diaptomids save *Heliodiaptomus contortus* (Gurney, 1907), in which this somite is shorter than the next two somites combined.

The male urosome invariably has five somites in Diaptomidae. The anal somite together with preceding two somites and/or the caudal rami is generally bent to the right side to a varying degree in different taxa, perhaps to aid in clasping the female during mating. A similar condition is also seen in *M. pseudohebes*. The urosome nevertheless can be straight as in the other two species of *Megadiaptomus* and in *Heliodiaptomus kolleruensis* Ranga Reddy & Radhakrishna, 1981, among others.

The caudal rami are longer in *M. montanus* **n. sp.** than in its congeners (see Table 1). While the caudal rami in the males of *M. pseudohebes* are asymmetrical, with the right ramus being somewhat longer and more slender than the left ramus, both rami are symmetrical in both sexes of the other two species of *Megadiaptomus*. Rarely, as in *Arctodiaptomus michaeli* Ranga Reddy, Balkhi & Yousuf, 1999, the caudal rami are markedly slender and elongated, being three to four times as long as wide.

Antennule

In Diaptomidae, both appendages are symmetrical and as long as the prosome, or slightly longer in females of large-bodied species, but they extend beyond the caudal setae in species that are small and slender, such as those of *Allodiaptomus* and *Neodiaptomus* Kiefer, 1932, among others. In both A1 of the female and the left A1 of the male of *M. montanus* **n. sp.**, segment 11 bears two setae (the proximal one modified as already described), whereas it has one seta in the other two species of *Megadiaptomus* and in most other Indian diaptomids (see Ranga Reddy, 1994). The left A1 of the male is unmodified and bears similar chaetotaxy to that of the female, whereas the right A1, as usual, is modified into a clasping organ with species-specific features. Generally in Diaptomidae, a spine or spinous process of varying size is found on each of segments 8 and 10–16. In all three species of *Megadiaptomus*, segments 14–16 lack any such structure, and segments 8 and 10–13 have almost similar ones. In most diaptomid species, segment 20 is produced into a spinous process of varying size and shape, which is helpful in discriminating among congeners and even subgenera as in the case of *Arctodiaptomus* (see Kiefer, 1978). This spinous process is strikingly reduced in *M. montanus* **n. sp.**, being rather short and knob-like, about 1/4 as long as segment 21, and lined with a narrow hyaline membrane, whereas it is at least half as long as the next segment but without any hyaline membrane in the two congeners (Table 1). In small and slender diaptomid species, the spinous process tends to be very long and even rod-like (see Ranga Reddy, 1994).

P1–P4 setal and spine armature

The P2–P4 are generally conservative in diaptomids, providing no species-level taxonomic clues. The enp3 has a full complement of seven (2 outer + 2 apical +3 inner) setae in most cases. The proximal outer seta is consistently missing in certain species (Ranga Reddy & Dumont, 1998; Ranga Reddy, 2013a), and an exceptionally reduced setal armature occurs in *A.* (*H.*) *parvispineus*, which was originally described from the Tibetan Plateau by Kiefer (1935), and recently redescribed from Yunnan, China, by Shu *et al.* (2013). In this species, one seta is missing not only on enp3 of P2–P4 but also on exp3 and enp2 of P1. The functional significance of the setal reduction of P1–P4 is yet to be established.

