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Cover: Life and death in one night - wolf hunting the hare. Mixed media—gouache, acrylics, pen & colour pencils. © Dupati Poojitha.

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COMMUNICATION

A new species of *Arctodiaptomus* Kiefer, 1932 (Copepoda: Diaptomidae) from the Kumaun Himalaya of India

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Abstract: A new species of the freshwater copepod genus *Arctodiaptomus* is described from a high-altitude lake of Kumaun Himalaya. The undescribed species differs from their congeners by the presence of a strong comb-shape denticulated spine at the antepenultimate segment of male right antennule. Basis of the male fifth right leg possess a butterfly shape hyaline membrane on the inner lateral side; 2-segmented endopod with board distinct proximal segment. Endopodite of the female fifth leg is elongated round apex without any septum. The identified diaptomid tends to be restricted in the Himalayan region; it seems apparently isolated from the purported main area of the origin.

Keywords: *Arctodiaptomus kumaunensis* sp. nov., Calanoida, carotenoids, diaptomids, Maheshwar Kund, morphology, photoprotectant, plankton, western Himalaya.

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Competing interests: The authors declare no competing interests.

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Author contributions: Shaikhom Inaotombi: Conceptualization, methodology, data collection (field sampling, laboratory analysis), writing—original draft. Debajit Sarma: Funding acquisition, supervision, project administration, data collection (field sampling), writing—review & editing.

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INTRODUCTION

So far, 441 species of diaptomids have been described from 60 genera (Boxshall & Defaye 2008). In the Palaearctic region, *Heliodiaptomus* Kiefer, 1932 is one of the most described genera while *Arctodiaptomus* is represented by 76 species. Knowledge on distribution status of the genera is currently hindered by underestimation due to the lack of taxonomic expertise. Some *Arctodiaptomus* are highly invasive and tolerant to extreme environments (Rizo et al. 2015). They show limited distribution ranges that linked primarily with ancient biogeographical events (Leibold et al. 2010). Indian diaptomids are represented by Diaptomin and Paradiaptominae subfamilies. Diaptominae are dominant and represented by over 50 species from 12 genera; while Paradiaptominae has a single genus and species in India (Rayner 2000; Dussart & Defaye 2002). Most Indian Diaptomidae were recorded from the Gondwana Indian Peninsular region (Reddy 2013), and the existing information from the Himalayan region is limited. Many species may confine to different elevations which were originally isolated and further acclimatized or adapted to the recurrent extreme environment. Here, we describe a new pigmented species of *Arctodiaptomus* from a high-altitude lake of Kumaun Himalaya.

MATERIAL AND METHODS

Plankton sample was collected from Lake Maheshwar Kund of Uttarakhand, India (Figure 1) using 0.22 mm plankton net. The diaptomids were sorted out and fixed with 70% ethanol; vials were stored for further identification. Materials were dissected in water + glycerin drop and scan under a high magnification microscope. Descriptions were made based on the observation and photographs of each section are illustrated below. The type specimens were further deposited at Central Entomological Laboratory, Zoological Survey of India, Kolkata, India.

RESULT

Order Calanoida
Family Diaptomidae Baird, 1850
Subfamily Diaptominae Kiefer, 1932
Genus *Arctodiaptomus* Kiefer, 1932

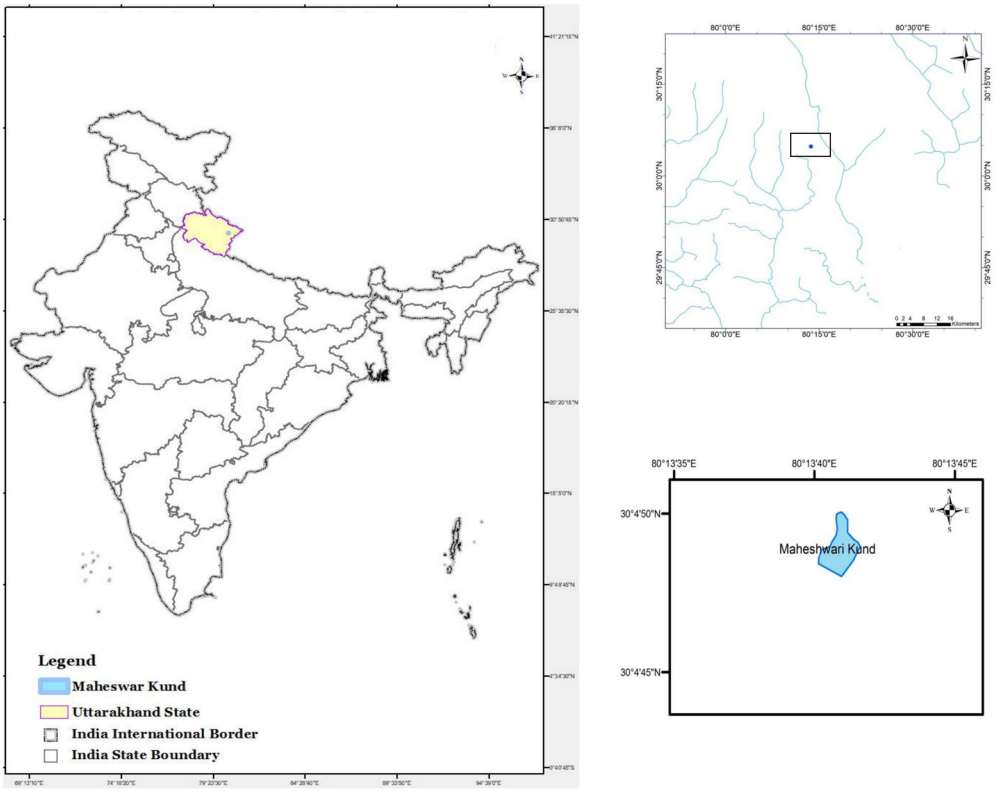

Figure 1. The location map showing type locality (Maheshwar Kund) of *Arctodiaptomus kumaunensis* sp. nov.

***Arctodiaptomus kumaunensis* sp. nov.**

(Image 1–6; Figures 2–3).

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Material examined

Holotype: C7099/2, 13 May 2016, female, Maheshwar Kund (5,219 m), a high-altitude lake of Kumaun Himalaya, Uttarakhand, India (30.080 ^{0}N, 80.504 ^{0}E). Specimens were preserved in 70% ethanol with a drop of glycerin. Vials containing 4 un-dissected specimens were deposited in Central Entomological Laboratory, Zoological Survey of India, Kolkata.

