Zoosyst. Evol. 100 (4) 2024, 1211–1230 | DOI 10.3897/zse.100.129089

PENSOFT

für Natur MUSEUM FÜR NATURKUNDE BERLIN

A new species of *Thermocyclops* Kiefer, 1927 (Crustacea, Copepoda, Cyclopoida, Cyclopidae) from temporary habitats, with a discussion on the diversity and distribution of the genus in Thailand

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https://zoobank.org/C526568E-EBE2-46E5-A58A-D54C2ACCC04F

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Academic editor: Kay Van Damme ♦ **Received** 5 June 2024 ♦ **Accepted** 16 August 2024 ♦ **Published** 2 September 2024

Abstract

Thermocyclops Kiefer, 1927, is a genus of Cyclopidae, one of the most diverse families among cyclopoids. To date, 13 species of this genus have been recorded in Thailand. Through intensive sampling of rice fields in central Thailand and temporary waters in northeastern Thailand, one new species, *Thermocyclops oryzae* **sp. nov.**, was discovered. This new species is clearly distinguished from other *Thermocyclops* by the presence of a serrated lobe on the posterior surface of the medial expansion of the basipodite of the fourth swimming leg. Moreover, it can be distinguished from its congeners by (i) ornamentation on the genital double-somite, succeeding two urosomites and caudal ramus; (ii) the length and width ratio of the caudal ramus; (iii) the length ratio of the innermost terminal seta (VI) and the outermost terminal seta (III); (iv) the number of setae on the second endopodal segment of the antenna; (v) projection and ornamentation on the intercoxal sclerites of the first to fourth swimming legs; (vi) the surface ornamentation of the medial margin of the basipodite of the first to fourth swimming legs; and (vii) the relative length of two apical spines of the third endopodal segment of the fourth swimming leg. The present discovery increases the number of species in this genus in Thailand to 14. A pictorial key to all species is proposed, and their ecologies and distributions within Thailand are updated and discussed.

Key Words

Diversity, habitat preference, niche heterogeneity, temporary habitat, Thailand, *Thermocyclops oryzae* sp. nov.

Introduction

A total of 170 copepod species have been found in freshwater habitats in Thailand (Saetang et al. 2020; Sanoamuang and Dabseepai 2021; Saetang and Maiphae 2023). Cyclopidae is one of the most diverse families of cyclopoids. Approximately 66 valid species of *Thermocyclops* Kiefer, 1927, have been recorded worldwide (Walter and Boxshall 2024), 13 of which have been found in Thailand (Sanoamuang 1999; Wongrat and Pipatcharoenchai 2003; Alekseev and Sanoamuang 2006; Proongkiat 2006; Wansuang and Sanoamuang 2006; Chittapun et al. 2009; Koompoot 2010; Watiroyram 2012; Boonyanusith 2013; Karanovic et al. 2017; Maiphae et al. 2023; Soe and Sanoamuang 2023). Most of these species are widely distributed, while a few have a restricted distribution. The latter group includes two recently described species in Thailand that are restricted to caves: *T. parahastatus* Karanovic, Koomput & Sanoamuang, 2017 and *T. thailandensis* Karanovic, Koomput & Sanoamuang, 2017.

However, more species can be expected, particularly in special habitats that are less explored than lakes, such as caves and temporary water bodies. This is a general fact in tropical zooplankton, where considerable diversity remains to be explored (Brendonck et al. 2022). Rice fields are an example of temporary habitats that provide a unique form of complex temporary habitats (Edirisinghe and Bambaradeniya 2006). They encompass the different characteristics of each phase through which organisms pass during a cultivation cycle. Water levels and dry periods in rice fields are important features of transient aquatic ecosystems that affect not only the diversity and community structures of species but also the life histories of microscopic animals (Edirisinghe and Bambaradeniya 2006; Watanabe 2019). Moreover, rice fields are dynamic and undergo rapid physical, chemical, and biological changes. The heterogeneous composition of rice fields provides various niches for microscopic animals and contributes to their richness and biodiversity (Bambaradeniya et al. 2004). As reported in previous studies, copepods are often among the first groups of zooplankton to arrive and dominate in sampled ponds (Frisch and Green 2007). The rapid dispersal and dominance of certain cyclopoid copepods during early colonization are due to their rapid individual development and ability to store sperm. Given that cyclopoid copepods can survive periods of drought in the sediment of temporary ponds, initial and early colonization by cyclopoids is likely to have a significant effect on propagule banks and future plankton communities when such ponds refill (Frisch and Green 2007).

The present study investigates the diversity of this genus in temporary habitats, including rice fields, temporary canals, and temporary ponds. In a prior survey of five rice fields in central Thailand, 22 samples were collected, and a total of 9 species of this genus were found (Maiphae et al. 2023). Among them, an undescribed species of *Thermocyclops* was found that exhibited clear morphological differences from known species. Moreover, this unknown *Thermocyclops* was also discovered in zooplankton samples collected from seven temporary habitats in northeast Thailand. Therefore, the present study proposes one new species of *Thermocyclops* and provides detailed descriptions and illustrations of both females and males. In addition, a pictorial key to identify *Thermocyclops* species found in Thailand was proposed, the present diversity of the genus was updated, and its distribution in Thailand was discussed.

Materials and methods

Twenty-two samples were qualitatively collected between November 2022 and January 2024 from five rice fields in Suphan Buri Province, Central Thailand, using a plankton net with a 60 µm mesh. They were immediately preserved in 70% ethanol. Environmental variables, including pH, water temperature, conductivity, salinity, total dissolved solids, dissolved oxygen, and chlorophyll, were measured using a calibrated YSI EXO Multiparameter Sonde and YSI EXO Handheld Display 599150. In addition, specimens of the new species collected from six temporary roadside canals and one temporary pond in northeastern Thailand between May and July 2022 were examined.

All adult males and females were sorted using an Olympus SZ40 stereo microscope. Each specimen was dissected and mounted on a slide in glycerin, which was then sealed using nail varnish.

The specimens' morphological characteristics were examined and identified using an Olympus CH2 compound microscope. Drawings of complete and dissected specimens were made by using a camera lucida connected to the microscope. The final versions of the drawings were made using Adobe Illustrator 2024 software (version 28.2). Specimens for digital photographs were taken using an Olympus BX51 compound microscope with an Olympus DP21 digital camera system. Specimens for scanning electron microscopy (SEM) were dehydrated in graded ethanol concentrations and then transferred to pure isoamyl acetate. The specimens were subjected to the critical point drying process, mounted on stubs, coated with gold, and examined with a scanning electron microscope (LEO 1450 VP).

The specimens were identified to the species level in accordance with Ishida (2002), Mirabdullayev et al. (2003), and Hołyńska (2006). The descriptive terminology proposed by Huys and Boxshall (1991) was adopted. The abbreviations used in the text and figures are as follows: **A1** = antennule, **ae** = aesthetasc, **s** = spine, **A2** = antenna, **P1–P6** = first to sixth swimming legs, **ENP1 (2, 3) =** first (second and third) segment of endopod, **EXP1 (2, 3)** = first (second and third) segment of exopod, **G.S.** = genital double-somite.

All materials were deposited in the reference collection of the Princess Maha Chakri Sirindhorn National History Museum, Prince of Songkla University, Songkhla, Thailand.

Results

Systematics

Order CYCLOPOIDA Burmeister, 1834
Family CYCLOPIDAE Rafinesque, 1815

Genus *Thermocyclops* Kiefer, 1927

Type species. *Thermocyclops oithonoides* (Sars G.O., 1863).

***Thermocyclops oryzae* sp. nov.**
https://zoobank.org/384503A9-CDF6-4B54-8E62-1A5098C81F5B

Type locality. Central Thailand, Suphan Buri Province, Bang Pla Ma District, Phai Kong Din Subdistrict; 14°19'41.4"N, 100°15'05.5"E; rice field.

Other localities.

(1) Northeastern Thailand, Bueng Kan Province, So Phisai District, Kham Kaeo Subdistrict, Ban Kham Kaeo; 18°05'32.0"N, 103°31'52.3"E; temporary roadside canal; 3 June 2022; leg. S. Watiroyram.
(2) Northeastern Thailand, Sakon Nakhon Province, at the boundary between Ban Muang-In Plaeng District; 17°48'49.0"N, 103°35'19.8"E; temporary roadside canal; 16 May 2022; leg. S. Watiroyram.
(3) Northeastern Thailand, Sakon Nakon Province, Akat Amnuai District, Samakkhi Phatthana Subdistrict, Ban Nong Sam Kha; 17°19'41.5"N, 103°52'38.2"E; temporary roadside canal; 16 June 2022; leg. S. Watiroyram.
(4) Northeastern Thailand, Udon Thani Province, Nam Som District, Ban Yuak Subdistrict, Ban Champa Thong; 17°43'37.8"N, 102°11'20.4"E; temporary roadside canal; 19 June 2022; leg. S. Watiroyram.
(5) Northeastern Thailand, Udon Thani Province, Kumphawapi District, Nong Wa Subdistrict, Ban Nong Wa; 17°01'33.9"N, 102°58'55.8"E; temporary roadside canal; 18 June 2022; leg. S. Watiroyram.
(6) Northeastern Thailand, Ubon Ratchathani Province, Samrong District, Bon Subdistrict, Ban Kho Bon; 15°04'47.2"N, 104°48'00.9"E; temporary roadside canal; 3 May 2022; leg. S. Watiroyram.
(7) northeast Thailand, Ubon Ratchathani Province, Pho Sai District, Lao Ngam Subdistrict, Ban Pong Pao; 15°45'54.7"N, 105°23'33.0"E; temporary pond; 5 May 2022; leg. S. Watiroyram.

Material examined. ***Holotype*****.** • One adult female, dissected and mounted onto two slides, central Thailand, Suphan Buri Province, Bang Pla Ma District, Phai Kong Din Subdistrict, 27 March 2023, leg. T. Saetang and S. Maiphae; PSUZC-PK2010-01 and PSUZC-PK2010-02.

Allotype**.** • One adult male, dissected and mounted onto two slides, collected from the same locality as the holotype: PSUZC-PK2010-03 and PSUZC-PK2010-04.