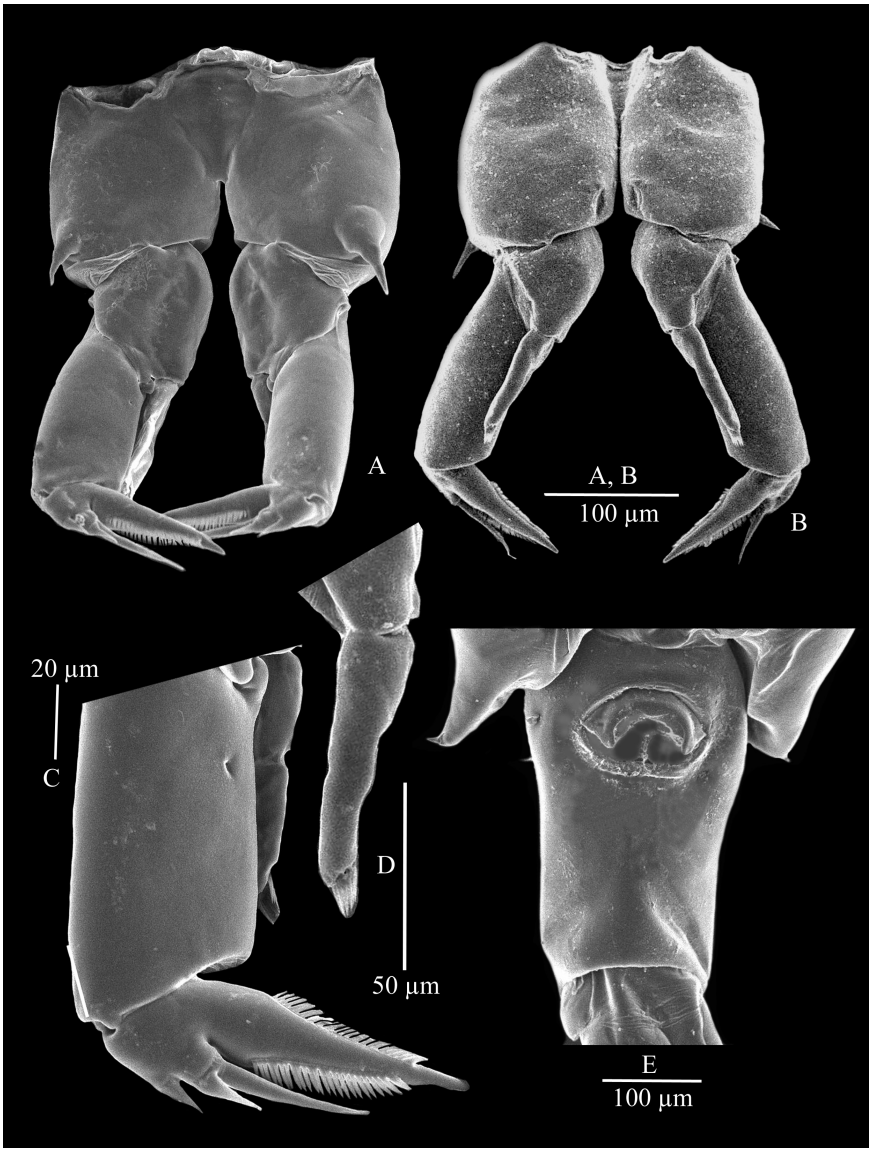

Figure 9. *Megadiaptomus montanus* **n. sp.**, SEM photographs, paratype female: P5, posterior view (**A**); same, anterior view (**B**); same, exp and enp, posterior view (**C**); same, left enp, anterior view (**D**); postero-lateral wings of pediger, genital double-somite, ventral view (**E**).

The armature details of P1–P4 are unfortunately lacking for most diaptomids because of the conventional presumption that they are conservative. The transformation of the outer spines on the exopodal segments of P2–P4 into spinose papillae has turned out to be a unique generic criterion for *Megadiaptomus*. In *S. chelospinus*, the spines are also similarly dilated but pointed (see Ranga Reddy, 1985), and the outer spine on exp1 of P1 is conspicuously long and somewhat setiform in *A. michaeli*. The coxal setae of P1–P4 are of the same length in most diaptomids. Among the species of *Megadiaptomus*, the coxal seta on P4 is short, barely reaching the end of basis, but it extends to the end of enp1 on P1–P3. In further contrast, the coxal seta on P4 is the longest, reaching almost to the end of enp, as in *Keraladiaptomus rangareddyi* Santos-Silva, Kakkassery, Maas & Dumont, 1994, and in *Phyllodiaptomus sasikumari* Ranga Reddy & Venkateswarlu, 1989.

Male Right P5

The P5 basis is somewhat rectangular, being 1.2 and 1.7 times as long as wide in *M. hebes* and *M. montanus* **n. sp.**, respectively, but quadrate in *M. pseudohebes*, and likewise the lobes and ornamentation associated with it are also different between the three species (Table 1).This character is useful in separating certain species of *Tropodiaptomus*, *Arctodiaptomus* Kiefer, 1932, *Heliodiaptomus* Kiefer, 1932, and other genera as well. Exp1is much wider than long and provided with two hyaline lobes of varying size and shape in all three species, as already described, but it is longer than wide in certain species of *Eodiaptomus* and other genera (Ranga Reddy, 1994), and produced into a large spinous process in *E. shihi*. The size and shape of exp2, together with the location and nature of the structures associated with it, are of great value in the taxonomy of diaptomids. When it has but a single lateral spine as in most Indian genera, its location could be a generic character as well. For example, the lateral spine is proximal in *Heliodiaptomus*, at about mid-outer margin in *Neodiaptomus*, in the proximal part of the distal half of the outer margin in *Tropodiaptomus*, sub-distal in *Megadiaptomus*, and far distal in *Eodiaptomus*, among others. The exp2 has two unequal lateral spines in *Allodiaptomus*, the proximal spine being larger than the distal one. The three species of *Megadiaptomus* can be separated from each other on the basis of a distinct series of characters (Table 1).