Allotype: C7100/2, 13 May 2016, male, preserved in 70% ethanol was deposited at Central Entomological Laboratory, Zoological Survey of India, Kolkata.

Paratypes: C7101/2 & C7102/2, 13 May 2016, two males & two females, vails containing two males (separately) and two females collected from the same site were deposited at Central Entomological Laboratory, Zoological Survey of India, Kolkata.

For analysis of physicochemical parameters, water samples were collected from the littoral zone of the lake in prewashed polyethylene bottles and transported to the laboratory under ideal condition (Wetzel & Likens 1979). Temperature, pH, conductivity, and dissolved oxygen (DO) were measured on the site itself using Hanna multi-parameter probe (Model 9828). Turbidity was measured using a turbidity meter (HACH 2100Q). Nitrite-nitrogen, nitrate-nitrogen, ammoniacal-nitrogen and phosphorous were estimated by Spectroquant Multy (Merck, Germany; SN072414). Alkalinity and hardness were estimated by titration methods. The method of analysis and formulation of the reagents used are based on American Public Health Association (1992).

Habit and Habitats

The new species is apparently a relict population in the high-altitude aquatic environment of the Kumaun Himalaya (2,446.6 m). The Maheshwar Kund is a shallow (7.3 m) oligotrophic small water body (average PO_4 P 0.04 mg/l). The water quality parameters (mean, n = 6) of the lake habitats were as follows: water temperature 15.1 ºC, pH 8.20, alkalinity 21 ppm, nitrate 0.90 ppm, oxidation-reduction potential 195 mV, total dissolved solids 17 ppm, conductivity 20 µScm^{-1}. The annual average rainfall in the region is 1308.6 mm as per (Purohit & Kaur 2016). The lake receives moderate hydroperiods and mainly fed by spring discharges, subsurface inflow streams, and direct rainfall. The catchment area covered by forest vegetation is mainly composed of *Quercus leucotricophora* A.Camus and *Rhododendron arboretum* Sm. The new species is predominantly found in the littoral zone where the accumulation of terrestrial plant debris was high. The turbidity of the water column was very low (0.97 NTU). The substratum has a low submerged macrophyte and sediment contains a moderate amount of organic matter (4.60 %) covered by a superficial mud layer.

Etymology: The specific name "*kumaunensis*" is named after the place "Kumaun Himalaya" of India where the new species is found.

Diagnosis: Female: Total length excluding caudal setae ranges from 1.42 mm to 1.64 mm (average 1.55 mm ± 0.08, n = 10); prosome length = 1.23 mm; prosome width = 0.41 mm (Image 1a, Figure 2A). Prosome is an oval shape with 5 pedigers cephalosome. The 5th pediger is slightly asymmetrical in the posterior wings reaching the proximal part of the genital somite.

Urosome (Image 1b, Figure 2B) 30 percent of the total length, divided into 3-segmented; Genital somite widened distally having slight lateral protrusions with sensillum. Long anal somite with two symmetrical caudal rami 2.2:1 length to width and haired along the distal half of both inner and outer margin; one dorsal, one small lateral and four-terminal setae (Image 1c, Figure 2C).

Antennules symmetrical, 25-segmented, reaching up to caudal ramus (Image 1d, Figure 2D). A long and stout seta on segment 1 reaching upto segment 5 (Image 1e). From segment 3–8 has either aesthetasc or one seta (Image 1f). The distribution of appendages per segment as 1(1+ae); 2(3+ae); 3(1+ae); 4(1); 5(1+ae); 6(1); 7(1+ae); 8(1); 9(2+sp); 10(1); 11(2); 12(1+ae); 13(2); 14(1+ae); 15(1); 16(1+ae); 17(1); 18(1); 19(1+ae); 20(1); 21(1); 22(2); 23(2); 24(2); 25(4+ae). Where, segments are representing by Arabic numerals, while number of setae = Arabic numeral in parenthesis; ae = aesthetasc; sp = spine. The right antennule has similar appendages distribution with left antennule.

Mandible (Image 2a, Figure 2F) with eight pointed teeth on gnathobase and one seta near tooth margin (Image 2b); basis with two setae; endopod 2-segmented, possesses two setae at the proximal while seven setae at the distal segment. Exopod 4-segmented; one seta each on the first three segments and three setae on the distant segment (Image 2c, Figure 2E).

First leg with one seta on the internal margin of coxa, reaching up to the proximal part of the first endopodal segment. Cluster plumose at the external margin in the joining of coxa and basis. Basis with 3-segmented exopod and 2-segmented endopod (Image 2d, Figure 2H).

