

Contribution to the knowledge of *Thraulius* Eaton, 1881 (Insecta: Ephemeroptera: Leptophlebiidae: Atalophlebiinae) from India with the description of five new species

M. Vasanth^{1,2}, K. A. Subramanian^{1*}, C. Selvakumar³ and K. G. Sivaramakrishnan⁴

¹Zoological Survey of India, Southern Regional Centre, Santhome High Road, Chennai - 600028, India;
Email: subbuka.zsi@gmail.com

²University of Madras, Chepauk, Chennai - 600005, India

³Department of Zoology, The Madura College (Autonomous), Madurai - 625011, Tamil Nadu, India

⁴Flat No 3, Door No 7, Gokulam Apartment, Gokulam Colony, West Mambalam, Chennai - 600033, India

Abstract

Five new species of the genus *Thraulius* Eaton, 1881 viz., *T. amravati* Vasanth, Subramanian and Selvakumar **sp. nov.**, *T. cuspidatus* Vasanth, Subramanian and Selvakumar **sp. nov.**, *T. malabarensis* Vasanth, Subramanian and Selvakumar **sp. nov.**, *T. plumeus* Selvakumar, Vasanth and Subramanian **sp. nov.**, and *T. vellimalaiensis* Vasanth, Subramanian and Selvakumar **sp. nov.**, are described based on the recent collection of larval materials from Western Ghats of Kerala and Tamil Nadu, Maharashtra, Meghalaya and Nagaland, India. The five new species described herein have two morpho groups based on gill I morphology (Li, *et al.*, 2006). *T. mudumalaiensis* Soman (1991) follows the first group with four species, with gills I dorsal and ventral lamella lanceolate and gills II–VII fimbriate (Table 1). The second group, comprising *T. malabarensis* **sp. nov.**, *T. thiagarajani* Balasubramanian and Muthukatturaja, 2019, and *T. gopalani* Grant and Sivaramakrishnan, 1985, have gills I, dorsally lanceolate and ventrally fimbriate and gill II–VII fimbriate (Table 2). There is also a geographical distribution of Indian *Thraulius* species, ecology of habitat information and a larval key to the known Oriental *Thraulius* Eaton, 1881 species.

Keywords: Ecology, Larva, Mayfly, New Species, *Thraulius*, The Western Ghats

Introduction

The genus *Thraulius* was established by Eaton in 1881 for the European species *Thraulius bellus*. Peters and Edmunds (1970) provided a comprehensive redefinition of the genus in the Eastern Hemisphere. This leptophlebiid genus is widespread throughout the Eastern Hemisphere, being found in Europe, southern Africa, Madagascar, the Comoro Islands, India, South Eastern Asia, Australia and the Indo-West Pacific (Grant and Peters, 1993). They showed that *Thraulius* is actually a group of closely related genera (the *Thraulius* group). Among the sixteen nominal species described from the Eastern Hemisphere, only five species, viz., *T. semicastaneus* Gillies, 1951, *T. gopalani* Grant and Sivaramakrishnan, 1985, *T. mudumalaiensis* Soman, 1991, *T. thiagarajani* Balasubramanian and

Muthukatturaja, 2019 and *T. jacobusi* Isack *et al.*, 2022 have so far been described from India. Among these, *T. semicastaneus* is known only from imago; *T. gopalani* and *T. thiagarajani* are known from both larval and alate stages; and *T. mudumalaiensis* and *T. jacobusi* Isack *et al.*, 2022 known only from larvae.

As a result of recent field surveys by the Zoological Survey of India (ZSI), five new species of the genus *Thraulius* are described herein based on larval collections: two species from Tamil Nadu and one species each from Kerala, Maharashtra, and Meghalaya, India. The diversification of the genus *Thraulius* within India is briefly discussed in the overall context of the origin and diversity of the *Thraulius* clade in southern and Southeast Asian regions.

* Author for correspondence

Table 1. Comparison of the larval characteristics of known species of *Thraulius* Eaton, 1881 in India**Group I:** Gill I dorsally lanceolate and ventrally fimbriate

Species Characters	<i>T. gopalani</i>	<i>T. thiagarajani</i>	<i>T. malabarensis</i> n. sp.
Colouration	Brownish yellow	Blackish brown with pale yellow	Brownish yellow
Labrum anterior emargination	Rectangular mesal	Rectangular mesal	Blunt teeth medially and two large blunt crenation on either side
Mandibles	Smoothly curved outer margin with few thin setae	Smoothly curved outer margin with 6-9 setae	Smoothly curved with 10 long hair-like setae
Hypopharynx	Lingua with well developed laterals	Lingua with minute hair like setae on the dorsal and ventral surface	Lingua with well-developed lateral processes; superlingua broad, short lateral projection on its arms
Claw	10–13 denticles decreasing apically	10–13 denticles increasing medially and apically decreasing with 5-minute sub apical denticles	Single row of 10 denticles
Gill I lamellae shape	Dorsally lanceolate and oval ventrally	Long lanceolate dorsally and oval ventrally	Dorsal slender, lanceolate, lamella oval, fimbriate
Gills II-VII lamellae shape	Dorsal and ventral lamellae oval shaped	Dorsal and ventral lamellae oval, gill VII smaller than others	Dorsal and ventral lamellae alike, each lamella oval and elongated with long marginal fringes, tracheae unbranched
Fore femur	Basal half white and apical half dark brown	Basal half with dark brown, apical half washed with yellowish brown	Basal half yellowish brown and apical half blackish
Hind tibia	Densely covered with short setae	Densely covered with short fine setae	Mix with dense stout and feathered setae on dorsal surface
Abdominal segments VIII-IX	Posterolateral spines are large and dark brown	Posterolateral spines are large and dark brown	Posterolateral spines are large and yellowish brown
Caudal filaments	Small stout setae surrounding segments, light brown towards the apex,	Without hairs on caudal filaments	Yellowish, whorl of setae on alternate segments, setae shorter than length of corresponding segment

Table 2. Comparison of the larval characteristics of known species of *Thraulius* Eaton, 1881 in India**Group II:** Gill I dorsal and ventral lamella lanceolate

Species Characters	<i>T. mudumalaiensis</i>	<i>T. jacobusi</i>	<i>T. cuspidatus</i> sp. nov.	<i>T. plumeus</i> sp. nov.	<i>T. vellimalaiensis</i> sp. nov.	<i>T. amravati</i> sp. nov.
Colouration	Brownish yellow	Brownish yellow	Blackish brown	Brownish yellow	Brownish yellow	Yellowish black
Labrum anteriomedian emargination	Smoothly curved without denticles	5–6 minute denticles	With blunt crenation medially	Broad with median undulation	Broad with median undulation	Concave medially
Mandibles	Smoothly curved, outer margin with few setae	Smoothly curved, outer margin with 10–12 setae	Not smoothly curved, outer margin with 7–8 setae	Not smoothly curved, outer margin with 6–7 setae	Not smoothly curved, outer margin with 2–3 setae	Smoothly curved, outer margin with 8–9 setae
Hypopharynx	Lingua is well developed laterals with apically submedian lobe notched; superlingua with a row of hairs on anterior margin	Lingua with well-developed laterals; superlingua with a row of long simple setae on outer margin	Lingua of anterior margin shallowly emarginated; superlingua well developed with lateral projection on its arms	Lingua with well developed lateral processes, anterior margin shallowly cleft	Lingua with well-developed lateral processes; anterior margin deeply cleft	Lingua with well developed lateral processes; superlingua with anteriorly dense row of setae
Claw	10 denticles increasing in size medially and decrease apically with 5 subapical denticles	11–12 large, stout denticles towards proximal end and 5 subapical denticles	10–11 denticles, progressively larger towards the apex	13–14 denticles progressively larger towards the apex	11–12 denticles and subapically 6 large denticles increasing towards the apex	A row of 9–10 denticles
Gill I Shape	Dorsally lanceolate and slender ventrally	Dorsal lamella slightly broader and ventral lamella slender	Dorsally lanceolate and slender ventrally	Dorsally long lanceolate, slender and ventral wider than dorsal	Dorsal short, slender and ventral wider than dorsal	Dorsal short, lanceolate and slender ventrally
Gills II–VII	Dorsally elliptical and oval ventrally	Dorsal and ventral elliptical with long fringed margins	Dorsal and ventral lamellae oval, margins are long fimbriate, without tracheation	Dorsal and ventral lamellae oval, tracheae clear	Dorsal and ventral lamellae oval and apex of margins with long fringes	Dorsal and ventral lamellae oval, without tracheation

Fore femur	–	Orange pigmentation (Subimago detail)	Basal half dark brown and apically with yellowish brown	Basal yellowish, apically yellowish mixed with black	Broad, basally white, apically yellowish and mixed with black	Uniformly yellowish
Hind tibia	Prominent setae on inner and outer margins and sub-equal in length	Outer and inner margin with row of stout and spine-like setae	Mixed with dense, thick, long and feathered setae on dorsal surface	Mixed with thick, long and feathered setae on dorsal surface	Thick and long setae on surface of both margins	Densely covered with thick and long setae on dorsal surface
Abdominal segment VIII–IX	Posterolateral spines are acuminate, light brownish yellow	Posterolateral spines are sharp, yellowish black	Posterolateral spines are larger, yellowish brown	Posterolateral spines are larger, yellowish brown	Posterolateral spines slightly larger and yellowish	Posterolateral spines moderately larger and dark brown
Caudal filaments	Small stout setae on surrounding segments, terminal filament longer than cerci	Spine-like setae, shorter than the length of the corresponding segment	Brown, setae shorter than segment of corresponding segment	Yellowish, setae shorter than the corresponding segment	Yellowish, stout setae smaller than the corresponding segment	Light yellowish, small stout setae shorter than the corresponding segment

Material and Methods

Larval materials were collected from streams and rivers in Indian states, *viz.*, Kerala, Maharashtra, Meghalaya, Nagaland and Tamil Nadu, during expeditions by the ZSI. The larvae were collected by kick-net sampling and hand picking with a fine brush. All materials were stored in 95% ethanol. In some cases, permanent mounts were made in Hoyer's medium to enable detailed microscopic observations.