Table 1. Morphological features of the Indian species of *Megadiaptomus*. A1, antennule; enp, endopod (enp1–3, endopodal segments 1–3); exp, exopod (exp1–3, exopodal segments 1–3); P5, leg 5; seg, segment.

	M. hebes	*M. pseudohebes*	*M. montanus* **n. sp.**
MALES			
Body length (mm)	2.56–2.79	2.21–2.74	2.00–2.52
Caudal ramus length:width	1.3	~ 2.0	> 2.0
Right A1:			
Length of spinous process of right A1 onseg20:seg 21	> 0.67:1	> 0.50:1	0.25:1
Right P5 basis:			
Mid-inner margin	With spinules	With hyaline lobe	With chitinous ridge
Accessory structure at mid-posterior margin	Hook-like	Hook-like	Spatulate lobe
Right P5 exp2 accessory process:			
Position and shape	Proximal, triangular	Mid-length, triangular	Proximal, quadrate
Origin of lateral spine	Right on lateral margin	Anterior plane close to lateral margin	As in *M. hebes*
Right P5 enp length *versus* exp1	Almost equal	Shorter	Equal
Right P5 end claw proximal part	Normal	Normal	Thickened
Left P5 coxal ornamentation	Present	Absent	Absent
Left P5 basis hyaline lobe on inner margin	Present	Present	Absent
Left P5 exp2:			
Size and orientation	Normal, almost in line with exp1	Almost as in *M. hebes*	Short and sharply bent inwards
Apical plate-like structure	Thumb-like, serrulate on inner margin and apex, slightly shorter than spiniform process	Thumb-like, serrulate, nearly as long as spiniform process	Triangular, serrulate on inner margin and apex, 0.3 as long as spiniform process
Apical spiniform process	Slender with long spinules on outer margin	Nearly as in *M. hebes*	Proximal half bulbous, with rows of spinules on inner surface, distal half drawn out into setiform structure
Left P5enp length *versus* exp1	Almost equal	Almost equal	Shorter
FEMALES			
Body length (mm)	2.79–2.97	2.5–3.01	2.25–3.0
Caudal ramuslength:width	~1.4	~1.5	> 2.0
Urosomites	2	2	3
P5 coxa:			
Ornamentation	Present	Absent	Absent
Size and symmetry of spines	Small, symmetrical	Small, symmetrical	Prominent, asymmetrical (right > left)
P5 exp3	Fused	Distinct	Fused
P5 enp length *versus* exp1	> 0.67:1	> 1.00:1	> 0.67:1

Male left P5

The length-width ratio of the basis, exp1, and exp2, and the nature of the terminal processes (outer thumb-like structure and inner seta or spiniform structure) of exp2 are different among diaptomids, providing vital taxonomic criteria for separating the genera and species (see Kiefer, 1978; Ranga Reddy, 1994). In his revised generic diagnosis of *Neodiaptomus*, Kiefer (1939: 126), the terminal processes of exp2 as '1 small spherical structure and 1short seta' as a criterion, and the same for *Arctodiaptomus* as 'slender digitiform terminal process, close to which arises a long seta on anterior side' (Kiefer, 1978: 16). As previously described, the inner terminal process of exp2 is remarkably transformed in *M. montanus* **n. sp.**, whereas it is almost normal in its congeners.

Female P5

The right P5 basis and end claw are generally slightly stouter than those of the left P5 among the diaptomids. The coxa of *Megadiaptomus* usually bears an outer hyaline spine, and the spine of the left P5 coxa is either equal to or larger than that of the right P5 coxa. While both coxal spines are equally minute and lie at about the middle of the caudal (posterior) plane in *M. hebes* and *M. pseudohebes*, in *M. montanus* **n. sp.** they are large and unequal, the left spine being larger than the right one, and each arising from a lobed structure at the disto-outer corner. The left coxal spine is distinctly larger that the right one as in *Heliodiaptomus contortus*, *H. viduus* and others (see Ranga Reddy, 1994). Exp3 is quadrate in *Megadiaptomus*, being basally fused in *M. hebes* and in the new species but distinct in *M. pseudohebes* (Table 1). The apomorphic state of the complete absence of exp3 is displayed by a few species of *Heliodiaptomus* and *Allodiaptomus*, whereas it is conspicuously large, a plesiomorphy, in *K. rangareddyi*. The inner seta on exp3 is about 2/3 as long as the end claw in *Megadiaptomus*, but the most plesiomorphic state is seen in *K. rangareddyi*, in which the seta is almost as long as P5.

Biogeography

Nearly half of the about 50 known Indian nominal diaptomids in 13 genera are endemic to the Gondwanan Indian Peninsula

Table 2. Currently known localities of *Megadiaptomus montanus* **n. sp.** in the Western Ghats of India and their present status.