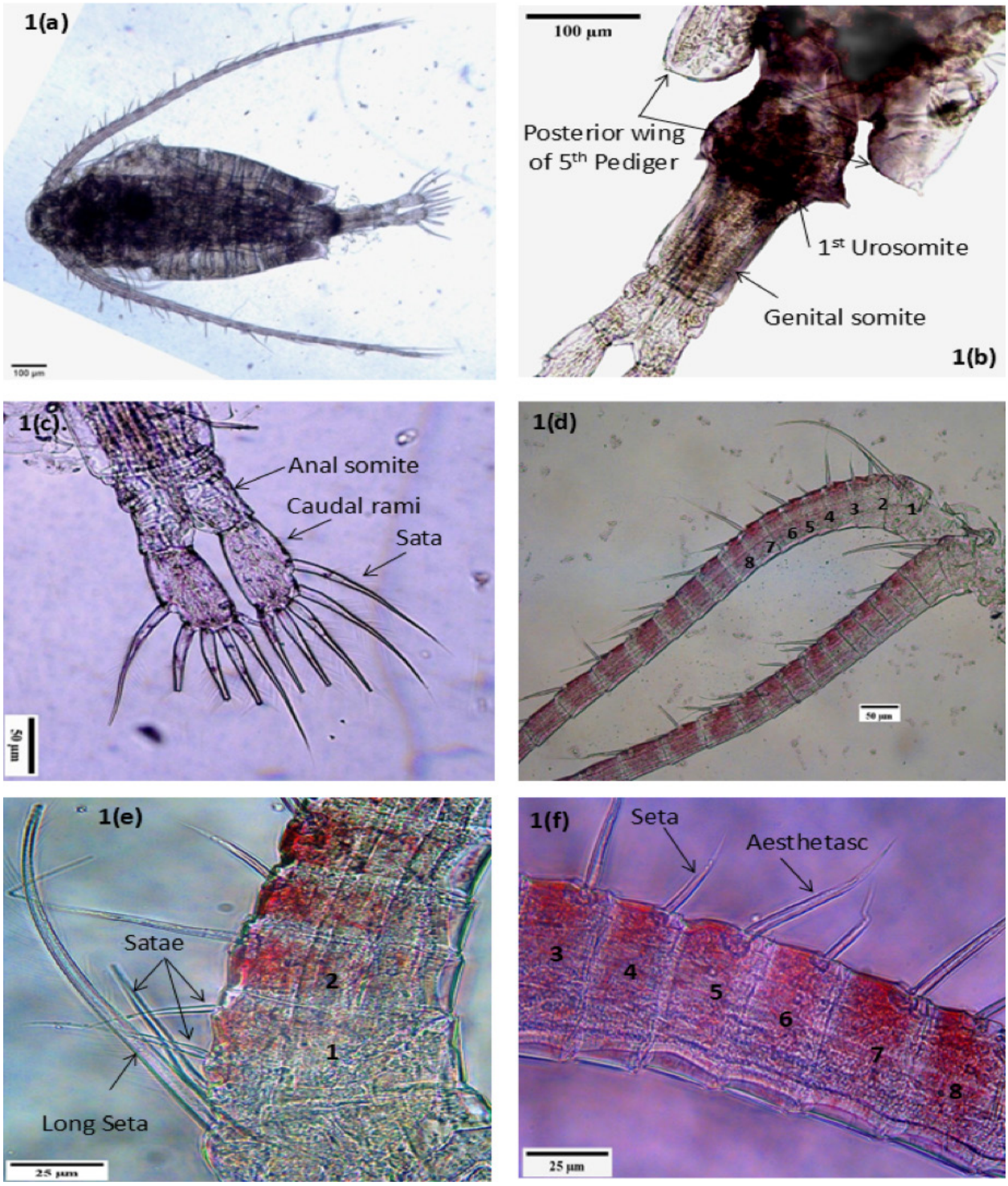

Image 1. a—*Arctodiaptomus kumaunensis* sp. nov. (female) | b—5th Prediger with 1st urosome and genital somite | c—Anal somites and caudal ramus of urosome | d—Antennules | e—Segment 1–4 of antennule | f—Segment 3–8 of antennules. © Inaotombi Shaikhom.

Maxilliped distinct and strong; coxa with three distinct lobes; one seta in first, two seta in second and three setae in third lobe of the coxa. Endopod 5-segmented; two setae each in second, third and fourth segments. Terminal fifth segment has four setae (Image 2e, Figure 2G).

Second, third and fourth swimming legs are biramous with 3-segmented rami (Image 2f, Figures 2I, 2J). Fifth

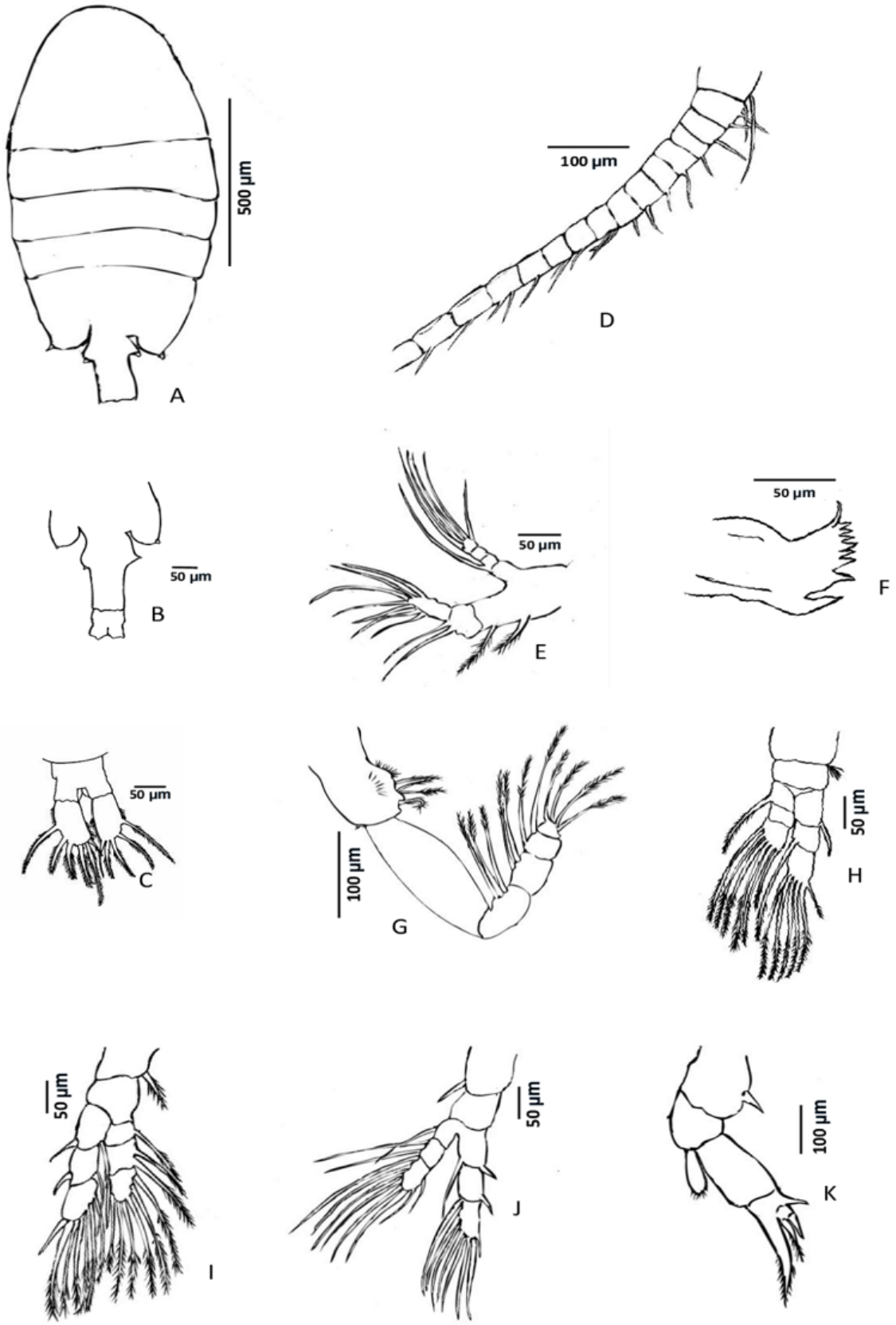

Figure 2. ***Arctodiaptomus kumaunensis*** **sp. nov., female (holotype): A—dorsal view | B—5th Prediger with 1st urosome and genital somite | C—anal somites and caudal ramus of urosome | D—antennules | E—mandible basis with mandibular palp | F—mandibular teeth with gnathobase | G—maxilliped | H—first leg | I—third swimming leg 3 | J—fourth swimming leg | K—symmetrical fifth leg. © Inaotombi Shaikhom.**