Paratype**.** • One adult female, dissected and mounted onto two slides, collected from the same locality as the holotype: PSUZC-PK2010-05 and PSUZC-PK2010-6.

Other specimens examined. Ten adult females, collected from those other seven localities and deposited in the collection of the second author (KK); two adult males, collected from the type locality and deposited in the collection of the fourth author (SM).

Differential diagnosis. *Thermocyclops oryzae* sp. nov. differs from congeneric species in the following characters: female, (i) caudal ramus elongate, about 3.5–4.1 times as long as wide, (ii) innermost terminal seta (VI) 1.1–1.3 times as long as outermost terminal seta (III), (iii) second endopodal segment of antenna with 8 setae, (iv) round projections on the distal margin of intercoxal sclerite of P1–P4 with spinules, (v) intercoxal sclerite of P1–P3 ornamented with one intermittent row of spinules on posterior surface, (vi) intercoxal sclerite of P4 ornamented with spinules arranged in two arcs on the anterior surface, and two transverse rows of spinules on the posterior surface, (vii) medial margin of basis of P4 with serrate lobe, (viii) inner apical spine of third endopodal segment of P4 length about 0.9 times as long as outer spine, (ix) exopodal and endopodal segments of P1–P4 with tiny spinules on posterior surface.

Description of the adult female. ***Body*** (Fig. 1A). Total body length measured from anterior margin of rostrum to posterior margin of caudal rami, ranging from 768–990 μm (mean 894 μm, n = 3; 990 μm in holotype).

Prosome (Figs 1A, B, 2A, B, 3C) composed of cephalothorax and three free prosomites (second to fourth pedigerous somites). Surface of prosome pitted. Cephalothorax and second pedigerous somites smooth along posterior margin (Figs 2A, B, 3C); third and fourth pedigerous somites coarsely serrated along posterior margin (Figs 1B, 2B arrow).

Urosome (Figs 1C–E, 2C, D, 3D, E, G, 10A) composed of fifth pedigerous somite, genital double-somite, two free urosomites, and anal somite with caudal rami. Fifth pedigerous somite ornamented with two dorsal sensilla and with dense pattern of tiny spinules on dorsal and lateral surface. Genital double-somite about as long as wide, with two dorsal sensilla; dorsal and ventral surfaces with irregular but mostly transverse short striae; coarsely serrated hyaline frill along posterior margin. Lateral arms of seminal receptacle slightly curved posteriorly. Two free urosomites with irregular but mostly transverse short striae dorsally and ventrally and with coarsely serrated hyaline frill along posterior margin. Anal somite with two dorsal sensilla at base of anal operculum; with spinules present along posterior margin on ventral surface; dorsal surface ornamented with tiny spinules; ventral surface unornamented. Caudal rami (Figs 1C–E, 2D, 3F). cylindrical, parallel, about 3.5–4.1 times as long as wide (mean 3.8, n = 13; 4.1 in holotype); inner margin without hairs; dorsal and ventral surfaces with dense pattern of tiny spinules. Each ramus with six setae: innermost terminal seta (VI) 1.1–1.3 times as long as outermost terminal seta (III).

Labrum (Figs 4A, 6C) trapezoidal, with nine teeth between two blunt lateral corners, posterior surface ornamented with two rows of long hairs.

A1 (Figs 3A, 4B, C) 17-segmented. Armature formula (number of segment-[number of setae + aesthetasc (ae) + spine (s)]) of each segment as follows: 1-[8], 2-[4], 3-[2], 4-[6], 5-[4], 6-[1+s], 7-[2], 8-[1], 9-[1], 10-[0], 11-[1], 12-[1+ae], 13-[0], 14-[1], 15-[2], 16-[2+ae], 17-[7+ae]. Last two antennular segments bearing hyaline membrane on ventral surface (Fig. 3A).

A2 (Figs 3B, 4D, E, 6A, B) composed of coxa, basis, and three-segmented endopod. Coxa rectangular, unarmed and unornamented. Basis cylindrical, with one outer bipinnate seta and two inner smooth setae along distal corner; anterior surface (Fig. 4D) ornamented with one oblique row of inner spinules along proximal part, one longitudinal row of inner spinules along middle part; posterior surface (Fig. 4E) ornamented with one oblique row of outer and inner spinules along proximal part, one longitudinal row of outer spinules in middle part, field of tiny spinules near base of inner setae, and one longitudinal

row of tiny spinules along inner margin. ENP1 with one inner smooth seta. ENP2 with 7–8 inner smooth setae. ENP3 with seven apical setae. Posterior surface of each endopodal segment ornamented with one longitudinal row of outer spinules.

Mandible (Fig. 5A, B, F) composed of coxa and palp. Coxal gnathobase with eleven chitinized teeth and two pinnate setae; anterior surface ornamented with one row of three spinules. Palp reduced, with one short smooth seta and two plumose setae.

Maxillule (Figs 5C, 6D, F) composed of praecoxa and two-segmented palp, representing one-segmented coxobasis and one-segmented endopod. Praecoxal arthrite with three smooth and one pinnate apical spine. Praecoxa with seven inner elements; one short naked proximalmost seta, one sub-proximal plumose seta, three middle smooth setae,

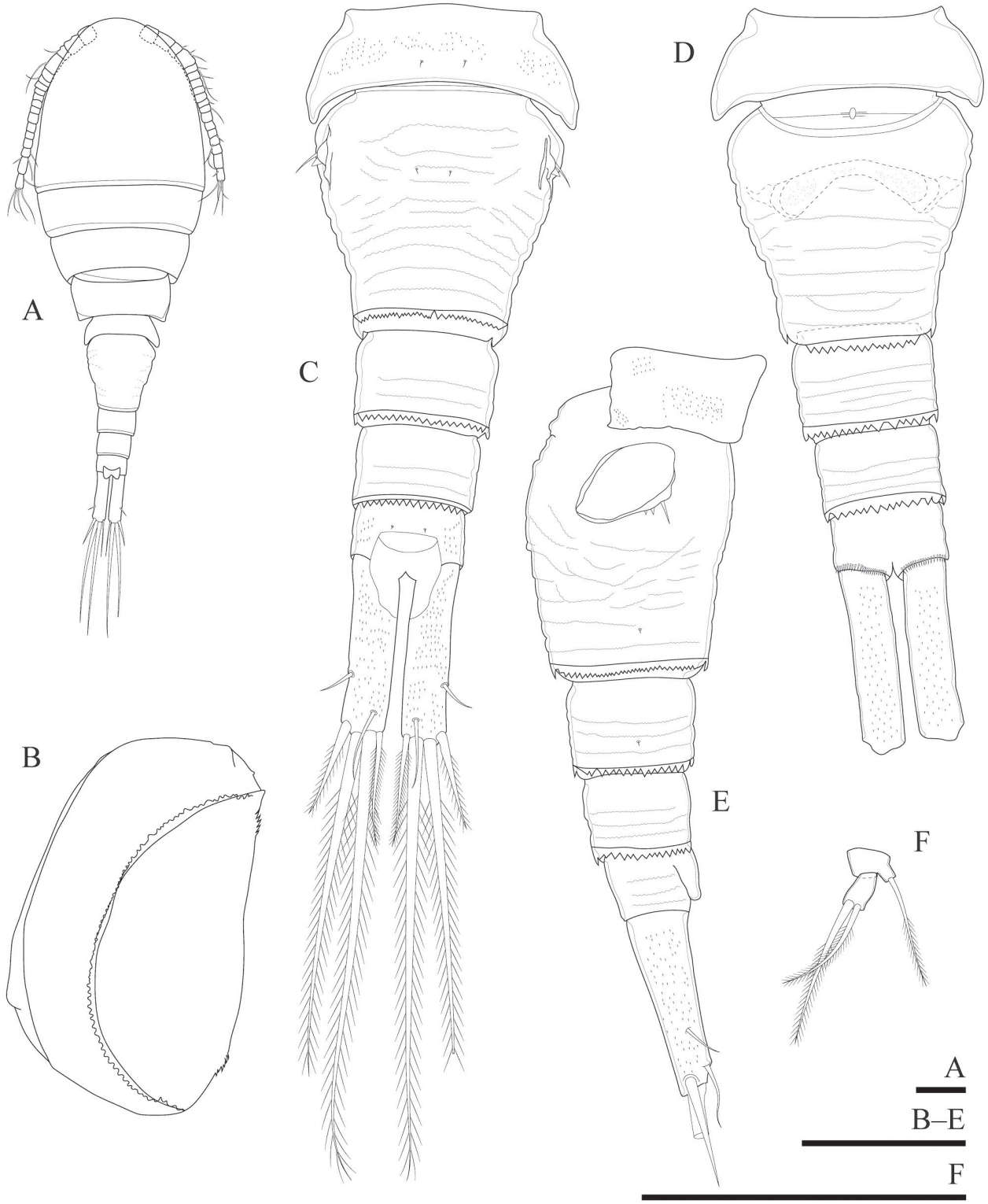

Figure 1. *Thermocyclops oryzae* sp. nov., female holotype. **A.** Habitus, dorsal view; **B.** Fourth pedigerous somite; **C.** Urosome, dorsal view; **D.** Urosome, ventral view; **E.** Urosome, lateral view; **F.** P5. Scale bars: 100 μm.