Photographs were taken with a Leica M205A and a Leica SAPO, while mouthparts, legs and gills were photographed with a Nikon 80i and a Leica DM3000 microscope. Photographs were edited and composed in Adobe Photoshop CS6. GPS coordinates were recorded during the expedition by a Garmin 750, and distribution maps were generated with the software QGIS 3.8.2 Zanzibar. The specimens are deposited in the National Zoological Collections (NZC), Central Entomological Laboratory (CEL), Zoological Survey of India, Kolkata and the Southern Regional Centre (SRC), the Zoological Survey of India (ZSI), Chennai, India. All species descriptions are based on the morphological species concept, and species descriptions are arranged alphabetically.

CEL - Central Entomological Laboratory, Kolkata
SRC - Southern Regional Centre, Chennai

ZSI - Zoological Survey of India

NZC - National Zoological Collections

All the measurements in millimetres (mm)

Taxonomic Accounts

Thraululus amravati Vasanth, Subramanian and Selvakumar **sp. nov.**

(Figures 1–14)

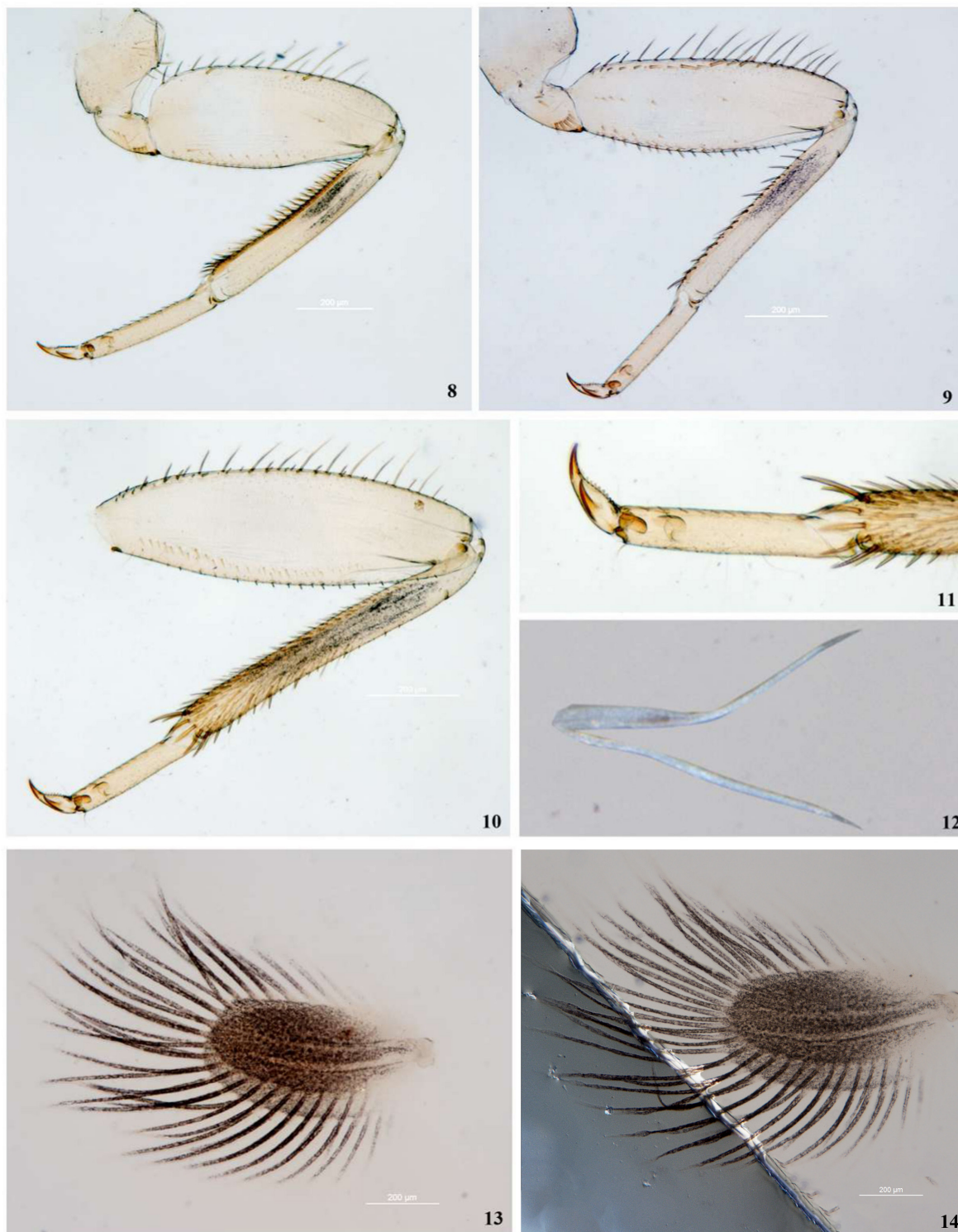
Material examined: Holotype: 1 larva, India, Maharashtra, Amravati District, Melghat Tiger Reserve Forest, Semadoh village, 21.505018°N, 077.218003°E; Alt. 443 m; 04.x.2018, coll. M. Vasanth (Reg. No. I/E/527). Type deposited in SRC/ZSI/Chennai.

Description (holotype): Mature larva. Body length 4.7–5.2; cerci 3.5–4.0, median filament 5 (Figure 1).

Head: Head capsule with dark brownish yellow washed area between ocelli; median line of vertex yellowish; clypeus margins slightly parallel. Labrum with slightly convex posterior margin, irregular rod-like setae on both dorsal and ventral surfaces, and sparse setae on both dorsal and ventral surfaces; additionally, median and apical row of setae dorsally along anterior margin; width slightly greater than clypeus; labrum with anteromedian emargination shallowly cleft with laterally rounded (Figure 2). Lingua of the hypopharynx with well-developed lateral processes (Figure 3). Mandibles with



Figures 1-7. Larva of *Thraululus amravati* sp. nov. 1. Dorsolateral view; 2. Labrum; 3. Hypopharynx; 4. Left mandible; 5. Right mandible; 6. Maxilla; 7. Labium



Figures 8–14. Larva of *Thraulius amravati* sp. nov. 8. Foreleg; 9. Midleg; 10. Hindleg; 11. Claw; 12. Gill I; 13. Gill II; 14. Gill V.

sparse lateral setae; prostheca of mandibles with stout, hair-like setae; mandibles smoothly curved with 5–6 hair-like setae anteriorly (Figures 4 and 5). Maxilla with dense, stout spines and thin setae on the anterior margin; an additional row of 22–24 pectinate setae present below these; maxilla outer margin with unevenly hair-like setae; palp three-segmented, with a few setae on the outer margin and a small tuft of apical setae on the third segment (Figure 6). Labium: glossa with thick, plate-like setae on the ventral surface, fewer setae on the dorsal surface; paraglossa with denser setae, fewer setae on the dorsal surface; I segment of labial palp with thick setae on both margins, II segment with setae on outer margin, an apical segment with III thick setae on the dorsal surface and fine setae on near apical gathered into small tufts; segment I length ca. 1.1 times segment II length, segment III length 0.7 times segment II length (Figure 7).

Thorax: Pronotum has pale, irregular brown markings on the dorsal surface. Mesonotum is yellowish brown, medially pale. Trochanter foreleg with white anterior and lateral surfaces; femora uniformly yellowish, tibiae blackish with very sparse and thin setae on inner margin, densely covered with a row of feathered setae, and a row of stout and transverse setae (Figure 8). All legs are pale, with denser, thicker, and more feathered setae on the surface of the hind tibiae; the tibia of all legs has dark black colour markings; and the tarsi of all legs has several stout setae on the inner margin and sparse setae on the outer margin (Figures 8, 9, and 10). A claw with a row of eight blunt denticles, (Figure 11).

Abdomen: Abdominal segments I–IX brown and pale brown laterally (Figure 1). Terga III–IX have posterolateral projections, and terga VIII–IX are larger than the others (Figure 1). Gills on segments I–VII; gills I slender, lanceolate, ventral lamellae slightly wider than dorsal (Figure 12); gills II–VII are similar in shape, with dorsal and ventral lamellae; each lamella elongated-ovate, with entire margins fimbriate; tracheae of gills are clear (Figures 13 and 14). Caudal filaments with a whorl of setae on alternate segments; setae shorter than the length of corresponding segment.

Adult: Unknown.

Etymology: The species is named after Amravati, a district of Maharashtra, India, where the type locality is situated.

Distribution: Maharashtra (Melghat Tiger Reserve, Amravati dist.).

Diagnosis: *Thraululus amravati* sp. nov. can be distinguished from other known species of the genus by the following combination of characters:

- The anteromedian emargination of the labrum shallowly cleft and laterally rounded (Figure 2);
- Smoothly curved mandibles with 5–6 hair-like setae anteriorly (Figures 4 and 5).
- Segment III of labial palp sub-equal to length of segment II (Figure 7).
- Segment III of maxillary palp greater than $\frac{1}{4}$ length of segment II (Figure 6).
- Abdominal segments I–IX, dorsally brown and pale brown laterally (Figure 1).
- All tibiae with medial black spots (Figures 8, 9 and 10).
- Hind tibia with dense, stout setae (Figure 10).
- Claw with a row of eight blunt denticles (Figure 11).
- Gills I are slender and lanceolate, with ventral lamellae wider than dorsal (Figure 12).
- Gills II–VII are oval, with marginal fringes, and the tracheae are slightly clear (Figures 13 and 14).