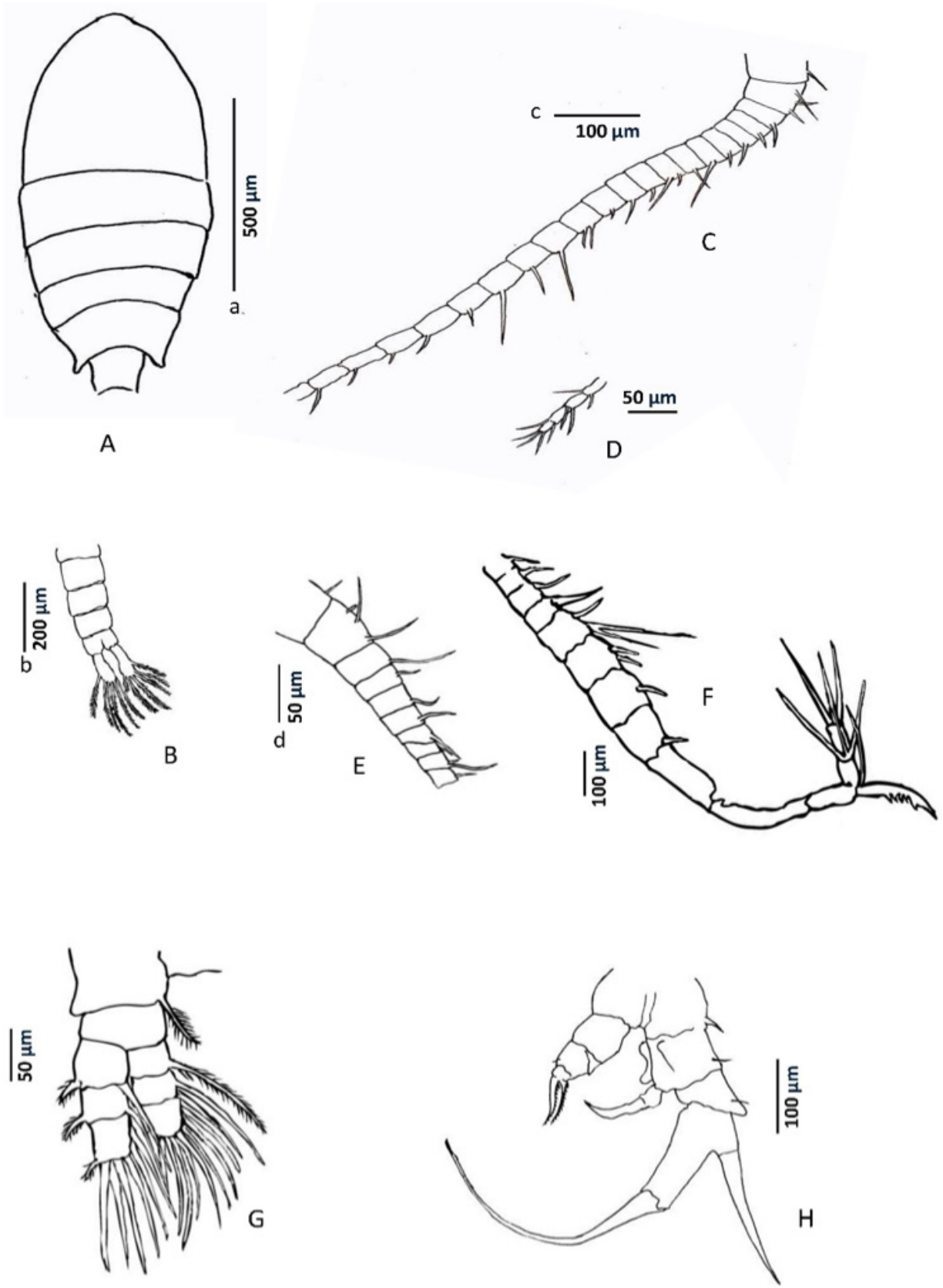

Figure 3. ***Arctodiaptomus kumaunensis*****, sp. nov., male (isotype): A—dorsal view | B—urosome | C—left antennule (1–21 segment) | D—left antennule (22–25) | E—right antennule (1–10 segment | F—right antennule (10–22 segment) | G—symmetrical third leg | H—asymmetrical fifth leg. © Inaotombi Shaikhom.**