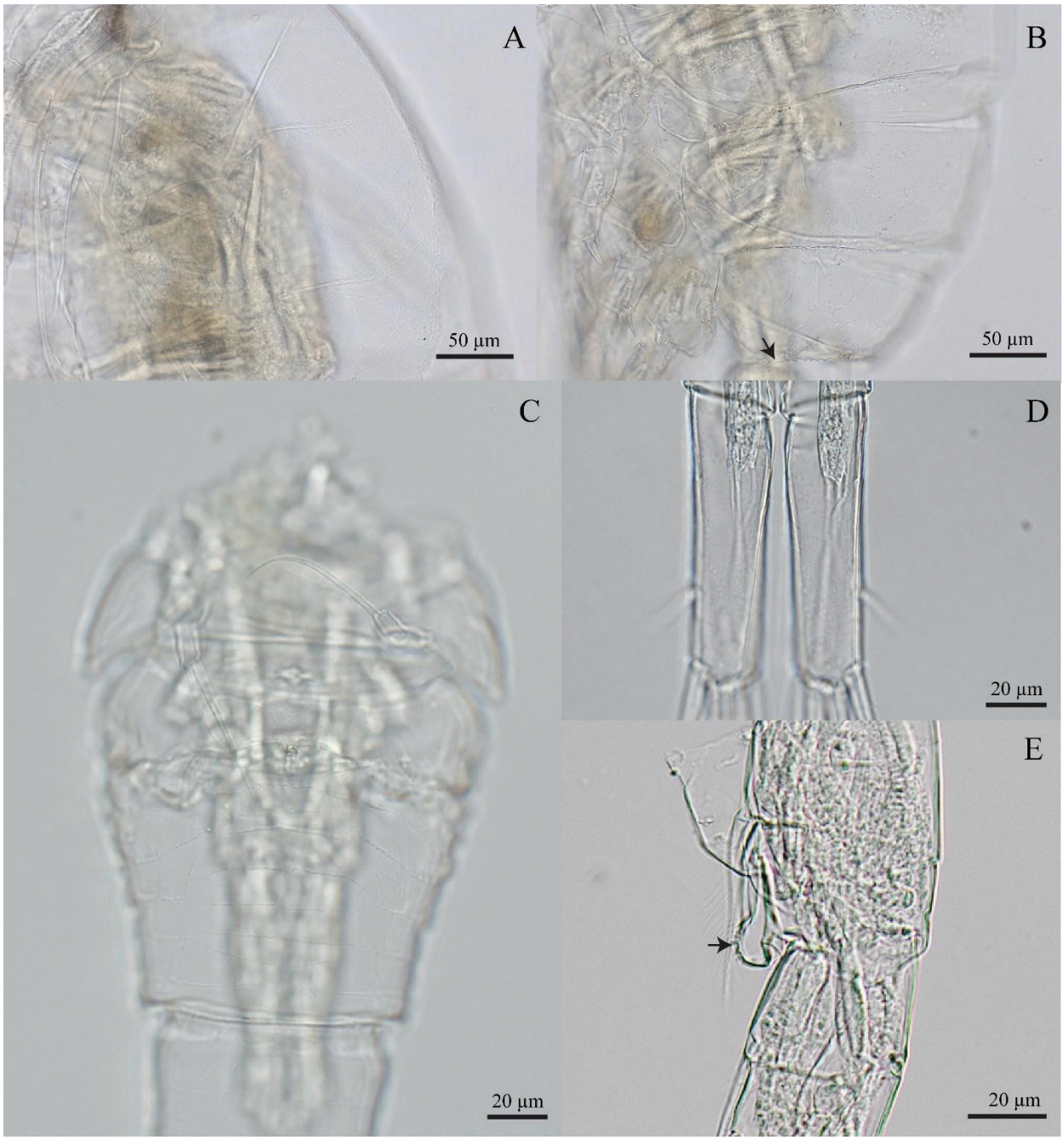

Figure 2. Digital photographs. *Thermocyclops oryzae* sp. nov., female, collected from a type locality. **A.** Cephalothorax, lateral view; **B.** Second to fourth pedigerous somites, lateral view (arrow indicates coarsely serrated posterior margin); **C.** Genital double-somite and P5, ventral view; **D.** Caudal rami, ventral view; **E.** P4 basis, lateral view (arrow indicates serrate lobe).

two distal smooth setae; group of tiny spinules present at base of short naked proximalmost seta. Coxobasis with one spiniform and two smooth setae apically; anterior surface ornamented with tiny spinules. Exopod reduced into one smooth seta near proximal part of coxobasis. Endopod with three apical smooth setae.

Maxilla (Figs 5D, 6E) composed of praecoxa, coxa, basis, and two-segmented endopod. Praecoxal endite with two apical pinnate setae. Coxa with two endites; proximal endite with one apical plumose seta; distal endite with two apical pinnate setae. Basis with claw-like endite and one pinnate seta. ENP1 with two pinnate setae. ENP2 with one pinnate and two smooth setae.

Maxilliped (Fig. 5E) composed of syncoxa, basis, and two-segmented endopod. Syncoxa cylindrical, with three inner pinnate setae; anterior surface ornamented with one group of spinules in middle part of segment. Basis with two inner pinnate setae; long spinules present on medial margin and anterior surface; posterior surface ornamented with two rows of outer spinules. ENP1 with one inner pinnate seta; anterior surface ornamented with one row of inner spinules. ENP2 with one inner pinnate and two inner smooth setae.

P1–**P4** (Figs 2E, 7A–D, 8A–D, 9A–G) composed of intercoxal sclerite, coxa, basis, three-segmented exopod, and three-segmented endopod. Armature formula of P1–P4 as in Table 1.

Table 1. Armature formula of P1–P4 in *Thermocyclops oryzae* sp. nov. (Arabic numerals representing setae and Roman numerals representing spine from outer-inner or outer-apical-inner margins).

Swimming legs	Coxa	Basis	EXP			ENP		
			1	2	3	1	2	3
P1	0–1	1–I	I–1	I–1	II, 2, 2	0–1	0–2	1, I1, 3
P2	0–1	1–0	I–1	I–1	II, I1, 3	0–1	0–2	1, I1, 3
P3	0–1	1–0	I–1	I–1	II, I1, 3	0–1	0–2	1, I1, 3
P4	0–1	1–0	I–1	I–1	II, I1, 3	0–1	0–2	1, II, 2

P1 (Figs 7A, B, 9A, 10B, D). Intercoxal sclerite subquadrate; distal margin with round projection bearing 6-7 spinules; anterior surface unornamented; posterior surface ornamented with one intermittent row of spinules. Coxa with one inner plumose seta; anterior surface ornamented with one longitudinal row of hair-like spinules laterally and three rows of tiny spinules along distal margin; posterior surface ornamented with one oblique row of hair-like spinules near the lateral margin.

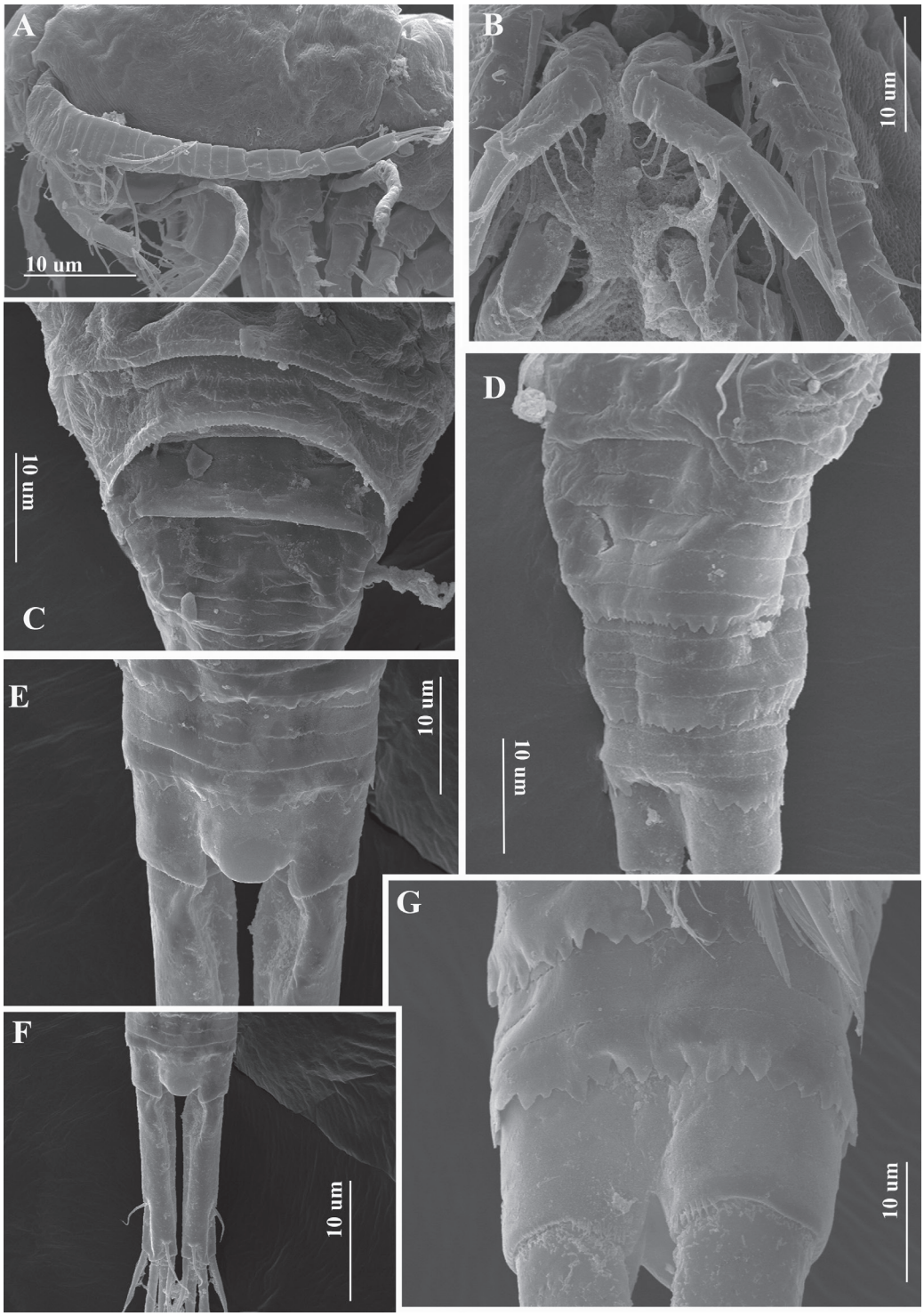

Figure 3. Scanning electron micrographs. *Thermocyclops oryzae* sp. nov., female, was collected from Kumphawapi District, Udon Thani Province, northeastern Thailand. **A.** Antennule and cephalothorax; **B.** Endopodal segments of antenna; **C.** Free prosomites, dorsal view; **D.** Urosomites lateroventral view; **E.** Anal somite, dorsal view; **F.** Caudal rami, dorsal view; **G.** Anal somite, ventral view.