Habitat: Larvae of this species were collected in medium sized stream (wide 3–12 m), at an altitude of 443m. In north Amravati district and South-Western Satpura mountain ranges (India, Maharashtra) (Figure 90). The stream bottom was covered with stones and gravels. Larvae were collected from under stones together with *Baetis* sp., Leptophlebiidae (*Choroterpes* sp.), Tricorythidae (*Sparsorythus* sp.) and Hydropsychidae (Trichoptera).

Thraululus cuspidatus Vasanth, Subramanian and Selvakumar sp. nov.

(Figures 15–32)

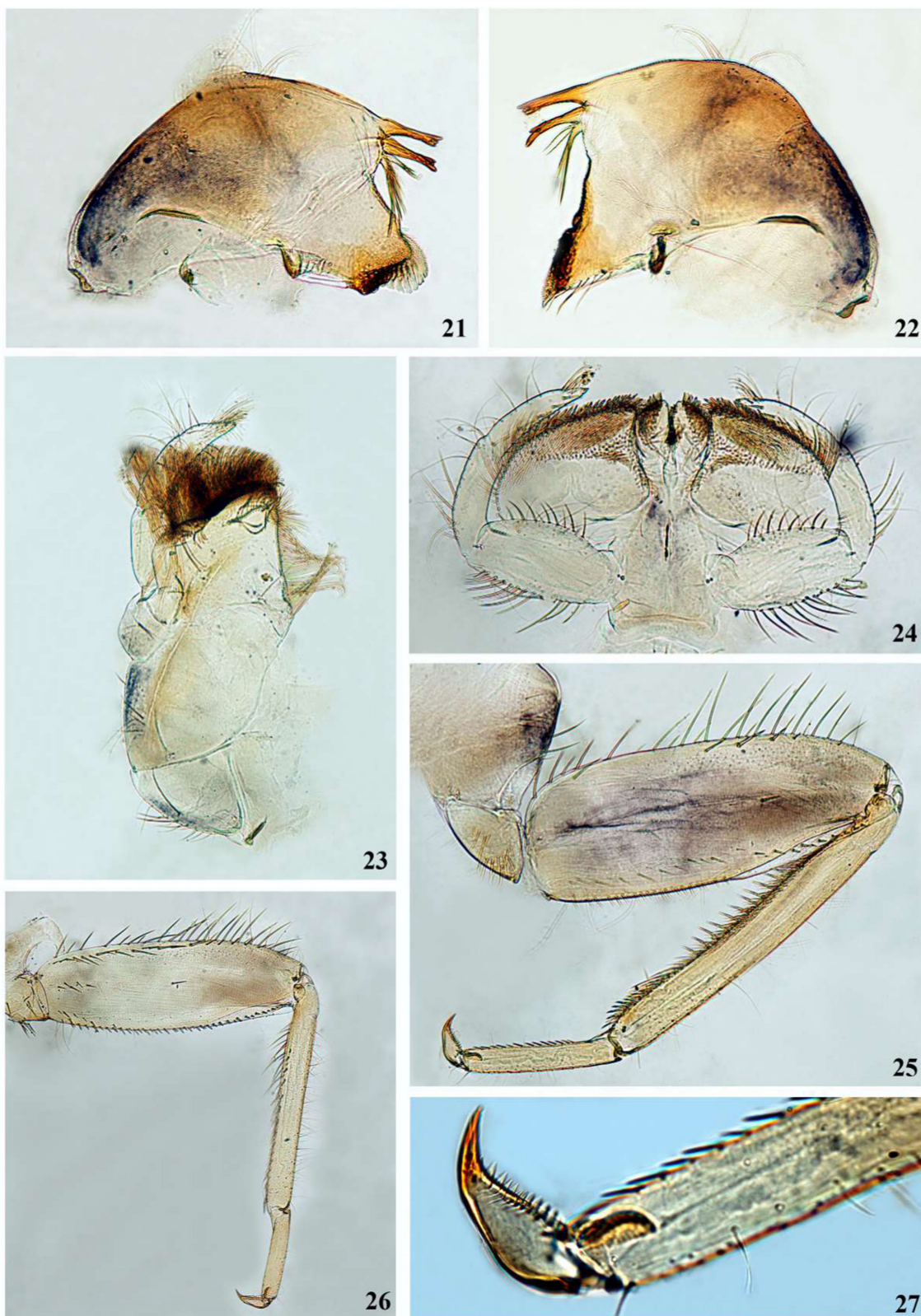
Material examined: Holotype: 1 mature larva, India, Tamil Nadu, Tirunelveli District, Kalakkad, Thalaiyoothu stream near Sengaltheri, 08.53699°N, 077.45233°E, Alt. 894 m, 14.viii.2019, colls. K. A. Subramanian and M. Vasanth (Reg. No. I/E/525). Paratypes: 2 larvae, same data as holotype (Reg. No. I/E/526). Types are deposited in SRC/ZSI/Chennai.

Description (holotype): Mature larva. Body length 4.5–5.0, cerci 5, median filament 6 (Figure 15).

Head: Head capsule with area between ocelli washed with black; median line of vertex pale; margins of clypeus parallel (Figure 15). Labrum with a slightly convex posterior margin, irregular sparse setae on both the dorsal and ventral surfaces, plentiful setae on anterior dorsal



Figures 15–20. Larva of *Thraulius cuspidatus* sp. nov. 15. Dorsal view; 16. Ventral view; 17. Labrum; 18. Labrum closer view; 19. Hypopharynx; 20. Hypopharynx closer view.



Figures 21–27. Larva of *Thraulius cuspidatus* sp. nov. 21. Left mandible; 22. Right mandible; 23. Maxilla; 24. Labium; 25. Foreleg; 26. Midleg; 27. Claw.



Figures 28–32. Larva of *Thraulius cuspidatus* sp. nov. 28. Hindleg; 29. Gill I; 30. Gill III; 31. Gill V; 32. Gill VII.

surface, a single row of dense setae at the anterior margin of the labrum dorsally (Figure 17); anterior emargination moderately concave with median blunt teeth projecting beyond the anterior edge of the labrum (Figure 18). Lingua of hypopharynx with well developed lateral processes, anterior margin shallowly emarginated; the hypopharyngeal superlingua has well-developed lateral projection with its arms. (Figures 19 and 20). Mandibles with sparse lateral setae; prostheca of the left mandible with a stout spine; outer margin of the mandible with 7–8 setae on the middle region (Figures 21 and 22). The maxilla has dense thick spines and fine setae on anterior margin, an additional row of 15 pectinate setae presents among these, a large thicker pectinate projection on the inner corner; the outer margin of maxilla and cardo with setae; the palp III segmented, the length of segment I is 1.3 times the length of segment II, an outer margin with few setae; the length of segment III 0.9–1.0 times the length of segment II, an outer and inner margins of palps with setae, the III segment with small tuft of apical setae (Figure 23). Labium: glossa with thick, plate-like setae on ventral surface and fewer setae on dorsal surface; paraglossa with denser but fewer setae on dorsal surface; first segment of labial palp with thick setae on inner and outer margins; second segment with setae on outer margin; apical segment with thick setae on dorsal and fine setae on tip; those near the apex of the apical segment gathered into small tufts; segment I length ca. 1.5 times segment II length; segment III length 0.7 times segment II length (Figure 24).

Thorax: Pronotum brown with pale irregular markings on the dorsal surface. Mesonotum is brown, and the median area is pale (Figure 15). Foreleg of trochanter with anterior surfaces black with brown, and lateral surface brownish yellow; basal femora $\frac{1}{2}$ of dark brown, apically with yellowish brown, tibiae brownish with very sparse and thin setae on the inner margin, densely covered with a row of feathered setae and with a row of stout and transverse setae (Figure 25). Hind femora with apically $\frac{1}{3}$ of blackish and stout setae on the outer margin, hind tibiae mixed with dense, thick and feathered setae on the surface; tarsi of all legs with several thick setae on the inner margin and sparse setae on the outer margin (Figures 25, 26 and 28). Claws with a row of 10–11 denticles, progressively larger towards apex (Figure 27).

Abdomen: Abdomen brown, with an indistinct paired submedian stripe along the body axis. Terga III–IX with

posterolateral projections (Figure 15). Sterna I–VII white and VIII–X dark brownish yellow (Figure 16). Gills on abdominal segment I–VII; gills I slender, lanceolate, ventral lamellae little wider than dorsal (Figure 29); gills II–VII similar in shape, oval, with marginal long fringes; tracheae of gills branched (Figures 30, 31 and 32). Caudal filaments with a whorl of setae on alternate segments; setae shorter than the length of corresponding segment.

Adult: Unknown.

Etymology: The species epithet is a Latin adjective, cuspidate, meaning cuspid-like shape of the anterior margin of the labrum.

Distribution: Tamil Nadu (Kalakkad and Mundanthurai Tiger Reserve Forest, Tirunelveli dist.).

Diagnosis: *Thraululus cuspidatus* sp. nov. can be distinguished from other known species of the genus by the following combination of characters:

- Labrum anterior emargination is moderately concave with median blunt teeth projecting beyond the anterior edge (Figures 17, 18).
- Superlingua hypopharynx has well-developed lateral projection with its arms (Figures 19, 20).
- Mandibular outer margin of with 7–8 setae on middle region (Figures 21, 22).
- Claws with a row of 10–11 denticles, progressively larger apically (Figure 27).