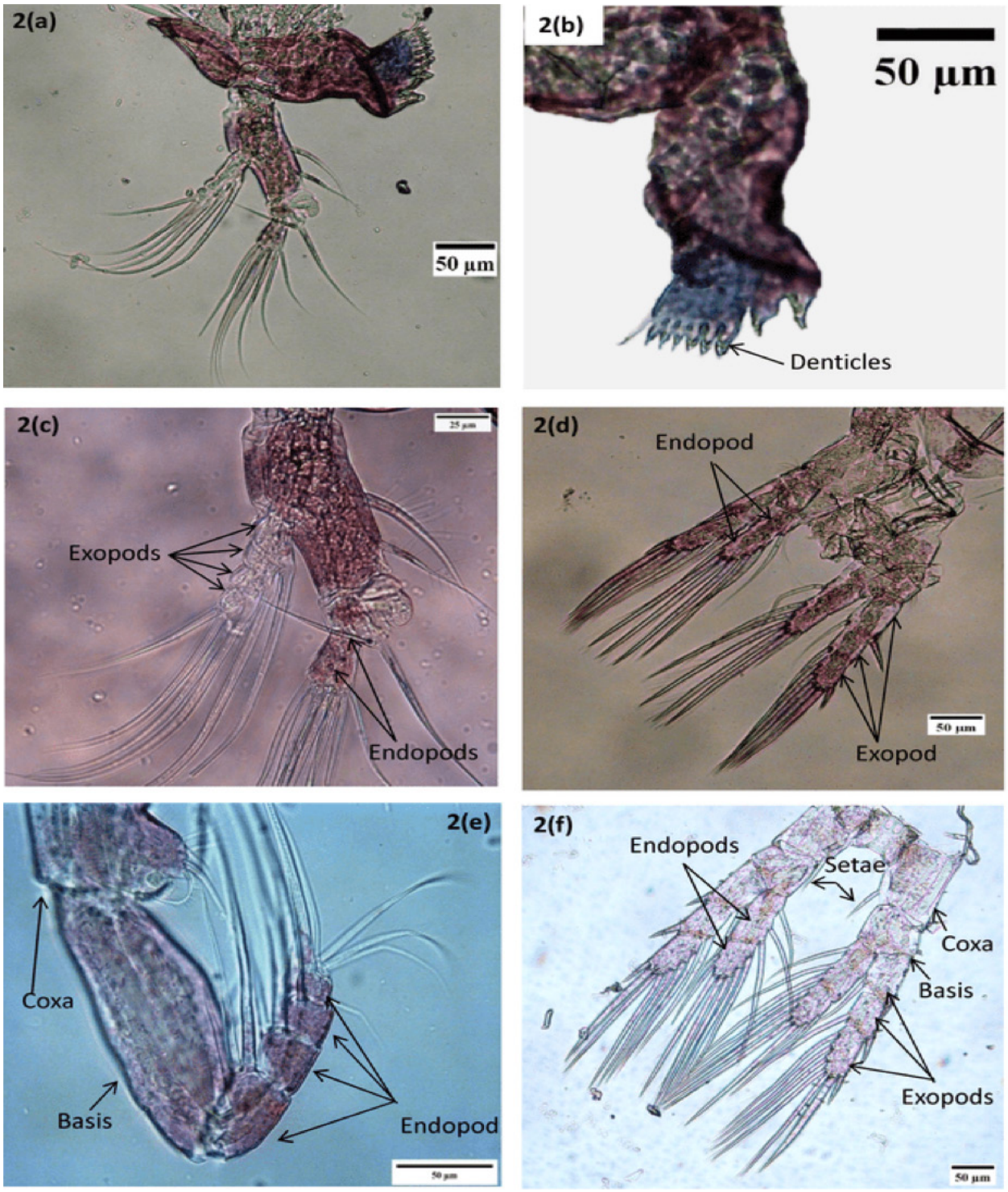

Image 2. ***Arctodiaptomus kumaunensis*** **sp. nov. (female): a—Mandible | b—Mandibular teeth with gnathobase | c—Mandible basis with mandibular palp | d—Swimming leg 1 | e—Maxilliped | f—Swimming leg 3. © Inaotombi Shaikhom.**

legs biramous, symmetrical (Image 3a); coxa roughly rectangular shape armed with reduced lateral process (Image 3b). Basis with short inner margin and possesses small delicate lateral seta. Endopod unsegmented and blunt end, nearly two times longer than wide. Exopod 3-segmented, exopod-1 about 1.7 times as long as wide; second exopod segment with long end claw at inner margin and a spine near the base of the third segment.

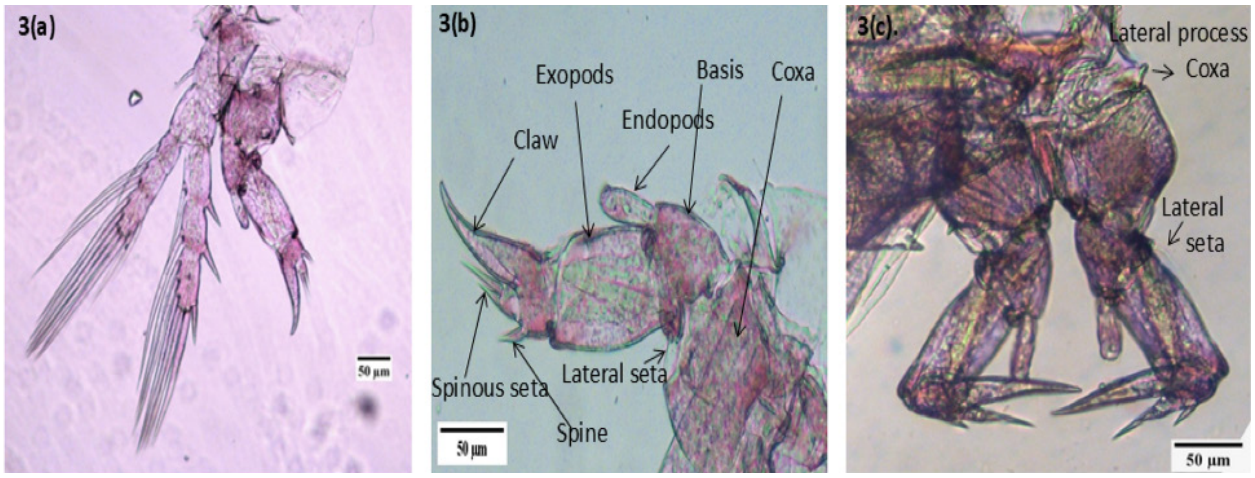

Image 3. *Arctodiaptomus kumaunensis* sp. nov.: a—Fourth and fifth Leg (Female) | b—Symmetrical biramous fifth leg (Female) | c—Fifth right leg (Female). © Inaotombi Shaikhom.