Basis with one outer plumose seta and one inner pinnate spine, distal tip of inner spine reaching middle of ENP2; anterior surface ornamented with two rows of tiny spinules between bases of exopod and endopod, one row of spinules at base of endopod, one row of spinules at base of inner spine, one row of inner tiny spinules along proximal margin of segment, and long setules on median margin of basis. EXP1 with one pinnate outer spine and one inner plumose seta; anterior surface ornamented with one longitudinal row of outer spinules and one longitudinal row of inner setules; one row of tiny spinules at base of outer spine; and one row of spinules along distal margin of segment; posterior surface ornamented with dense pattern of tiny spinules. EXP2 with one pinnate outer spine and one inner plumose seta; anterior surface ornamented as in EXP1. EXP3 with two pinnate outer spines,

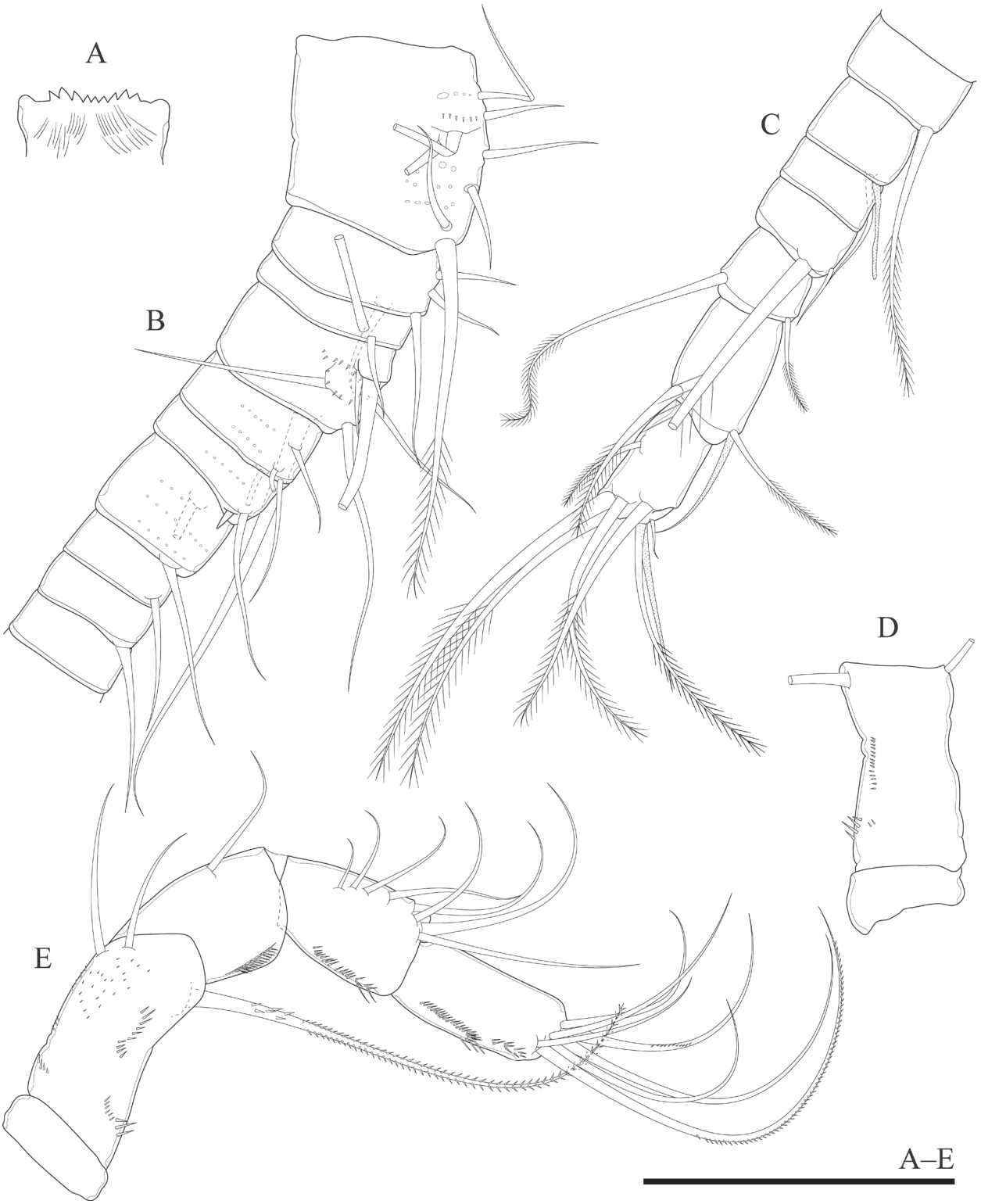

Figure 4. *Thermocyclops oryzae* sp. nov., female holotype. **A.** Labrum; **B.** Antennule, segments 1–10; **C.** Antennule, segments 11–17; **D.** Coxa and basis of antenna, anterior surface; **E.** Antenna, posterior surface. Scale bar: 100 µm.

two apical plumose setae, and two inner plumose setae; anterior surface ornamented as in EXP1 except one row of spinules along distal margin of segment. ENP1 with one inner plumose seta; anterior surface ornamented with one longitudinal row of outer setules and one row of spinules along distal margin of segment; posterior surface ornamented with dense pattern of tiny spinules. ENP2 two inner plumose setae; anterior surface ornamented as in ENP1. ENP3 with one outer plumose seta, two apical elements (outer element: one pinnate spine; inner element: one plumose seta), and three inner plumose setae; anterior surface ornamented as in ENP1.

P2 (Figs 7C, D, 9B, 10C). Intercoxal sclerite subquadrate; distal margin with round projection bearing 4–5 spinules; anterior surface unornamented; posterior surface ornamented with one intermittent row of spinules. Coxa with one inner plumose seta; intermittent longitudinal row of hair-like spinules on lateral margin; two rows of tiny spinules in proximal part; and two rows of tiny spinules along distal margin. Basis with one outer plumose seta; anterior surface ornamented with one row of tiny spinules near outer seta; one row of tiny spinules at base of exopod; one row of tiny spinules between bases of exopod and endopod; and one intermittent row of spinules near base of endopod; posterior surface ornamented with one row of spinules in distal part of medial expansion. EXP1 and EXP2, each with one pinnate outer spine and one inner plumose seta; anterior surface ornamented with one longitudinal row of outer spinules and one longitudinal row of inner setules; one row of tiny spinules at base of outer spine; and one row of spinules along distal margin of segment; posterior surface ornamented with one row of spinules along distal margin of segment, and dense pattern of tiny spinules. EXP3 with two pinnate outer spines, two apical elements (outer element: one pinnate spine; inner element:

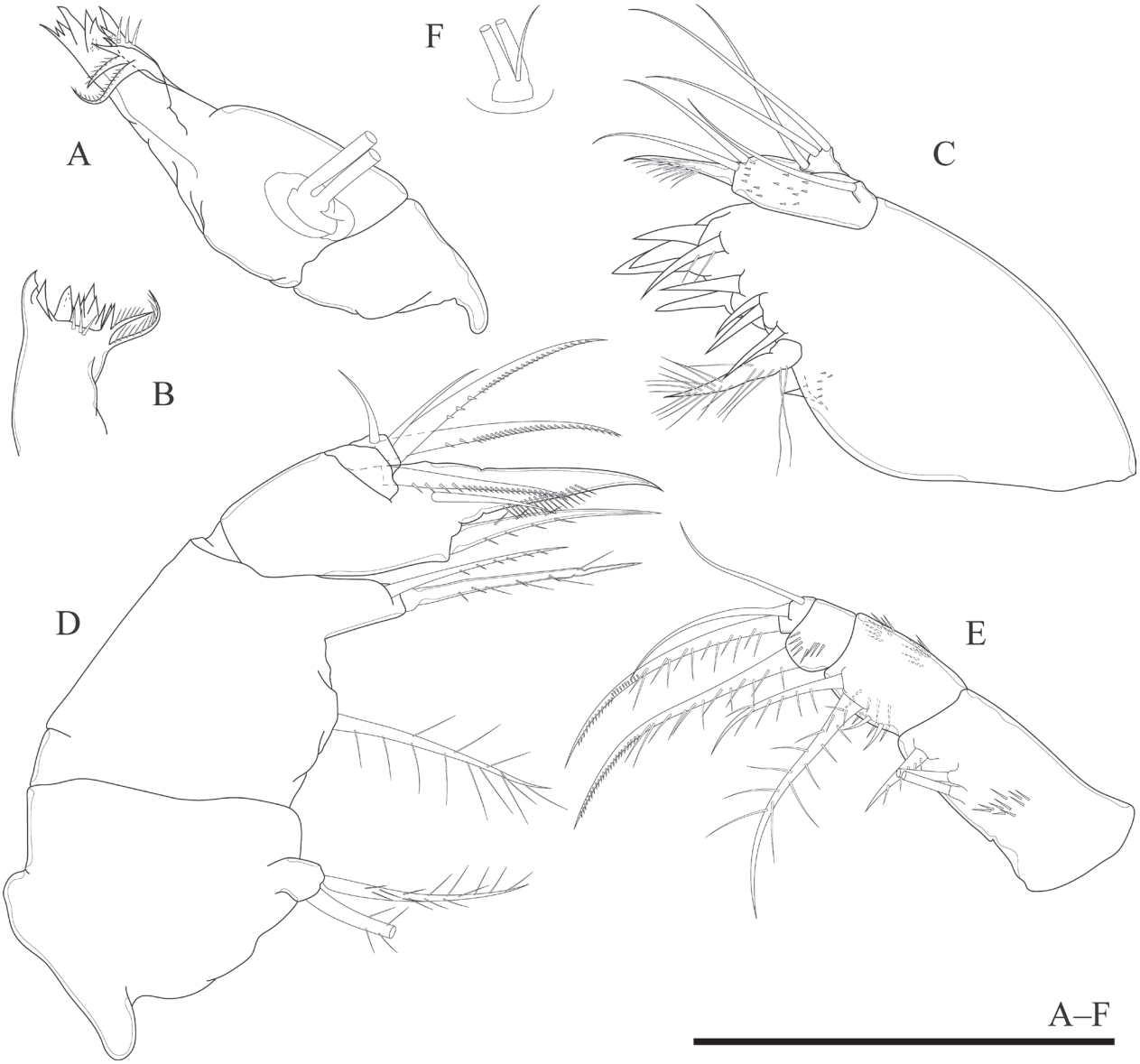

Figure 5. *Thermocyclops oryzae* sp. nov., female holotype. **A.** Mandible; **B.** Cutting edge of mandibular gnathobase; **C.** Maxillule; **D.** Maxilla; **E.** Maxilliped; **F.** Mandibular palp (**F.** Shows the female paratype; other drawings show the holotype). Scale bar: 100 μm.