Habitat: Larvae of this new species were collected in a small forest stream (wide 6–8 m) at an altitude of 894 m in Sengaltheri, Kalakad-Mundanthurai Tiger Reserve, Tamil Nadu. (Figure 91). The stream substrate is mainly covered with cobbles and pebbles. Larvae were collected under pebbles and were associated with *Baetis* sp., Heptageniidae (*Afronurus* sp., *Thalerosphyrus* sp.), Leptophlebiidae (*Choroterpes* sp.) and Hydropsychidae (Trichoptera).

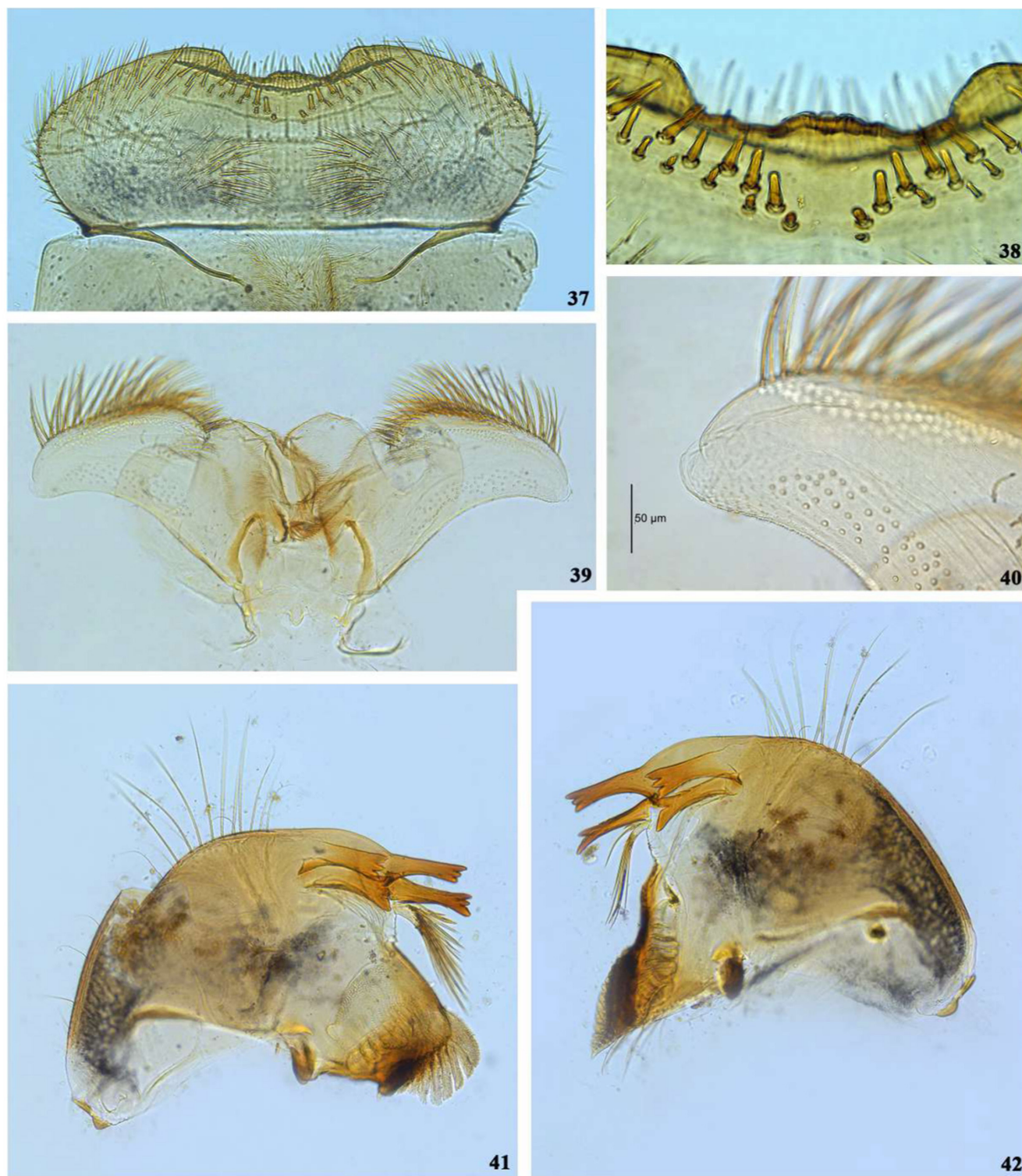
Thraululus malabarensis Vasanth, Subramanian and Selvakumar sp. nov.

(Figures 33–56)

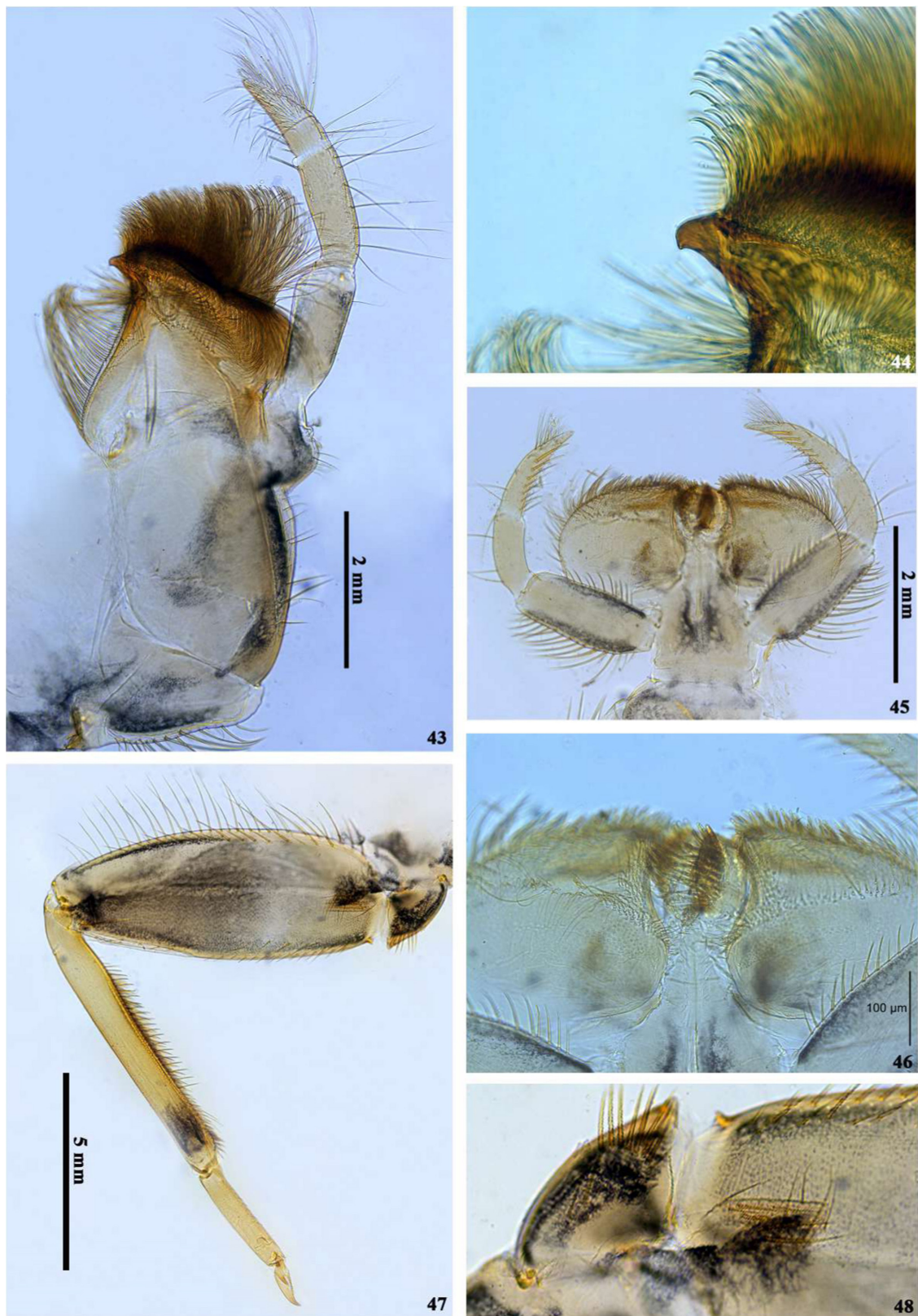
Material examined: Holotype: Mature larva, India, Kerala, Kannur District, Cheenkanni Puzha, Aralam WLS, 11.92121°N, 075.79362°E, 79.6 m, 12.ii.2021, colls. K. A. Subramanian and M. Vasanth (Reg. No. I/E/565). Paratypes: 5 larvae, same data as the holotype (Reg. No. I/E/566). 5 larvae, Kerala, Kannur District, Paripputhode, Aralam WLS, 11.97621° N, 075.82514° E, 122 m,