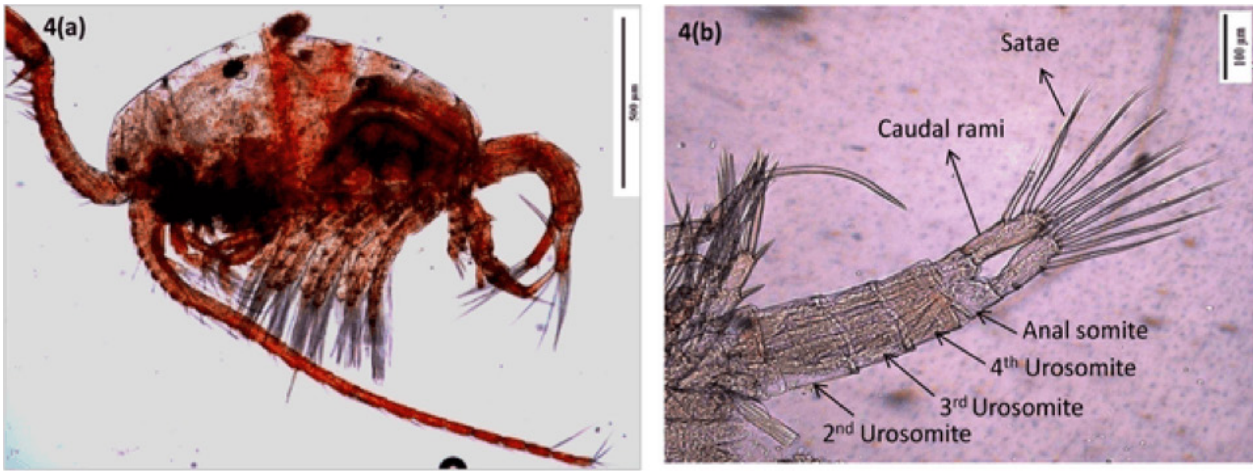

Image 4: a—*Arctodiaptomus kumaunensis* sp. nov. (male) | b—Urosome. © Inaotombi Shaikhom.

The third exopod segment extremely reduced with two spinous setae – one long and another short (Image 3c, Figure 2K).

Male

Total length excluding excluding caudal seta ranges from 1.45 mm to 1.56 mm with average length of 1.50 mm (± 0.05, n = 10); prosome length = 1.07 mm; prosome width = 0.45 mm; rostrum strong, no bifid. Fifth pedigerous somite tapering posteriorly with reduced lateral wings (Image 4a, Figure 3A).

Urosome 5-segmented, 30 percent of total body length. First urosomite without lateral spine; second to fourth urosomites equal size with slightly tapering posteriorly; fourth urosomite with slight protruding at the inner lateral margin. Anal somite reduces with 'v' shape infringe at the posterior middle margin; naked caudal rami symmetrical, about 2.7 times as long as wide and similar setae distribution with female ramus (Image 4b, Figure 3B).

Antennule asymmetrical; left antennule 25-segmented; longer seta at segment 3, 7, 9, 14, 16, 18, 21 and 23 (Image 5a, Figures 3C,D). Three setae in segment 2 (Image 5b) and one seta each on segment 3–8 (Image 5c). Right antennule with 22 segments; one seta each on segment 1, 3–8, 10, 11, 15, and 18–20. Seta of segment 3, 12, and 14 are exceptionally long (Image 5d, Figure 3E). One strong stout spine on segment 13; one short and one long seta on segment 14; longer seta reaching up to segment 17. Segment 15 with one seta and one spine; geniculated between segment 18 and 19 (Image 5e, Figure 3F). Two long setae at the distal margin

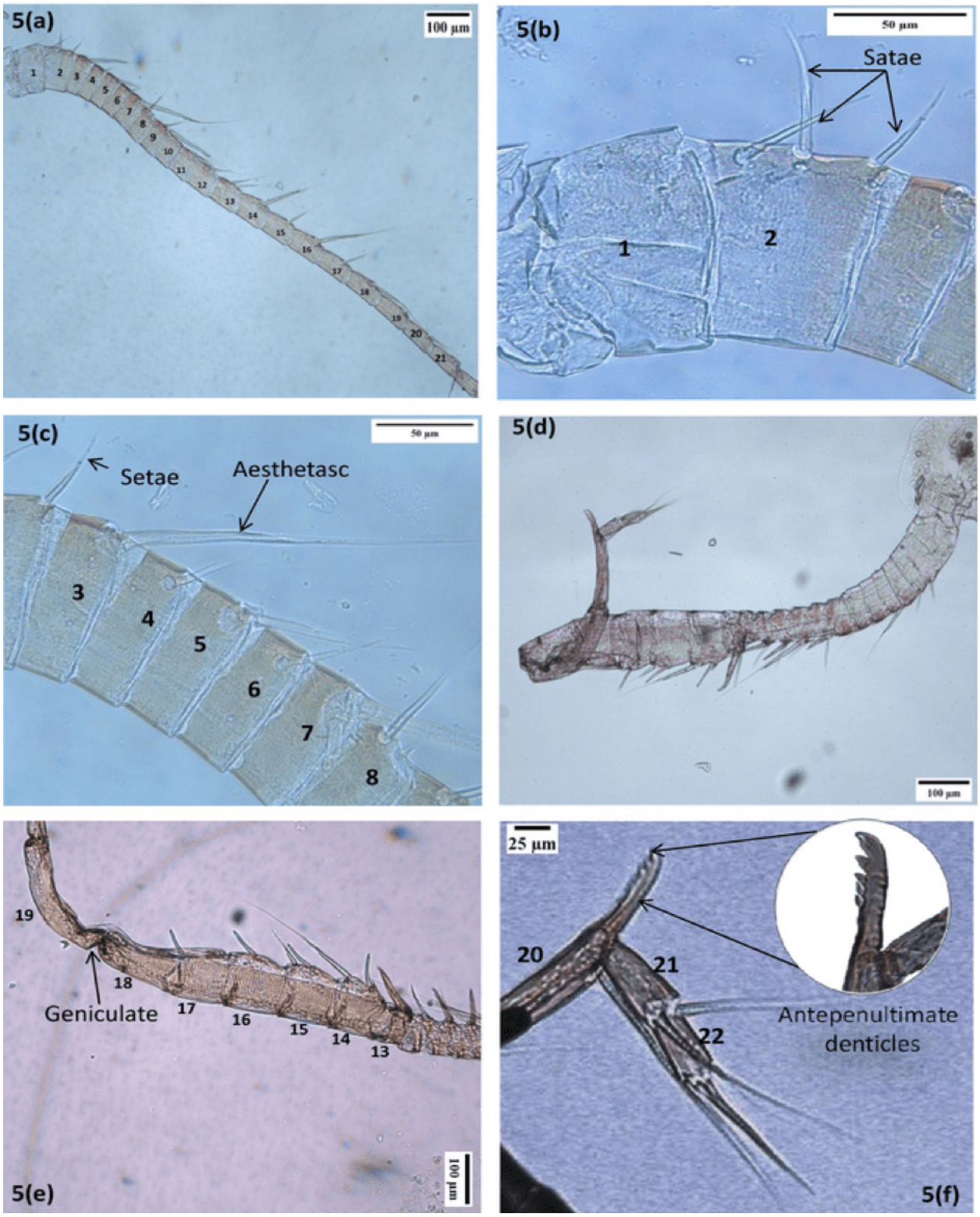

Image 5. *Arctodiaptomus kumaunensis* sp. nov. (male): a—Left antennule | b—Segments 1–2 left antennules | c—Segments 3–8 left antennules | d—Right antennules | e—Segments 13–19 right antennules | f—Segments 20–22 right antennules with antepenultimate. © Inaotombi Shaikhom.