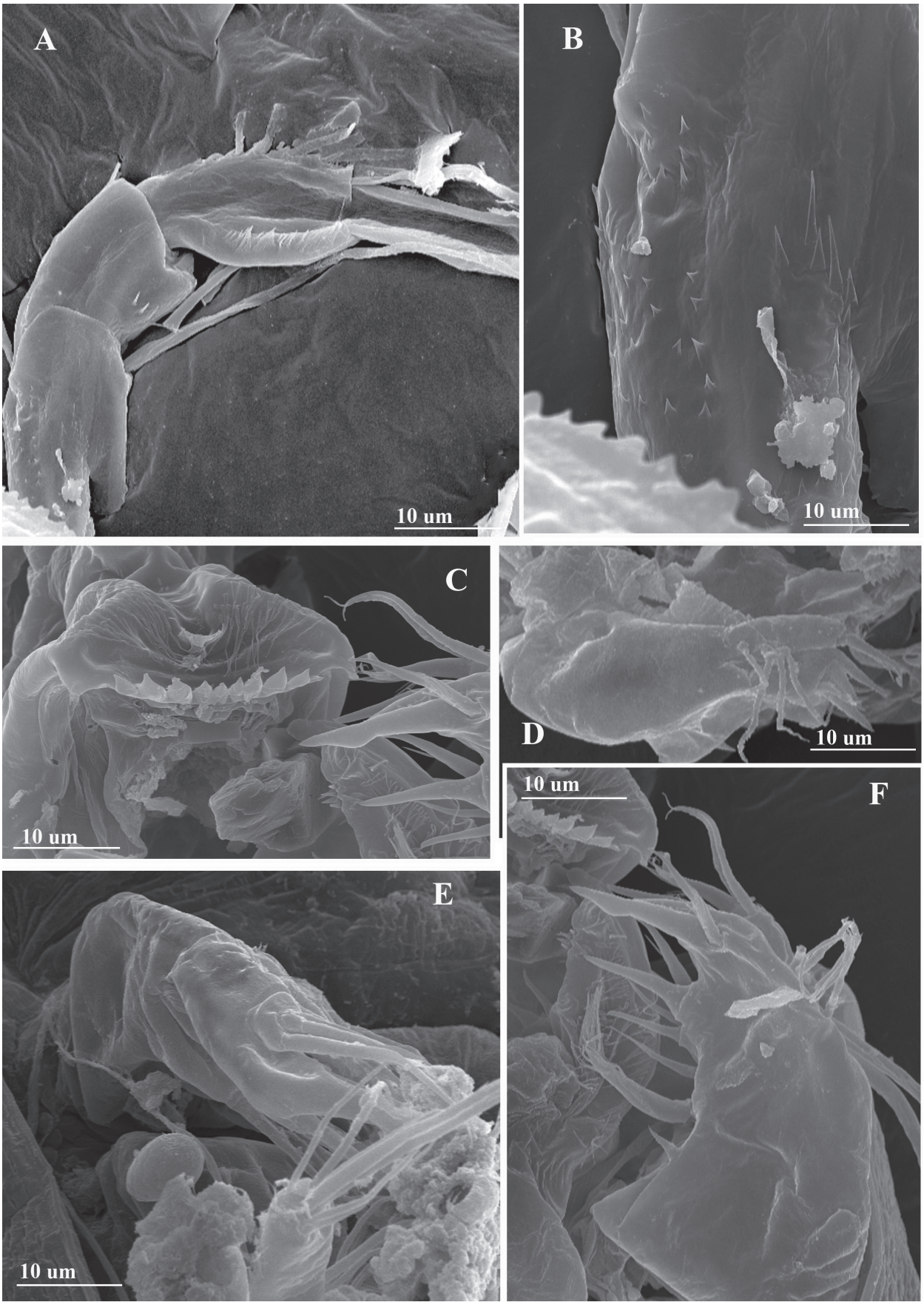

Figure 6. Scanning electron micrographs. *Thermocyclops oryzae* sp. nov., female, was collected from Kumphawapi District, Udon Thani Province, northeastern Thailand. **A.** Basis and endopodal segments of the antenna, posterior surface; **B.** Antennal basis, posterior surface; **C.** Labrum; **D.** Maxillule, anterior surface; **E.** Maxilla; **F.** Maxillule, posterior surface.

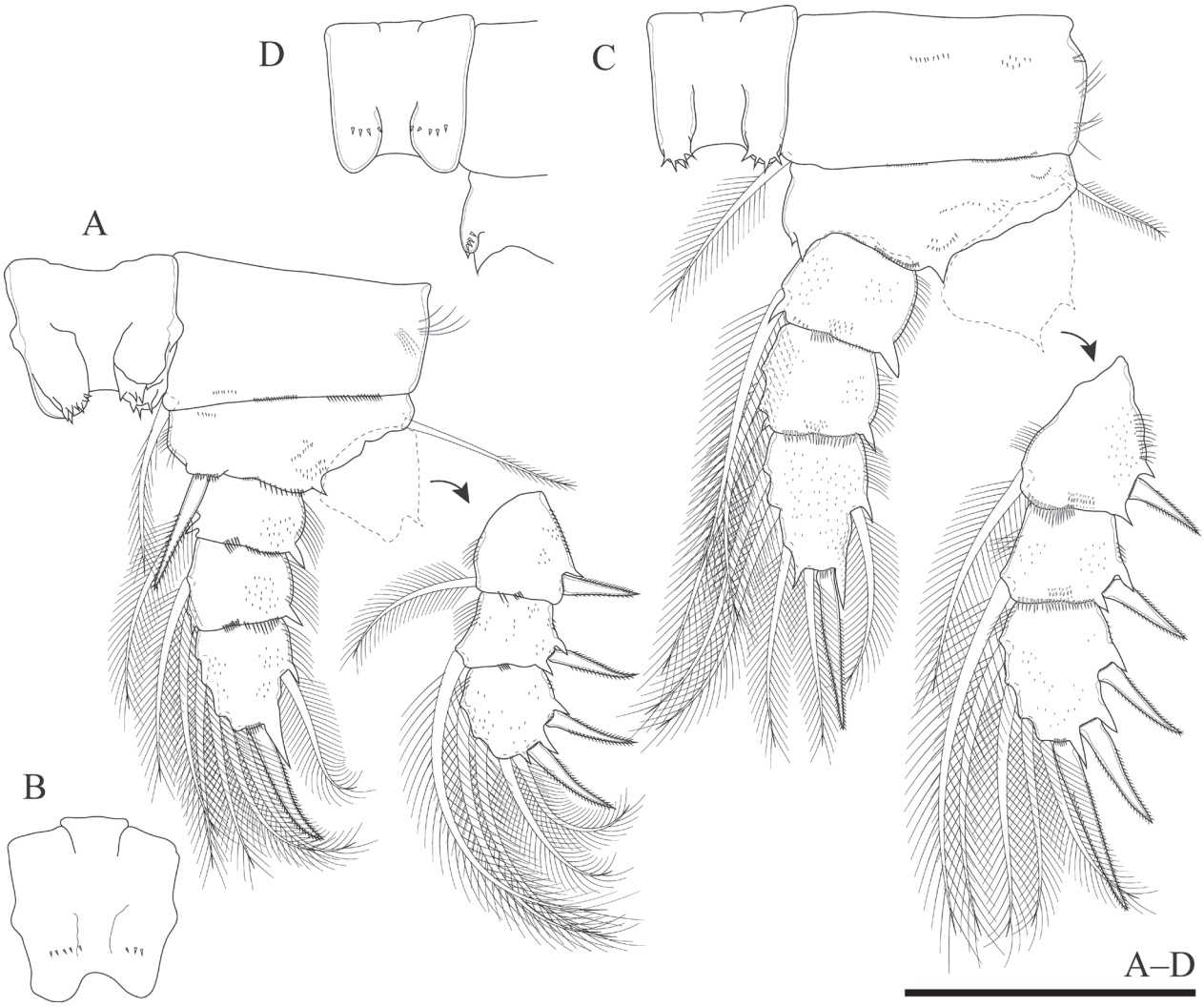

Figure 7. *Thermocyclops oryzae* sp. nov., female holotype. **A.** P1, anterior surface; **B.** Intercoxal sclerite of P1, posterior surface; **C.** P2, anterior surface; **D.** Intercoxal sclerite of P2, posterior surface. The dense pattern of tiny spinules shown in **A, C** is on the posterior surface. Scale bar: 100 μm.

one plumose seta), three inner plumose setae; posterior surface ornamented as in EXP1. ENP1 with one inner plumose seta; anterior surface ornamented with one longitudinal row of outer setules and one row of spinules along distal margin; posterior surface ornamented with one row of spinules along distal margin and dense pattern of tiny spinules. ENP2 two inner plumose setae; anterior and posterior surfaces ornamented as in ENP1. ENP3 with one outer plumose seta, two apical elements (outer element: one pinnate spine; inner element: one plumose seta), three inner plumose setae; anterior surface ornamented with one row of spinules along distal margin; posterior surface ornamented as in ENP1.

P3 (Figs 8A, B, 9C, 10E). Intercoxal sclerite subquadrate; distal margin with round projection bearing 5–6 spinules; anterior surface unornamented; posterior surface ornamented with one intermittent row of spinules. Coxa with one inner plumose seta; anterior surface ornamented with tiny spinules on lateral margin, three rows of tiny spinules along distal margin, and one row of tiny spinules near base of inner seta; posterior surface ornamented with one oblique row of hair-like spinules close to outer margin. Basis with one outer plumose seta. Anterior surface of basis ornamented with one row of tiny spinules between bases of exopod and endopod, one intermittent row of spinules near base of endopod, three rows of tiny spinules close to inner and distal parts of medial expansion (Fig. 8A). Both EXP1–3 and ENP1–3 as in P2.