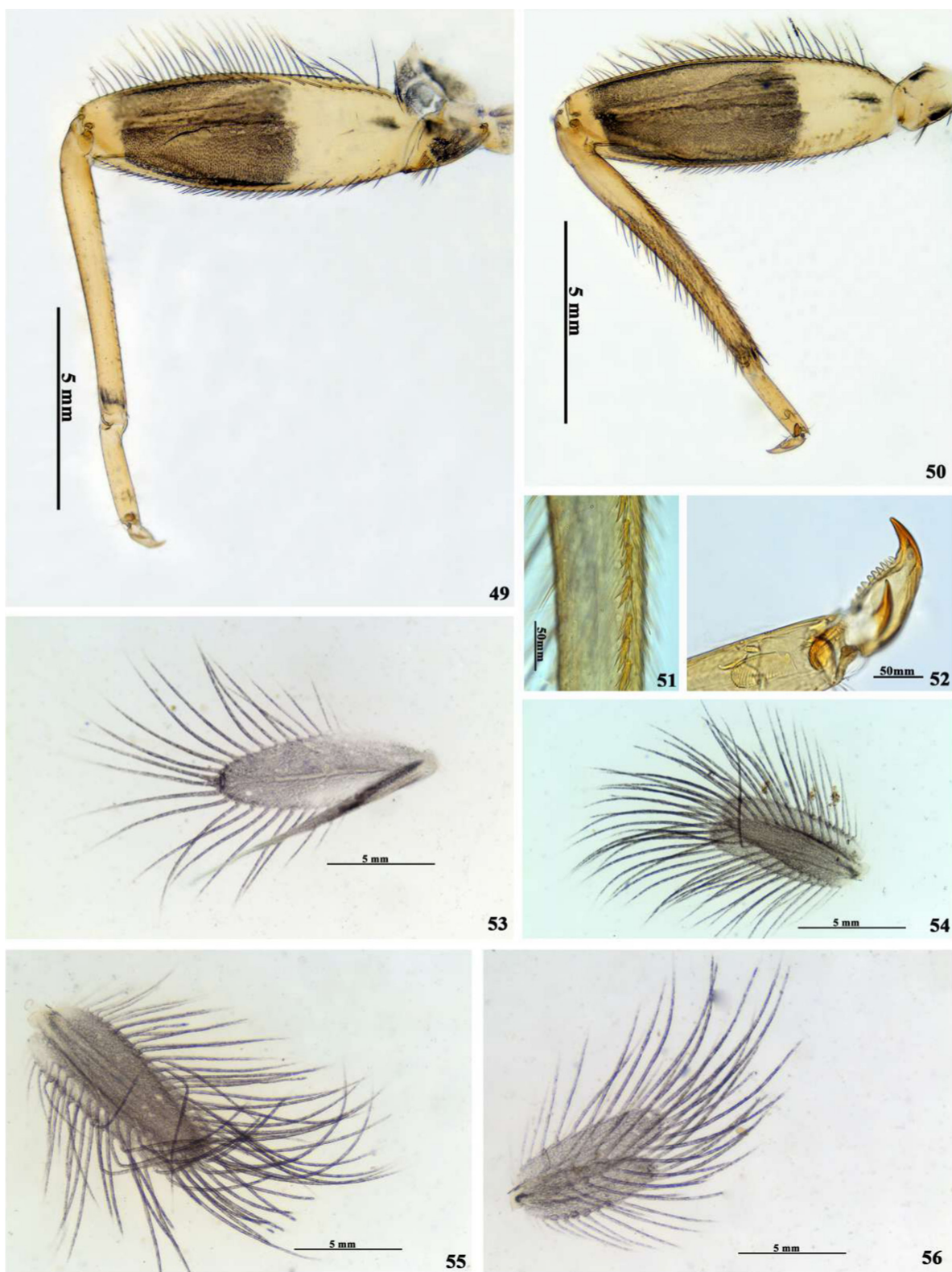
Figures 33–36. Larva of *Thraulius malabarensis* sp. nov. 33. Dorsal view; 34. Ventral view; 35. Abdomen I–V dorsal view; 36. Abdomen VIII–X ventral view.



Figures 37–42. Larva of *Thraululus malabarensis* **sp. nov.** 37. Labrum; 38. Labrum closer view; 39. Hypopharynx; 40. Hypopharynx closer view; 41. Left mandible; 42. Right mandible.



Figures 43–48. Larva of *Thraulius malabarensis* sp. nov. 43. Maxilla; 44. Maxilla closer view; 45. Labium; 46. Labium closer view; 47. Foreleg; 48. Fore leg closer view.



Figures 49–56. 49. Larva of *Thraulius malabarensis* sp. nov. Midleg; 50. Hindleg; 51. Hind tibiae closer view; 52. Claw; 53. Gill I; 54. Gill III; 55. Gill IV; 56. Gill VII.

13.ii.2021, colls. K. A. Subramanian and M. Vasanth (Reg. No. I/E/567). Types are deposited in SRC/ZSI/Chennai.

Description (holotype): Mature larva. Body length 8.5–9.0 mm, cerci 9.5–10.5 mm, median filament 11.0 mm (Figure 33).

Head: The head capsule and the area between the ocelli were washed in dark brown; the median line of the vertex was brown; and the clypeus margins were parallel. Labrum with straight posterior margin, dorsal surface with four rows of long hair-like setae, anterior part with thick spine-like setae; posterior-laterally rounded with small hair-like setae on apex; width of clypeus same as labrum; anteromedian emargination with small, blunt teeth medially and two large blunt teeth on either side (Figures 37 and 38). Lingua of hypopharynx with well-developed lateral processes; superlingua broad, short lateral projection on its arms (Figures 39 and 40). Mandibles with thin, hair-like setae laterally, smoothly curved with 10 long, hair-like setae on the anterior margin; prostheca of the left mandible with thicker spine-like setae, outer and inner incisors with 3 denticles each; prostheca of the right mandible with thin, spine-like setae, an outer incisor with 3 denticles, and an inner incisor with 2 denticles (Figures 41 and 42). Maxilla with dense, thick spines and thin setae on the anterior margin, an additional row of 15–16 simple setae present among these, and a large, thicker pectinate projection on the inner corner; outer margin of the maxilla with long, thin hair-like setae; palps 3 segmented, segment I 0.5x times longer than segment II, outer margin with few hair-like setae; segment III 0.2 times shorter than segment II, outer and inner margins of segment II with hair-like setae, segment III with tuft of hair-like setae apically (Figures 43 and 44). Glossa of labium with thick setae on the ventral surface, stout and hair-like setae on dorsal surface; paraglossa with thick stout setae on dorsal surface; segment I of labial palp with thick setae on inner and outer margins, segment II with few long hair-like setae on outer margin, an apical segment with a tuft of fine hair-like setae; surface with seven thick setae, segment I length ca. 1.5x times the length of segment II, segment III 0.7x times the length of segment II (Figures 45 and 46).

Thorax: Pronotum brown with black irregular markings on the dorsal surface. Mesonotum brown, median area brownish yellow with black markings (Figure 33). Legs yellowish brown with black maculae medially; fore femora with two rows of thick and long hair-like setae on

anterior margin and two rows of long hair-like setae starts with proximal part to posterior margin; dorsal surface of the proximal region with bunch long hair-like setae (Figure 48); tibiae with black maculae distally, fine and stout setae on inner margin; mid and hind femur with two rows of long hair-like setae and small black maculae on proximally and the dark black band start from half of each femur; mid tibiae yellowish brown black maculae proximally (Figure 49); hind tibiae mix with denser, stout and feathered setae on the surface; tarsi of all legs with thick setae on inner margin and small sparse setae on outer margins (Figures 47, 48, 49 and 50). Claws with a row of 10 denticles (Figure 51).

Abdomen: Abdomen yellowish brown, with median pale stripe and pale paired patches on segments I–VIII. The paired square patches progressively reduce in size from anterior to posterior. Ventrally, the terga I–VII with paired dark brown squarish blotches (Figure 34). The markings in terga VIII–X are indistinct. Terga VII–IX with posterolateral projections, terga VIII–IX larger than terga VII. Gills on segments I–VII; gill I slender, lanceolate, ventral lamellae large fimbriate (Figure 53); gills II–VII similar in shape, dorsal and ventral lamellae alike; each lamella oval and elongated with long marginal fringes, tracheae unbranched; (Figures 54, 55 and 56). Caudal filaments with a whorl of setae on alternate segments; setae shorter than the length of the corresponding segment.

Adult: Unknown.

Etymology: The species named after the old, popular name of North Kerala.

Distribution: Kerala (Aralam WLS, Kannur).

Diagnosis: *Thraululus malabarensis* **sp. nov.** can be distinguished from other known species of the genus by the following combination of characters:

- anteromedian emargination of the labrum with small, blunt teeth medially and two large, blunt crenations on either side (Figures 37 and 38).
- superlingua of hypopharynx is broad with short lateral projection on its arms (Figures 39 and 40).
- abdominal terga VIII–IX with large posterolateral spines (Figure 36).
- claw with a row of 10 denticles (Figure 52).
- The gill I is slender, lanceolate, ventral lamellae oval, fimbriate (Figure 53).
- gills II–VII on tracheae unbranched (Figures 54, 55 and 56).



Figures 57–63. Larva of *Thraulus plumeus* sp. nov. 57. Dorsal view; 58. Abdomen ventral view; 59. Labrum; 60. Labrum undulate closer view; 61. Hypopharynx; 62. Left mandible; 63. Right mandible.



Figures 64–70. Larva of *Thraulius plumeus* sp. nov. 64. Maxilla; 65. Labium; 66. Foreleg; 67. Midleg; 68. Hindleg; 69. Tibia closer view; 70. Claw.



Figures 71–73. Larva of *Thraulius plumeus* sp. nov. 71. Gill I; 72. Gill II; 73. Gill IV.