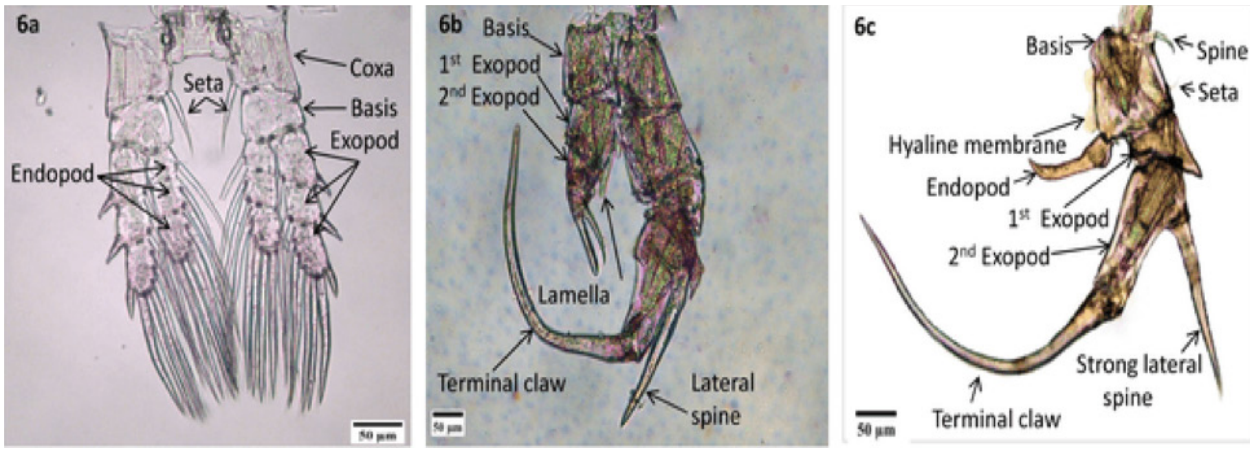

Image 6. *Arctodiaptomus kumaunensis* sp. nov. (male): a—Symmetrical 3rd Leg | b—Asymmetrical fifth leg | c—Fifth right leg. © Inaotombi Shaikhom.

of both segment 19 and 20. A strong and long comb-like process with five denticles on antepenultimate distal outer margin of segment 20 reaching well beyond the distal margin of succeeding segment (Image 5f). Segment 21 with two long setae and terminal segment with two long and two short setae.

Swimming legs similar with the female leg; 4 biramous. Leg 1 having one seta on coxa and basis with 3 segmented exopod and 2-segmented endopod. 2–4 leg symmetrical with one seta on coxa, basis with 3-segmented exopod and endopod (Image 6a, Figure 3G). Leg 4 biramous with 3-segmented rami similar with female leg 4. Fifth leg asymmetrical, left fifth leg short, reach up to the middle of first exopod segment of the proximal right fifth leg. Basis rectangular shape with one narrow hyaline lamella along inner margin and one triangular hyaline lamella along bottom margin. Exopod 2-segmented, first exopod segment slightly wider than second. Second exopod broad at proximal and tapering at the distal armed with two dactylus like spines (Image 6b, Figure 3H). Endopod is extremely reduced. Right fifth leg longer than left; coxa short and bear a slender spinous process on the distal portion of external margin. Basis roughly rectangular shape; possesses a very thin delicate seta at outer margin. A butterfly shaped hyaline membrane attached on the inner lateral side. Exopod 2-segmented, first exopod very short and triangulation expansion at the outer distant margin; second exopod four times longer than the first segment. Strong straight lateral spine at distal first quarter; longer than spine bearing segment. Terminal claw is relatively slender, curved, tapering gradually from the enlarged base and 1.5 times longer than combine length of exopod 1 and expod 2. Endopod 2-segmented, roughly curved tapering at the end reaching midlength of second exopodite segment. Proximal segment board and 0.3 times as long as the distant segment (Image 6c, Figure 3H).

Table 1. Armature formula of the female swimming legs.

Legs	Coxa	Basis	Exopod	Endopod
1st Leg	0–1	0-0	I-1; 0-1; I,3,2	0–1; 2, 3,1
2nd Leg	0–1	0-0	I-1; I-1; I,3,3	0–1; 0–2; 2,2,3
3rd Leg	0–1	0-0	I-1; I-1; I,3,3	0–1; 0–2; 2,2,3
4th Leg	0–1	0-0	I-1; I-1; I,3,3	0–1; 0–2; 2,2,3

DISCUSSION

The *Arctodiaptomus* genus is widely distributed in the Palaearctic region (Reid 2007). They are generally found in small clear water bodies having well developed littoral vegetation (Woltereck 1941; Segers et al. 1995). Among the *Arctodiaptomus*, the species of *A. dorsalis* are considered as neotropical and occurs in perennial ponds, lakes, phreatic and groundwater (Suárez-Morales & Reid 2003). They are also present in temporary water bodies including seasonal floodplain and able to survive in overwinter (Havel et al. 2000; Williams-Howze 1997). *Arctodiaptomus alpinus* and *Arctodiaptomus parvispineus* are cold stenothermal species that usually occurs in oligotrophic high altitude mountain water bodies (Raina & Vass 1993; dos Santos Silva et al. 1994; Reddy 1994; Jersabek et al. 2001; Shu et al. 2013b).

The new species described herein corresponds with *A. parvispineus* reported by Kiefer in 1935 from

Table 2. Morphological features of the genus Arctodiaptomus recorded from the Indian Himalaya.