P4 (Figs 2E, 8C, D, 9D–G, 10F, G). Intercoxal sclerite subquadrate, distal margin with round projection bearing 6 spinules; anterior surface ornamented with one intermittent row of spinules; posterior surface ornamented with two intermittent rows of spinules. Coxa with one inner plumose seta; anterior surface ornamented with one oblique row of tiny spinules in middle of the segment and two rows of tiny spinules along distal margin; posterior surface ornamented with one oblique row of tiny spinules in subproximal part, two oblique rows of spinules close to outer margin, one row of spinules along subdistal margin. Basis with one outer plumose seta; anterior surface ornamented with one row of spinules near base of endopod, one row of inner spinules along subproximal part, and one row of inner

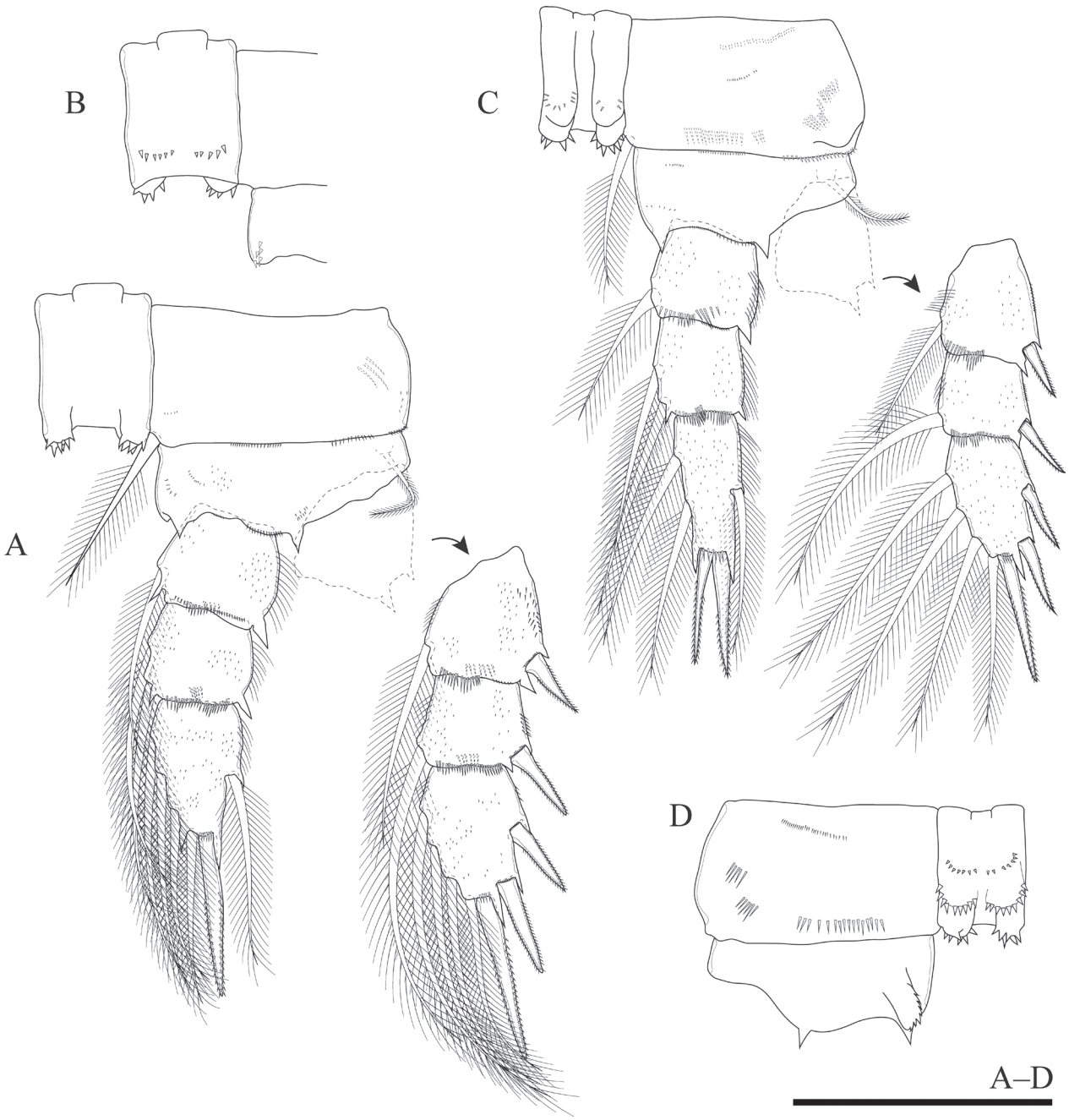

Figure 8. *Thermocyclops oryzae* sp. nov., female holotype. **A.** P3, anterior surface; **B.** Intercoxal sclerite of P3, posterior surface; **C.** P4, anterior surface; **D.** Protopodite of P4, posterior surface. The dense pattern of tiny spinules shown in **A.** and **C.** is on the posterior surface. Scale bar: 100 μm.

spinules along subdistal part; posterior surface ornamented with one distal serrate lobe close to inner margin. EXP1 and EXP2 as in P2, except posterior surface unornamented along distal margin. EXP3 as in P2, except anterior surface without longitudinal row of inner setules. ENP1 and ENP2 as in P2. ENP3 with one outer plumose seta, two apical spines, and two inner plumose setae; inner apical spine about 0.9 times as long as the outer apical spine.

P5 (Figs 1F, 10A) composed of coxobasis and one-segmented exopod. Coxobasis with one outer seta. Exopod with one apical outer smooth seta and one subapical inner pinnate spine; length of the inner apical spine about 1.3 times as long as the outer apical seta.

P6 (Fig. 1C, E) reduced to simple cuticular plate inserted latero-dorsally on genital double-somite, with two subequal smooth spines and one smooth seta; seta about five times as long as spines; surface unornamented.

Description of the adult male. ***Body*** (Fig. 11A). Total body length measured from anterior margin of rostrum to posterior margin of caudal rami, ranging from 686–789 μm (mean 748 μm, n = 3, 789 μm in allotype).

Urosome (Figs 11B–D, 12A–C) composed of fifth pedigerous somite, genital somite, three free urosomites, and anal somite with caudal rami. Fifth pedigerous somite ornamented with two dorsal sensilla. Genital somite about 0.8 times as long as wide, with two dorsal sensilla, anterior and posterior surfaces with irregular but mostly

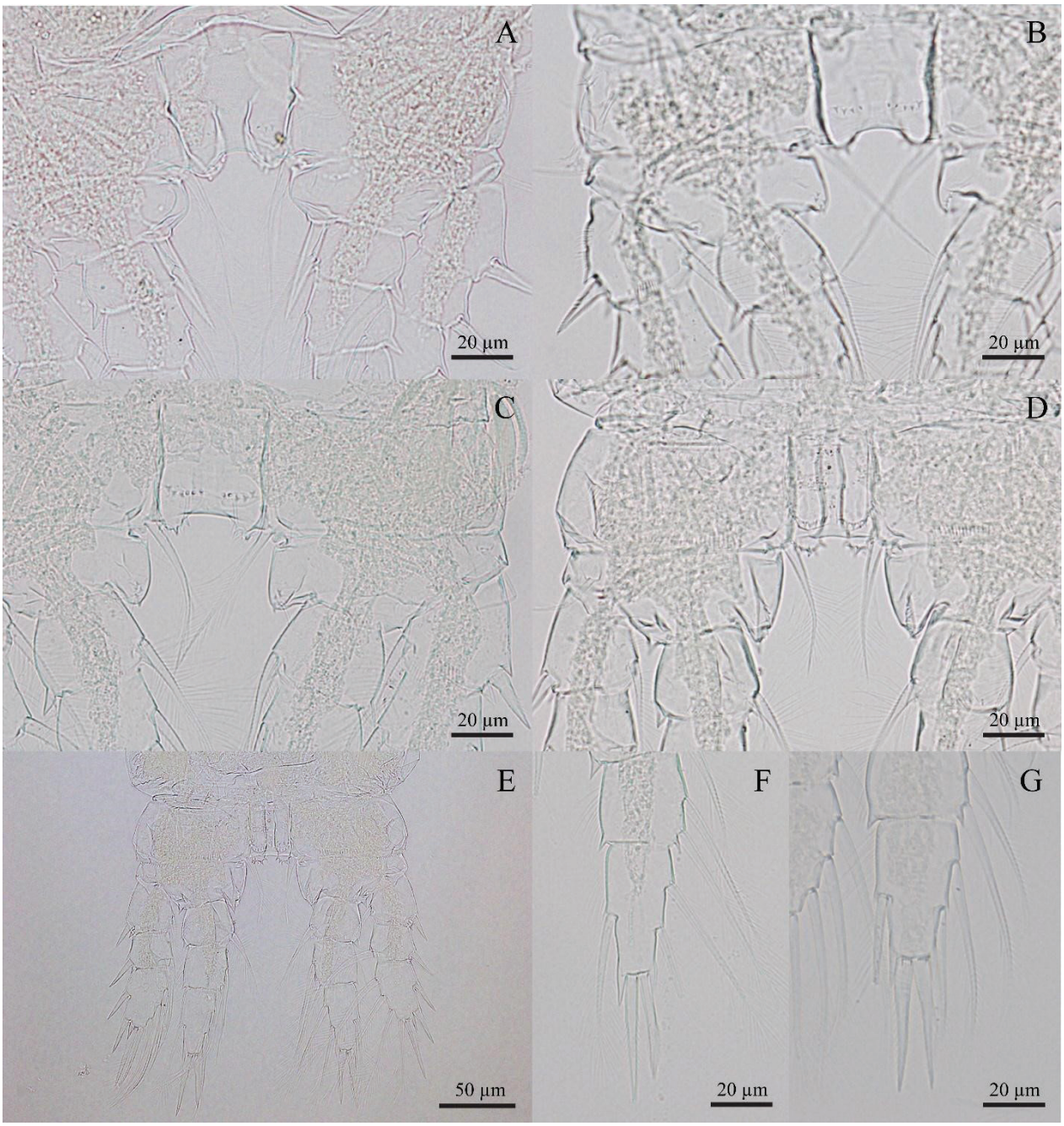

Figure 9. Digital photographs. *Thermocyclops oryzae* sp. nov., female, collected from a type locality. **A.** P1, posterior surface; **B.** P2, posterior surface; **C.** P3, posterior surface; **D, E.** P4, posterior surface; **F, G.** Apical spines of P4 ENP3.

transverse short striae, and with coarsely serrated hyaline frill along posterior margin. Succeeding two urosomites with irregular but mostly transverse striae on both dorsal and ventral surfaces and with coarsely serrated hyaline frill along posterior margin. The fifth urosomite with coarsely serrated hyaline frill along posterior margin. Anal somite with two dorsal sensilla at base of anal operculum; and posterior margin with spinules on both ventral and dorsal surfaces. Caudal rami cylindrical, parallel, about 3.7–3.9 times as long as wide; inner margin without hairs; outer margin ornamented with one transverse row of spinules inserted at distance of 1/3 ramus length measured from anterior margin and at base of outermost terminal seta (III) (Figs 11B–D, 12B, C, arrows). Each ramus with six setae: innermost terminal seta (VI) 1.4–1.5 times as long as outermost terminal seta (III).