Habitat: Larvae of this new species were collected from a third-order stream (wide 15–20 m), at an altitude of about 80 m from the Aralam wildlife Sanctuary, Kerala (Figure 92). The water temperature (28–32 °C) and bottom substrate was mainly cobbles and stones. Larvae were collected from stones associated with *Baetis* sp., Heptageniidae (*Afronurus* sp., *Thalerosphyrus* sp.), Leptophlebiidae (*Choroterpes* sp.), Perlidae (Plecoptera), Hydropsychidae (Trichoptera). The northern bank of the stream is forested, and the southern bank is covered with mixed plantation and human habitation.

Thraulius plumeus Selvakumar, Vasanth and Subramanian sp. nov.

(Figures 57–73)

Material examined: Holotype: Larva, India, Meghalaya, East Jaintia Hills, Daidung Village Pool, 25.33547°N, 92.61981°E, 1079 m, 12.iii.2016, coll. E. Eyarin Jhamalar (Reg. No. 5145/H13). Paratypes: 3 larvae, same data as holotype (Reg. No. 5146/H13); 1 larva, Meghalaya, East Jaintia hills, Daidung village stream, 25.33389°N, 92.62089°E, 1112 m, 12.iii.2016, coll. E. Eyarin Jhamalar (Reg. No. 5151/H13); 1 larva, Meghalaya, East Khasi hills, Parsmile, Santmain Nala, 25.53903°N, 91.84417°E, 1790 m, 27.ii.2016, coll. E. Eyarin Jhamalar (Reg. No. 5152/H13); 1 larva, Nagaland, Peren district, Intanki National Park, Dhansri river, 25.55940°N, 93.52678°E, 185 m, 22.iii.2017, coll. C. Selvakumar (Reg. No. 5674/H13).

Types are deposited in CEL, Kolkata.

Description (holotype): Mature larva. Body length 4.5–5.0, cerci 5, median filament 6 (Figure 57).

Head: Head capsule and area between ocelli washed with dark brown; median line of vertex pale; margins of clypeus parallel. Labrum with posterior margin slightly convex, irregular sparse setae on both dorsal and ventral surfaces, additionally median and an apical row of setae dorsally along the anterior margin; width slightly greater than clypeus; labrum anteromedian emargination broad with undulate medially (Figures 59 and 60). Lingua of hypopharynx with well-developed lateral processes, anterior margin shallowly cleft (Figure 61). Mandibles with sparse lateral setae, prosthema of the left mandible with a stout spine (Figures 62 and 63). Maxilla with dense stout spines and fine setae on anterior margin, a large stout pectinate projection on the inner corner; outer margin of maxilla and cardo with setae; palp III segmented, length of segment I 1.2–1.4 times length of segment II, outer margin with few setae on segment II; length of segment III 0.8–0.9 times length of segment II, outer and inner margins of both with setae, the third segment with a small tuft of apical setae (Figure 64). Labium: glossa with thick plate-like setae on the ventral surface, fewer setae on dorsal surface; paraglossa with denser but fewer setae on dorsal surface; I segment of labial palp with thick setae on margins, II segment with setae on outer margin, an apical

segment with thick and fine setae on margin and surface, those near apex of apical segment gathered into small tufts; segment I length ca. 1.2 times segment II length, segment III length 0.9 times segment II length (Figure 65).

Thorax: Pronotum brown with pale irregular markings on the dorsal surface. Mesonotum brown, median area pale. Foreleg of trochanter with anterior surfaces light black, and lateral surface yellowish; basal femora yellowish, apically yellowish mixed with black, tibiae blackish with very sparse and thin setae on the inner margin, densely covered with a row of feathered setae and with a row of stout and transverse setae (Figure 66). Hind tibiae dense with feathered and hair-like setae on the dorsal surface; tarsi of all legs with several stout setae on the inner margin and sparse setae on the outer margins (Figures 66, 67 and 68). Claws with a row of 13–14 denticles, progressively larger towards the apex (Figure 70).

Abdomen: Abdomen brown, with indistinct paired submedian pale spots along the body axis. Terga III–IX with posterolateral projections, terga VIII–IX larger (Figure 57). Sterna with blackish brown, segment I–VII medially dark brown and segment VIII–X yellowish brown (Figure 58). Segments I–VII with gills; gills I slender, lanceolate, ventral lamellae wider than dorsal (Figure 71); gills II–VII similar in shape, with dorsal and ventral lamellae; each lamella elongated-ovate, with entire margins fimbriate; tracheae visible (Figures 72 and 73). Caudal filaments with a whorl of setae on alternate segments; setae shorter than the length of the corresponding segment.

Adult: Unknown.

Etymology: The species epithet is a Latin adjective and means feathery. It refers to the feather-like setae on the hind tibia.

Distribution: Meghalaya and Nagaland (Intanki NP, Peren dist.).

Diagnosis: *Thraulius plumeus* **sp. nov.** can be distinguished from other known species of the genus by the following combination of characters:

- Labrum anteromedian emargination of broad with undulate medially (Figures 59 and 60).
- Dorsal surface of the hind tibia, there are dense feathered and hair-like setae (Figures 68 and 69).
- Claws with a row of 13–14 denticles, progressively larger towards the apex (Figure 68).

- Gills I slender, lanceolate, ventral lamellae wider than dorsal (Figure 71).

Habitat: Larvae of the new species were collected in a small stream (width 5–8 m) at an elevation of approximately 185 m in Nagaland, India (Figure 93). The bottom substrate is mainly stones and silt. Larvae were collected from under the stones and associated with *Baetis* sp., *Caenis* sp., and other Heptageniidae species.

Thraulius vellimalaiensis Vasanth, Subramanian and Selvakumar **sp. nov.**

(Figures 74–88)

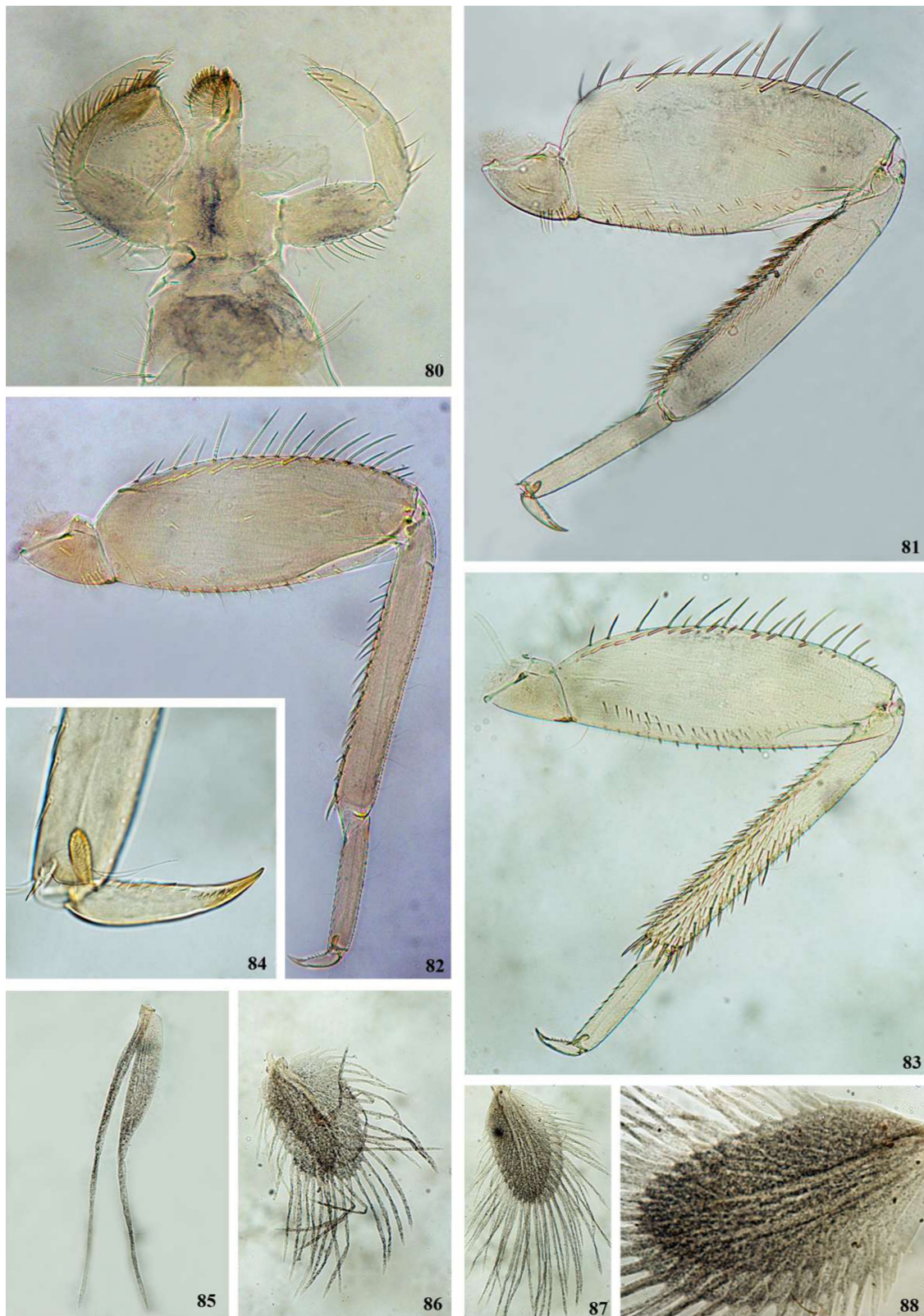
Material examined: Holotype: 1 larva, India, Tamil Nadu, Theni, Megamalai WLS, Vellimalai, Bommiyamman River, near Bommarajapuram, 09.61906°N, 077.40639°E, 768 m, 25.ii.2019, coll. M. Vasanth (Reg. No. I/E/522). Paratype: 1 larva, (Reg. No. I/E/523) same data as holotype. 2 larva, India, Tamil Nadu, Theni, Megamalai WLS, Vellimalai, Charlmedu stream, near the Moolavaigai River, 09.58504°N, 077.41904°E, 716 m, 24.ii.2019, coll. M. Vasanth (Reg. No. I/E/524). Types are deposited in SRC/ZSI/Chennai.