		***Arctodiaptomus* (*Haplodiaptomus*) *parvispineus* Kiefer 1935**	***Arctodiaptomus* (*Rhabdodiaptomus*) *michaeli* Reddy et al. 1990**	***Arctodiaptomus kumaunensis* sp. nov.**
MALES (♂)				
Body length excluding caudal setae (mm)		1.83 mm	1.31 mm	1.50 mm
Caudal ramus length:width		1:3	1:4	1:2.7
Right Antennule (♂)				
	Segment 13	No stout spine.	Very short spine.	Long stout spine.
	Segment 18–19	No geniculated	No geniculated	Geniculated
	Segment 20–21	No spine or hyaline membrane on antepenultimate segment.	Spinous process nearly straight and round apex on antepenultimate segment.	A comb-shaped process with 5 denticles on antepenultimate segment.
Right fifth leg (♂)				
	Right fifth leg basis	Hyaline lobe each on posterior face and distal inner margin;	A large hyaline lobe on the inner margin.	A butterfly shape hyaline lobe on inner margin.
	Right fifth leg exopod-2	1.6 times as long as median wide; lunate chitinous lobe on posterior surface.	2 times as long as median wide; crescentic hyaline lobe near disto-inner corner.	3 times as long as median wide; no hyaline lobe.
	Right fifth leg endopod	1-segmented, apex oblique, with short coarse hairs.	1-segmented, apex oblique, with transverse row of short, coarse hairs.	2-segmented, proximal segment boarder; 0.3 times as long as distant segment; roughly curved tapering at the end.
Left fifth leg (♂)				
	Left fifth leg basis	Almost trapezoid; 3 hyaline lamella outgrowths on posterior surface: one lobe on upper, second narrow lamella along inner margin, third triangular lamella along bottom margin.	Almost rectangular; one narrow hyaline lamella along inner margin;	Rectangular; one narrow hyaline lamella along posterior inner margin and one triangular hyaline lamella along on proximal margin.
	Left fifth leg exopods	2-segmented; proximal conical shape and distal small almost rounded.	2-segmented; proximal conical shape and distal almost oval.	2-segmented; proximal conical shape and broader at proximal and gradual tapering upto the distal segment.
	Left fifth leg apical process	2 terminal processes; outer finger-like spinose process and inner out curved setiform process longer than spine.	2 terminal processes; outer finger-like spinose process and inner out curved setiform process slightly longer than spine.	2 terminal processes; outer finger-like spinose process and inner out curved setiform process slightly shorter than spine.
	Left fifth leg endopod	1-segmented; small and reaching up to mid length of second exopod; apex rounded with minute spines	Slightly cylindrical non segmented reaching mid length of second exopod; apex rounded with transverse row of coarse hairs, and minute spine on inner side.	Extremely reduces.
FEMALES (♀)				
Mean body length excluding caudal sate (mm)		1.83	1.56	1.55
Caudal ramus length:width		1:2.3	1:2.7	1:2.2
Fifth leg (♀)				
	Fifth leg (♀) coxa	Roughly conical, armed with sensillum at proximal outer margin and triangular spine at disto-outer corner on posterior surface.	Roughly rectangular armed with small broad-based hyaline spine at disto-outer corner on posterior surface.	Roughly rectangular armed with lateral processes at proximal outer margin.
	Fifth (♀) exopod1	1.5 times as long as wide; 2 lateral sensilla on outer margin.	Right leg stouter than left leg; 1.5 times as long as wide; 2 sensilla on outer margin.	1.7 times as long as wide; no sensilla on outer margin.
	Fifth (♀) endopod	A vague cross septum at mid length; an apex rounded with row of short hairs.	Weakly divided 2 unequal segments; an apex rounded with transverse row of short coarse hairs, and small spine on each side.	Endopodite no cross septum, apex rounded with a row of short hairs.

a pond in Chushol, Ladakh of western Himalaya, India. As the species was not described completely, a new re-description was made by Shu et al. (2013a) with its collected from Potatso National Park of Yunnan, China. Some similar morphological features in female *A. parvispineus* and *A. kumaunensis* sp. nov. are 25-segmented antennules; second exopod segment (end claw) slender, both margins with fine spinules, a thick spine near the base of third segment, lateral margins nearly straight but curved at the end. The male *A. parvispineus* and *A. kumaunensis* sp. nov. have almost similar sizes. Right antennule armed with relatively long spines on segment 8, 10, and 11. Basis of right fifth leg in male is a trapezoid shape, 1.5 times longer than wide. *A. kumaunensis* sp. nov. has also a close affinity to *Arctodiaptomus michaeli* (Reddy et al. 1990), particularly the hyaline membrane in the fifth right leg of the male and second exopod on fifth leg of the female. *A. kumaunensis* sp. nov. shared some diagnostic characters with sub-genus *Hesperodiaptomus* such as formation of long process in the ante-penultimate segment of the male geniculate antennule and presence of slender terminal curved claw in the male fifth leg which is gradually tapering to the tip.

As compared with congeners of the genus *Arctodiaptomus*, the newly described taxon showed many distinguished features. The second exopod segment of the male right leg in *Arctodiaptomus kumaunensis* sp. nov. is relatively long (3 times as long as median wide) and no hyaline lobe possesses. The geniculate between segment 18 and 19 of the right antennule was not found in other Himalayan nominal species. Segment 13 of the male right antennule of *Arctodiaptomus kumaunensis* sp. nov. has a relatively stout spine. A strong comb-like process with 5 denticles on segment 20–21 antepenultimate segment of male right antennules is useful in separating the close relative species. The endopodite of the male 5th leg is extremely reduced and the endopodite of the female 5th leg is elongated but has no septum. The three corresponding species of Himalayan *Arctodiaptomus* can be separated from each other based on the characters in Table 2.

The most specialized character of male *A. kumaunensis* sp. nov. is the presence of a strong comb-shaped denticulate spine on the antepenultimate segment of right antennule. The spine reaches well beyond the distal margin of the succeeding segment. The endopod of the right fifth leg in male *A. kumaunensis* is two segmented and observed typical ornamentation. Basis of which processes a butterfly shape hyaline membrane on the inner lateral side. Expod-2 of male right fifth leg thrice as long as median wide. The peculiar character of *A. kumaunensis* sp. nov. is reddish body colour. The concentration of pigment carotenoids, astaxanthin, in the newly described species is 1.9 µg/mg. The identified diaptomid tends to adapt well in the Himalayan Mountain system with this photoprotectant.

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