A1 (Fig. 13A–D) 17-segmented. Armature formula (number of segment-[number of setae + aesthetasc (ae) + spine (s)]) of each segment as follows: 1-[8+3ae], 2-[4], 3-[2], 4-[1], 5-[1], 6-[2], 7-[1], 8-[2], 9-[1+s], 10-[2], 11-[2], 12-[2], 13-[1+ae], 14-[2+ 1 plate-like modified seta], 15-[1 + 2 plate-like modified setae], 16-[4], 17-[7+ae].

P6 (Fig. 11D) inserted latero-dorsally on genital somite with three smooth setae, length of the outermost seta about 1.4 times as long as the innermost seta, and middle seta about 0.6 times as long as the innermost seta; P6 flap ornamented with two rows of spinules.

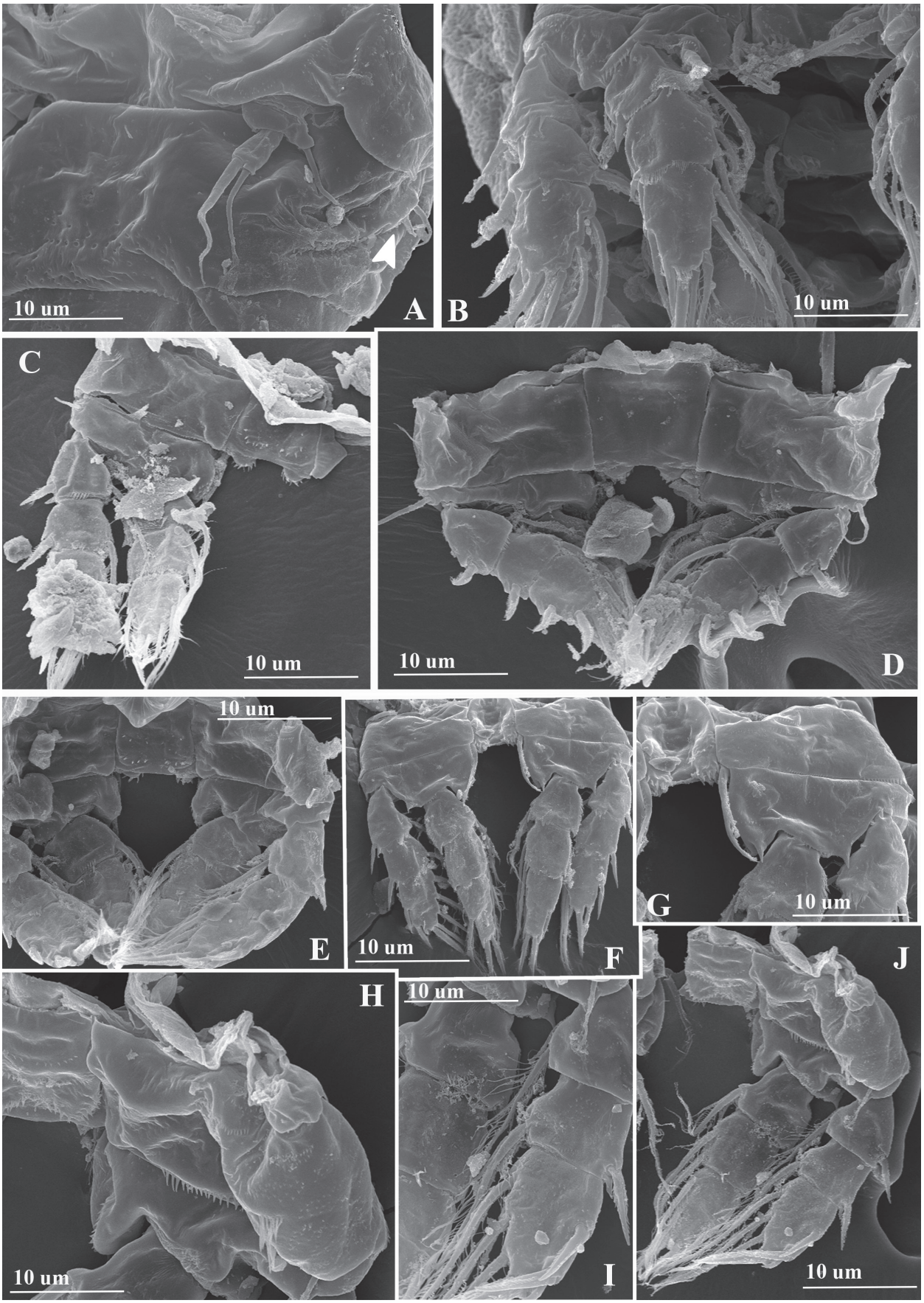

Figure 10. Scanning electron micrographs. *Thermocyclops oryzae* sp. nov., female, was collected from Kumphawapi District, Udon Thani Province, northeastern Thailand. **A.** P5 and pediger 5 (arrow indicates P6); **B.** P1, anterior surface; **C.** P2, posterior surface; **D.** P1, posterior surface; **E.** P3, posterior surface; **F.** P4, anterior surface; **G.** Coxa and basis of P4, anterior surface; **H.** Coxa and basis of P4, posterior surface; **I.** EXP and ENP of P4, posterior surface; **J.** P4, posterior surface.

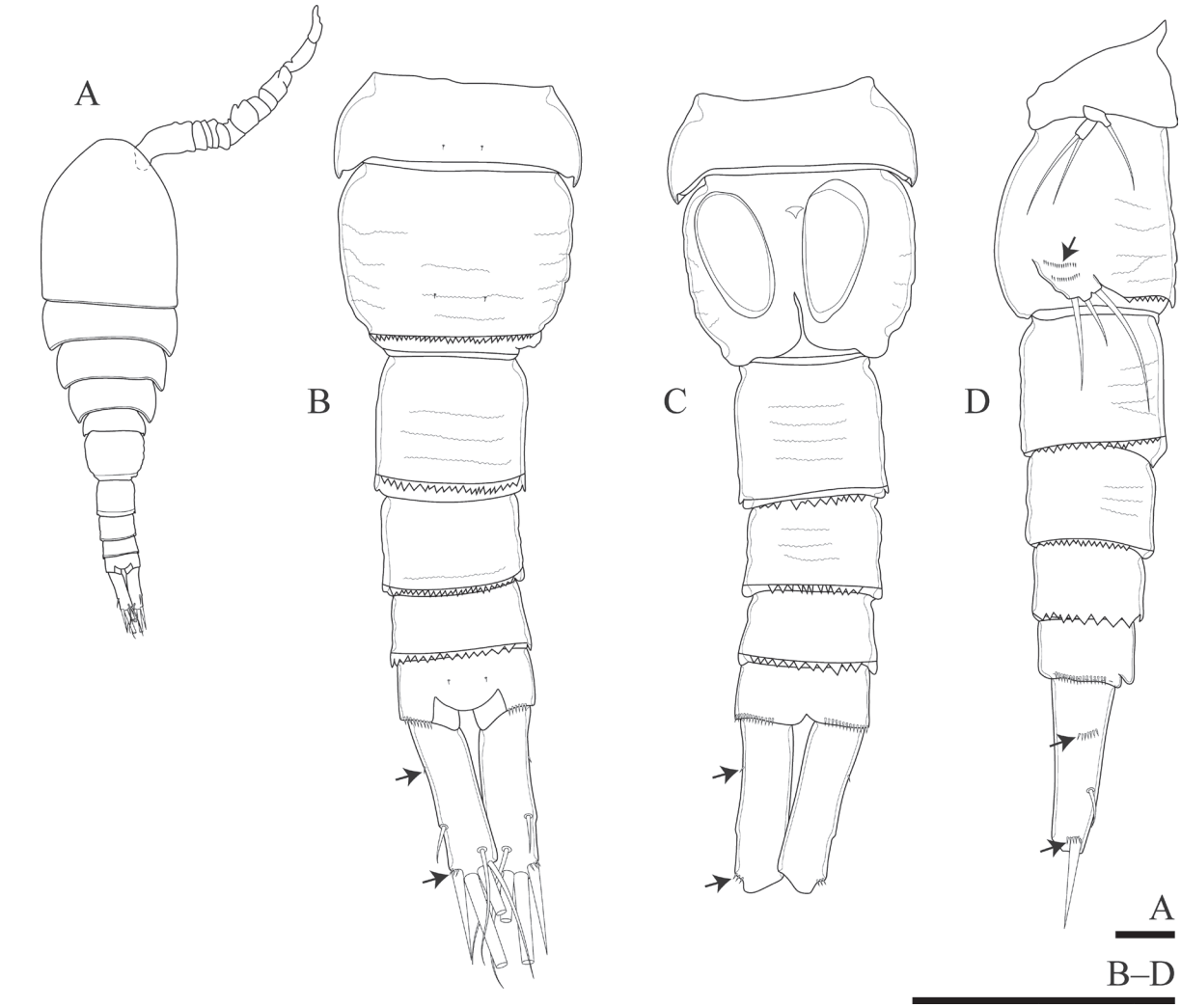

Figure 11. *Thermocyclops oryzae* sp. nov., male allotype. **A.** Habitus, dorsal surface; **B.** Urosome, dorsal surface; **C.** Urosome, ventral surface; **D.** Urosome, lateral surface (arrows indicate rows of spinules on the caudal ramus). Scale bars: 100 µm.