Description: Mature larva. Body length 9.5–10.5 mm, cerci 5.5–6.5 mm, median filament 7.5 mm (Figure 74).

Head: Head capsule and area between ocelli washed with dark brown; the area between median ocelli and frons pale; median line of vertex pale brown; margins of clypeus parallel. Labrum with posterior margin convex, irregular sparse setae on both dorsal and ventral surfaces, labrum anteromedian emargination broad with undulate medially 2.2x longer than the width (Figure 75). Lingua of hypopharynx with well developed lateral processes, anterior margin shallowly cleft; superlingua slightly developed lateral projection with its arms (Figure 76). Mandibles with sparse lateral setae, prosthema of the left mandible with a stout spine-like setae and outer and inner incisors with 3 denticles each. Right mandible outer incisor with 3 denticles and inner incisor with 2 denticles (Figures 77 and 78). Maxilla with dense stout spines and fine setae on anterior margin, an additional row of 17–18 pectinate setae; outer margin of maxilla with hair-like long setae; palp III segmented, length of segment I 0.5x times length of segment II, outer margin with few hair-like setae; length of segment III 0.3x times shorter than segment II, outer and inner margins with thin hair-like setae, III segment with an apically small



Figures 74–79. Larva of *Thraulius vellimalaiensis* sp. nov. 74. Dorsal view; 75. Labrum; 76. Hypopharynx; 77. Left mandible; 78. Right mandible; 79. Maxilla.



Figures 80–86. Larva of *Thraulius vellimalaiensis* sp. nov. 80. Labium; 81. Foreleg; 82. Midleg; 83. Hindleg; 84. Claw; 85. Gill I; 86. Gill III; 87. Gill V; 88. Gill VI.

tuft of hair-like setae (Figure 79). Labium: glossa with thick plate-like setae on the ventral surface, stout setae on dorsal surface; paraglossa with denser but hair-like stout setae on dorsal surface; segment I of labial palp with thick setae on margins, II segment with setae on outer margin, III segment with thick and fine hair-like setae on outer margin and dorsal surface; III segment apically small cluster of thin setae; segment I length ca. 1.0 times segment II length, segment III length 1.2 times length of segment II (Figure 80).

Thorax: Pronotum brown with black irregular markings on the dorsal surface. Mesonotum brown, median area pale. Foreleg of trochanter with anterior surfaces lite black, and lateral surface yellowish; femora broad, basal femora white, apically lite yellowish mixed with black, tibiae blackish yellow with very sparse and thin setae on inner margin, densely covered with a row of feathered setae and with a row of stout and transverse setae (Figure 81). All legs pale; hind tibiae mixed with denser, thick and feathered setae on the surface; tarsi of all legs with several thick

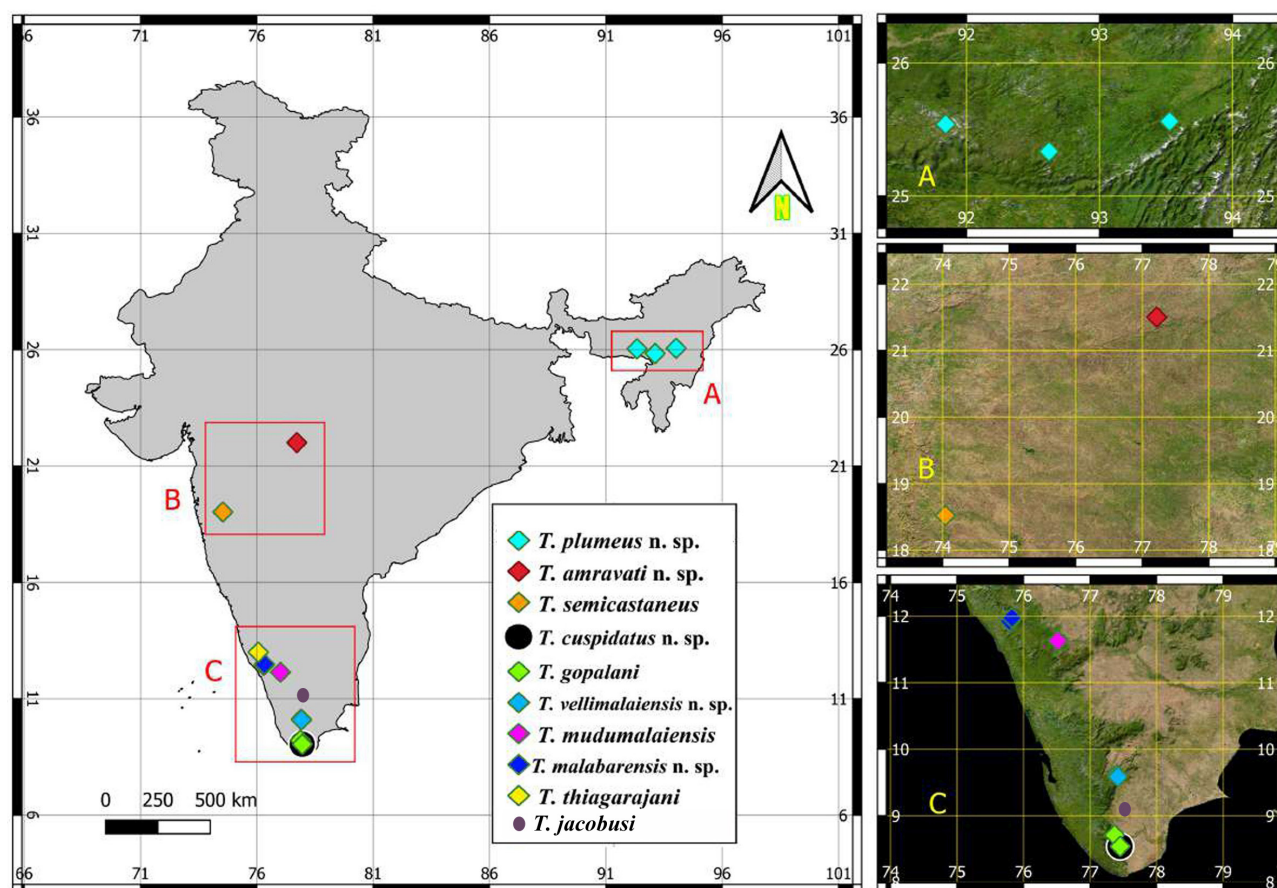
setae on inner margin and sparse setae on outer margins (Figures 81, 82 and 83). Claw with a row of 11-12 denticles, progressively shorter towards the apex (Figure 84).

Abdomen: Abdomen brown mixed with black, with indistinct paired pale submedian spots along the body axis. Terga III–IX with posterolateral projections, terga VIII–IX larger. Sterna is uniformly yellowish. Segments I–VII with gills; gills I slender, lanceolate, ventral lamellae wider than dorsal (Figure 85); gills II–VII similar in shape, with dorsal and ventral lamellae; each lamella elongated-ovate, with entire margins long fimbriate; tracheae of gills slightly clear (Figures 86, 87 and 88). Caudal filaments with a whorl of setae on alternate segments; setae shorter than the length of the corresponding segment.

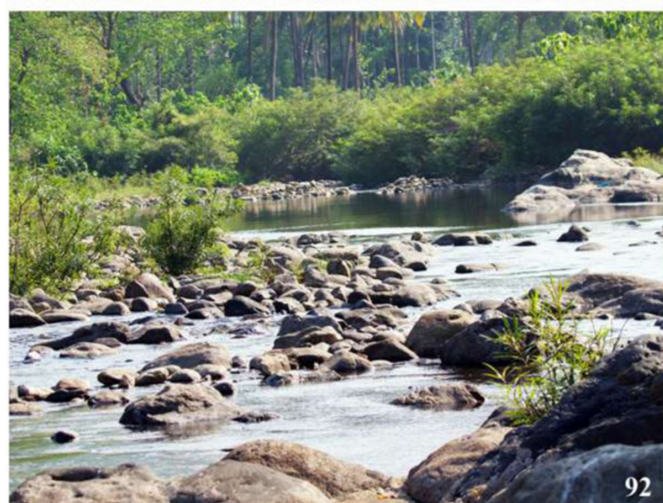
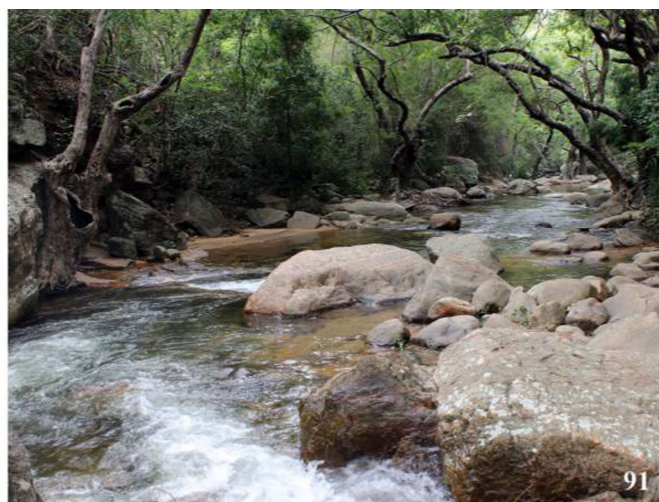
Adult: Unknown.