Site	Coordinates	Habitat	Nature of threats (terminology adapted from Watve, 2013)
Tableland, Panchgani	17°55'46.20"N, 73°48'25.56" E	Pools and ponds	Heavy tourism, pollution, grazing by cattle and horses
Medha to Pachgani road	17°51'06.48"N, 73°47'53.88"E	Pools	Organic pollution
Kusavade	17°33'53.28"N, 73°55'16.32"E	Pools and ponds	Wind-farms, cattle grazing, religious tourism
Mhavshi	17°26'09.24"N, 73°55'43.68"E	Pools and ponds	Wind farms, cattle grazing, religious tourism, quarrying
Kaas	17°43'12.36"N, 73°49'21.72"E	Ponds	Tourism
Masai	16°49'03.72"N, 74°04'35.40"E	Pools and ponds	Cattle grazing, religious tourism, quarrying
Jhenda	16°54'23.40"N, 73°50'13.92"E	Pools and ponds	Mining, organic and inorganic pollution, religious tourism

(Ranga Reddy, 2013a, b). The Indian Peninsula '*per se* is biogeographically *India vera*, the largest and oldest region of differentiation of the original floras and faunas of India' (Mani, 1974: 700). Whereas *Megadiaptomus* is endemic to Sri Lanka and peninsular India (Fig. 1), the monotypic *Spicodiaptomus* and *Keraladiaptomus* are typically endemic to peninsular India (Fig. 1). Two other related genera, the paradiaptomid *Paradiaptomus* and the diaptomid *Tropodiaptomus*, which occur throughout India, have distributional patterns that suggest a Gondwanan affinity, as both taxa show remarkable radiations in Africa. *Tropodiaptomus* also occurs in south-east Asia, and considerable species endemism is found in the Indian subcontinent (11 species) and south-east Asia (12 species) (see Dussart & Defaye, 2002). There is only one Indian species of *Paradiaptomus* (*P. greeni*), which is endemic to India and Sri Lanka. *Megadiaptomus hebes* and *M. montanus* **n. sp.** are so far known from altitudes of 700–1300 m whereas *M. pseudohebes* occurs in the coastal belt of 25–30 m above the sea level. These unique radiations of Gondwanan taxa, and the endemic genera like *Megadiaptomus*, *Spicodiaptomus*, and *Keraladiaptomus*, can potentially be indicative of India's long isolation prior to collision with Asia. The Indian endemics apparently represent the 'peculiar biota' of Briggs (1989) and are consistent with the presumed tectonic history of India as an isolated continent in the Tethys Sea for about 100 mya. Not surprisingly, the Gondwanan heritage is represented by the various groundwater crustacean genera of peninsular India (Ranga Reddy, 2011).

Conservation status of the species of Megadiaptomus

Most temporary water bodies are among the highly endangered inland water ecosystems in the world (Reid *et al.*, 2002), being threatened by tourism, changing land use patterns, organic and inorganic pollution, and other types of anthropogenic factors that adversely affect the characteristic aquatic fauna. Their 'invisibility' to conservation agencies (Marrone *et al.*, 2006), stemming largely from lack of knowledge of their biota and the ecology of inland water ecosystems, especially in the Indian context, has further aggravated this problem. The faunistic investigations done on the temporary water bodies of Andhra Pradesh during the past two decades or so have revealed that *M. pseudohebes* has gone extinct in the habitats from which it was previously collected by Radhakrishna & Ranga Reddy (1977), Ranga Reddy & Devi (1985), and Ranga Reddy (1988). Although it was consistently found during the monsoon seasons (July to October) of 2002–2008 in an abandoned quarry pond on the outskirts of Guntur town, this habitat subsequently disappeared owing to the establishment of a hollow-brick industry. It possibly still persists in some unstudied pools and ponds in Andhra Pradesh state. The area of occupancy of *M. pseudohebes* is less than 10 km^2. Hence, according to IUCN criteria, it can be assigned to the Critically Endangered (CR B2) category.

Nothing is yet known about the current distribution of *M. hebes*. *Megadiaptomus montanus* **n. sp.**, as of now, occurs in several ponds and pools of NWG. It should be noted, however, that these ponds exist only on high plateaus, and the species has never been found in the regions lying between these peaks (Kulkarni & Pai, 2016a). Their area of occupancy is therefore < 30 km^2. These plateaus also increasingly face various anthropogenic pressures (Table 2). We therefore recommend that this species be included in the EN B2 category of IUCN (http://www.iucnredlist.org/documents/RedListGuidelines.pdf). These large-bodied species, and their unique habitats, deserve special attention for the sake of their conservation.

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