Etymology: The species named after the type locality of Vellimalai, Megamalai WLS, Theni District, Tamil Nadu, India.

Distribution: Tamil Nadu (Megamalai WLS, Theni).



Figures 89. Geographical distribution map of *Thraulius* species from India.



Figures 90–95. Habitat photos of new species of *Thraulius*: 90. *T. amravati* sp. nov., 91. *T. cuspidatus* sp. nov., 92. *T. malabarensis* sp. nov., 93. *T. plumeus* sp. nov., and 94, 95. *T. vellimalaiensis* sp. nov.

Diagnosis: *Thraulius vellimalaiensis* **sp. nov.** can be distinguished from other known species of the genus by the following combination of characters:

- Labrum anteromedian emargination is broad with undulate medially (Figure 75).
- Hypopharynx of superlingua slightly developed, lateral projection with its arms (Figure 76).
- Mandibles are smoothly curved with 2–3 hair-like setae on the anterior margin (Figures 77 and 78).
- Hind tibia with stout pointed setae (Figure 83).
- Claw with a row of 12 denticles, progressively shorter towards the apex (Figure 84).
- Gill I slender, lanceolate, ventral lamellae wider than dorsal (Figure 85).
- Gill II–VII oval, with marginal fringes, tracheae of gills clear slightly (Figures 86, 87 and 88).

Habitat: Larvae of the new species were collected in a small sized stream (wide 5–8 m) with stones and gravel, at an altitude of 768m (Figures 94 and 95). Larvae were associated with *Baetis* sp., Heptageniidae (*Afronurus* sp.), Leptophlebiidae (*Choroterpes* sp.), *Caenis* sp., Hydropsychidae (Trichoptera).

Larval key to the Oriental species of *Thraulius* Eaton, 1881

1. Abdominal segment I with unilamellate gill...
.....*T. femoratus* Li, Liu & Zhou, 2006
- Abdominal segment I with bilamellate gill.....2
2. Ventral lamella of gill I fimbriate.....3
- Ventral lamella of gill I slender or lanceolate.....5
3. Anteromedian emargination of labrum with small, blunt crenation medially.....
.....*T. malabarensis* **sp. nov.**
- Anteromedian emargination of labrum without blunt crenation medially.....4
4. Labrum with rectangular median emargination; gills on abdominal segments II–VII similar in size.....*T. gopalani* Grant & Sivaramakrishnan 1985
- Labrum without rectangular median emargination; gills on abdominal segments II–VII not similar in size.....*T. thiagarajani* Balasubramanian & Muthukatturja 2019
5. Dorsal and ventral lamella of gill I similar in size.....6

- Dorsal and ventral lamella of gill I not similar in size8
- 6. Dorsum of middle and hind femora with black, broad markings on distal half; anteromedian emargination of labrum with undulate medially; claw with a row of denticles progressively larger apical ly.....*T. fatuus* Kang & Yang 1994
- Dorsum of middle and hind femora pale; anteromedian emargination of labrum without undulate medially; median denticles of claw larger than apical.....7
- 7. Labrum with dense setae near the anteromedian margin; galea-lacinia of maxilla with 19–20 comb-shaped setae near the anterior margin.....*T. macilentus* Kang & Yang 1994
- Labrum with sparse setae near the anteromedian margin; galea-lacinia of maxilla with 24–26 comb-shaped setae near the anterior margin.....*T. umbrosus* Kang & Yang 1994
- 8. Anteromedian emargination of labrum with median undulation.....9
- Anteromedian emargination of labrum without median undulation.....11
- 9. Claw with a row of 13–14 denticles, progressively larger towards apex.....
.....*T. plumbeus* **sp. nov.**
- Claw with a row of 11–12 denticles, progressively shorter towards apex.....10
- 10. Lateral margin of mandibles smoothly curved with 10–12 simple setae.....
.....*T. jacobusi* Isack *et al.*, 2022
- Lateral margin of mandibles not smoothly curved with 1–2 simple setae.....
.....*T. vellimalaiensis* **sp. nov.**
- 11. Anteromedian emargination of labrum cuspidate medially; claw with a row of 10–11 denticles.....
.....*T. cuspidatus* **sp. nov.**
- Anteromedian emargination of labrum not cuspidate medially.....12
- 12. Claw with minute denticles in apical set.....13
- Claw without minute denticles in apical set.....14
- 13. Claw with 5 minute denticles in apical set and 10 larger denticles in basal row; segment III

- of labial palp little longer of segment I....
*T. mudumalaiensis* Soman 1991
- Claw with 3 minute denticles in apical set and 8 larger denticles in basal row; segment III of labial palp equal to length of segment II.....*T. bishopi* Peters & Tsui 1973
 - 14. Claw with a row of 5 blunt denticles; segment 3 of labial palp little more than $\frac{3}{4}$ length of segment II; segment III of maxillary palp equal to length of segment 2.....*T. demoulini* Peters & Tsui 1973
 - Claw with a row of 8 blunt denticles; segment 3 of labial palp equal to length of segment II; segment III of maxillary palp more than $\frac{1}{4}$ length of segment 2.....*T. amravati* **sp. nov.**

Discussion

Lack of species level morphological and molecular phylogenetic studies in India on the genus *Thraulius* sensu lato hamper prediction of the probable time of arrival and diversification of this genus in the Indian subregion of the Oriental Realm. However, Peters and Edmunds (1970), Peters and Tsui (1972), and Li, *et al.*, (2006) pointed out that gill shape is correlated with water flow and dissolved oxygen concentration, resulting in an array of structural diversity. Accordingly, two morphological species groups of *Thraulius* sensu lato have evolved in

the Indian context. The first group comprises *Thraulius mudumalaiensis*, *T. jacobusi* and four new species viz., *T. amravati* **sp. nov.**, *T. cuspidatus* **sp. nov.**, *T. plumeus* **sp. nov.**, and *T. vellimalaiensis* **sp. nov.**, having filamentous gill I and fimbriate gills II–VII. The second group constitute of *T. gopalani*, *T. thiagarajani* and *T. malabarensis* **sp. nov.** has dorsal lamella of the first abdominal tracheal gill lanceolate and ventral lamella fimbriate thus gill I is dissimilar to others. Apparently, they imply two evolutionary lineages, which future molecular phylogenetic studies alone can confirm.

Acknowledgements

The authors are grateful to the Director, Zoological Survey of India, Kolkata, for providing facilities to carry out the research work. The authors are grateful to the funding support from All India Coordinated Project on Taxonomy (AICOPTAX) and Long-Term Ecological Observatories (LTEO) Project, Ministry of Environment, Forest and Climate Change, Government of India for carrying out this research. C. Selvakumar thank the Head, Department of Zoology, the Principal and the Management, The Madura College (Autonomous), Madurai for their support and encouragement. We also thank Tamil Nadu, Kerala, Maharashtra, Meghalaya and Nagaland Forest Departments for providing necessary permissions and their help in field surveys.

References

- Balasubramanian, C. and Muthukatturaja, M. 2019. A new mayfly *Thraulius* species (Ephemeroptera: Leptophlebiidae) from Peninsular India. *Zootaxa*, **4638**(1):136-142.
- Eaton A.E. 1881. An announcement of new genera of the Ephemeridae. *Entomologist's Monthly Magazine*, **17**:191-197.
- Gillies, M.T. 1951. Further notes on Ephemeroptera from India and South East Asia. *Proceedings of the Royal Entomological Society of London*, (B), **20**:121-130.
- Grant, P.M. and Peters, W.L. 1993. Description of four new genera of *Thraulius* group mayflies from the Eastern Hemisphere and redescription of *Simothraulius* and *Chiusanophlebia* (Ephemeroptera: Leptophlebiidae: Atalophlebiidae). *Transactions of the American Entomological Society*, **119**(2):131-168.
- Grant, P.M. and Sivaramakrishnan, K.G. 1985. A new species of *Thraulius* (Ephemeroptera: Leptophlebiidae) from southern India. *Florida Entomologist*, **68**(3):424-432 (Grant and Sivaramakrishnan, 1985).
- Isack, R., Srinivasan, P., Sivaruban, T. and Barathy, S. (2022). A new species of *Thraulius* Eaton, 1881 (Ephemeroptera: Leptophlebiidae) from the Western Ghats, South India. *Aquatic Insects*, 1-8. DOI: 10.1080/01650424.2022.2096241.
- Li, P., Liu, D. and Zhou, C.-F. 2006. A new species of *Thraulius* from Nanjing (Eastern China) with single first gill (Insecta: Ephemeroptera: Leptophlebiidae). *Zoological Science*, **23**:641-645.

- Peters, W.L. and Edmunds, G.F. Jr. 1970. Revision of the generic classification of the Eastern Hemisphere Leptophlebiidae (Ephemeroptera). *Pacific Insects*, **12**(1):157-240.
- Peters, W.L. and Tsui, P.T.P. 1972. New species of *Thraulius* from Asia (Leptophlebiidae: Ephemeroptera). *Oriental Insects*, **6**:1-17.
- Sivaramakrishnan, K.G. and Venkataraman, K. 1987. Biosystematic studies of South Indian Leptophlebiidae and Heptageniidae in relation to egg ultrastructure and phylogenetic interpretations. *Proceedings of the Indian Academy of Sciences, Animal Sciences*, **96**(5):637-646.
- Soman, A.K.A. 1991. A new species of *Thraulius* (Ephemeroptera:Leptophlebiidae: Atolophlebiinae) from Nilgiris, South India. *Journal of the Bombay Natural History Society*, **88**(1):99-102.