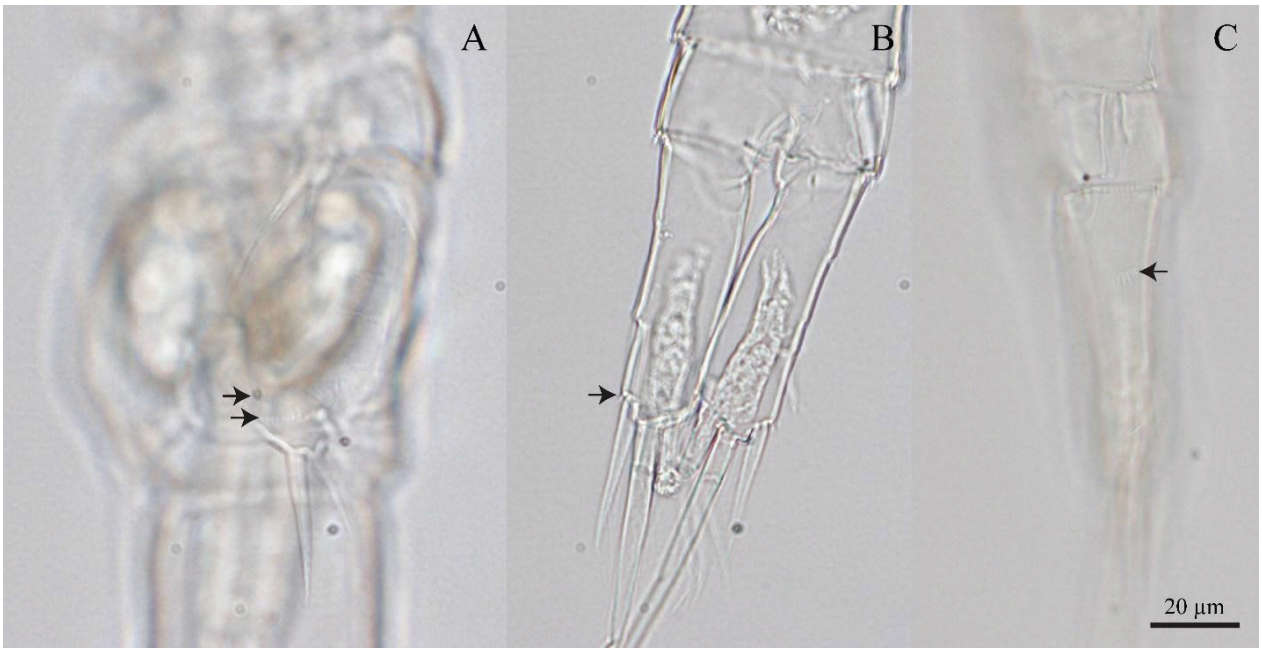

Figure 12. Digital photographs. *Thermocyclops oryzae* sp. nov., male allotype. **A.** P6, lateral surface (arrows indicate two rows of spinules); **B.** Caudal rami, ventral surface (arrow indicates a row of spinules); **C.** Caudal rami, lateral surface (arrow indicates a row of spinules).

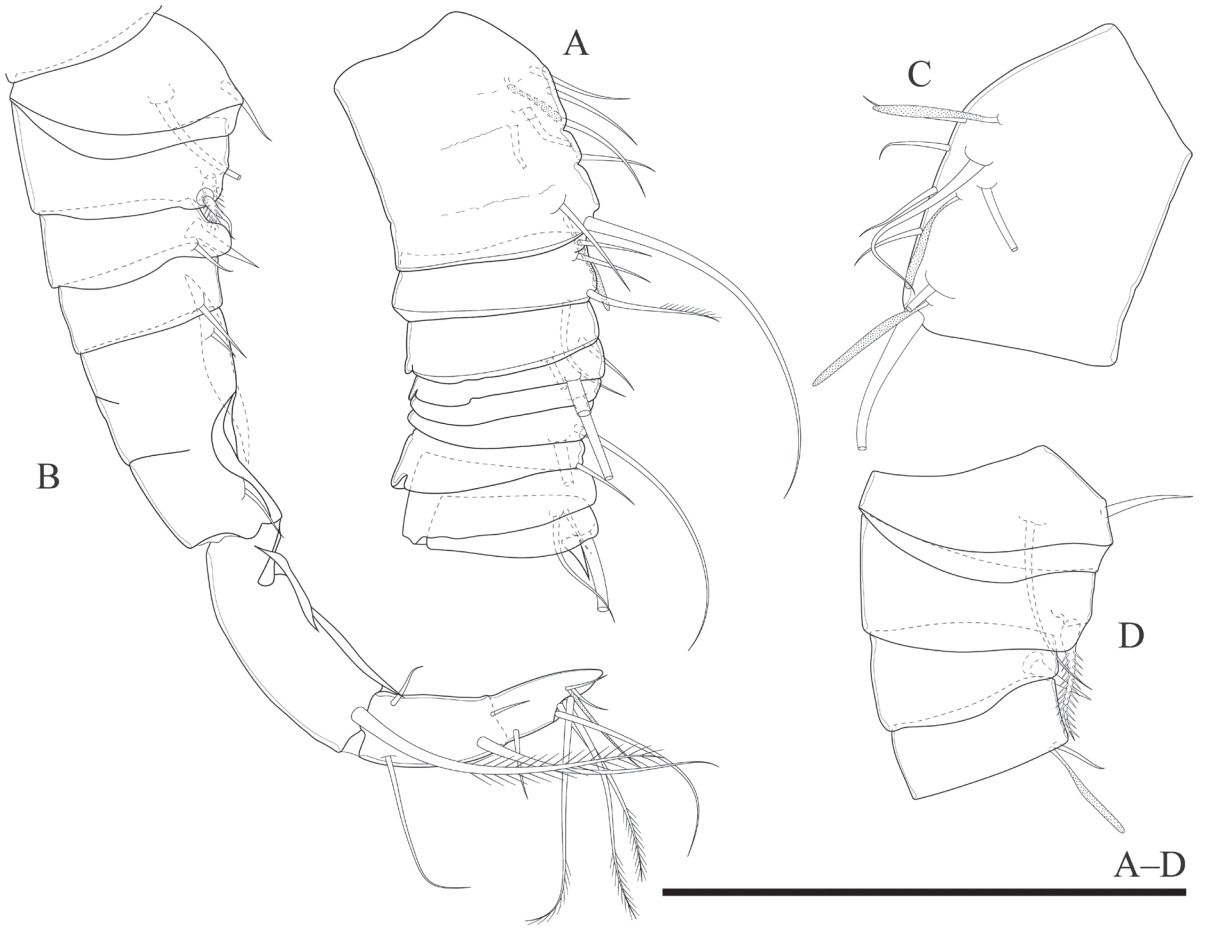

Figure 13. *Thermocyclops oryzae* sp. nov., **A–B** male allotype; **C–D** other specimens collected from type locality. **A.** Antennule, segments 1–9; **B.** Antennule, segments 10–17; **C.** Antennule, segments 1; **D.** Antennule, segments 10–13. Scale bar: 100 µm.

Prosome, A2, labrum, mandible, maxillule, maxilla, maxilliped, P1–P4 (not shown), and P5 (Fig. 11D) same as female.

Variability. Morphological variabilities in female specimens were observed in i) intercoxal sclerite of P1 of specimens from northeast Thailand is naked on the posterior surface ($n = 7$) (Fig. 10D), but one intermittent row of spinules present in specimens from central Thailand ($n = 5$) (Fig. 7B); ii) the inner apical spine of the third endopodal segment of P4 shorter or as long as the outer apical spine (Figs 8C, 9E–G, 10F); and iii) P6 of one specimen from a temporary pond in northeast Thailand has one short spine and one slender seta instead of three elements (Fig. 10A, arrow).

Etymology. The specific name '*oryzae*', which means rice, is derived from the habitat type ("rice") of the type locality".

Co-occurring species. In our samples, the new taxon co-occurred with *Cryptocyclops* sp., *Mesocyclops affinis* Van de Velde, 1987; *M. aspericornis* (Daday, 1906); *M. ogunnus* Onabamiro 1957; *M. thermocyclopoides* Harada, 1931; *Microcyclops* sp., *Thermocyclops crassus* (Fischer, 1853); *T. decipiens* (Kiefer, 1929); *T. operculifer* (Kiefer, 1930); *T. rylovi* (Smirnov, 1928); *T. vermifer* Lindberg, 1935; and *T. wolterecki* Kiefer, 1938.

Distribution and ecology. *Thermocyclops oryzae* sp. nov. is widespread in Thailand, both in the west and northeast. However, it has only been recorded in temporary habitats, including rice fields, temporary roadside canals, and temporary ponds. It was recorded in four out of 22 samples collected from five rice fields in Suphan Buri province during three planting seasons between November 2022 and January 2024. The environmental parameters measured in the studied rice fields were as follows: water temperature ranged from 31.8–36.1 °C, conductivity ranged from 1176.5–1449.9 µs cm-1, salinity ranged from 0.21–0.58 psu, total dissolved solids ranged from 77–676 mg L-1, dissolved oxygen ranged from 7.54–7.54 mg L-1, pH 7.0–7.3, chlorophyll a ranged from 5.31–17.39 µs L-1, and water depth was 10 cm with a substrate of mud. In addition, the temporary canals and temporary pond in the northeast, where this species was found, were not vegetated, but the grass and morning glory (*Ipomoea*) grew near the water's edge.

Pictorial keys to *Thermocyclops* species found in Thailand

The pictorial key of the *Thermocyclops* species found in Thailand is presented in Fig. 14 to facilitate easy and quick identification.

Species diversity and distribution of *Thermocyclops* in Thai water bodies

In Thailand, *Thermocyclops* have been found in various types of freshwater habitats, including rice fields, canals, lakes, and swamps (Sanoamuang 1999; Wongrat and Pipatcharoenchai 2003; Alekseev and Sanoamuang 2006; Proongkiat 2006; Wansuang and Sanoamuang 2006; Chittapun et al. 2009; Koompoot 2010; Watiroyram 2012; Boonyanusith 2013; Karanovic et al. 2017; Maiphae et al. 2023; Soe and Sanoamuang 2023). A total of 14 species have been recorded in Thailand to

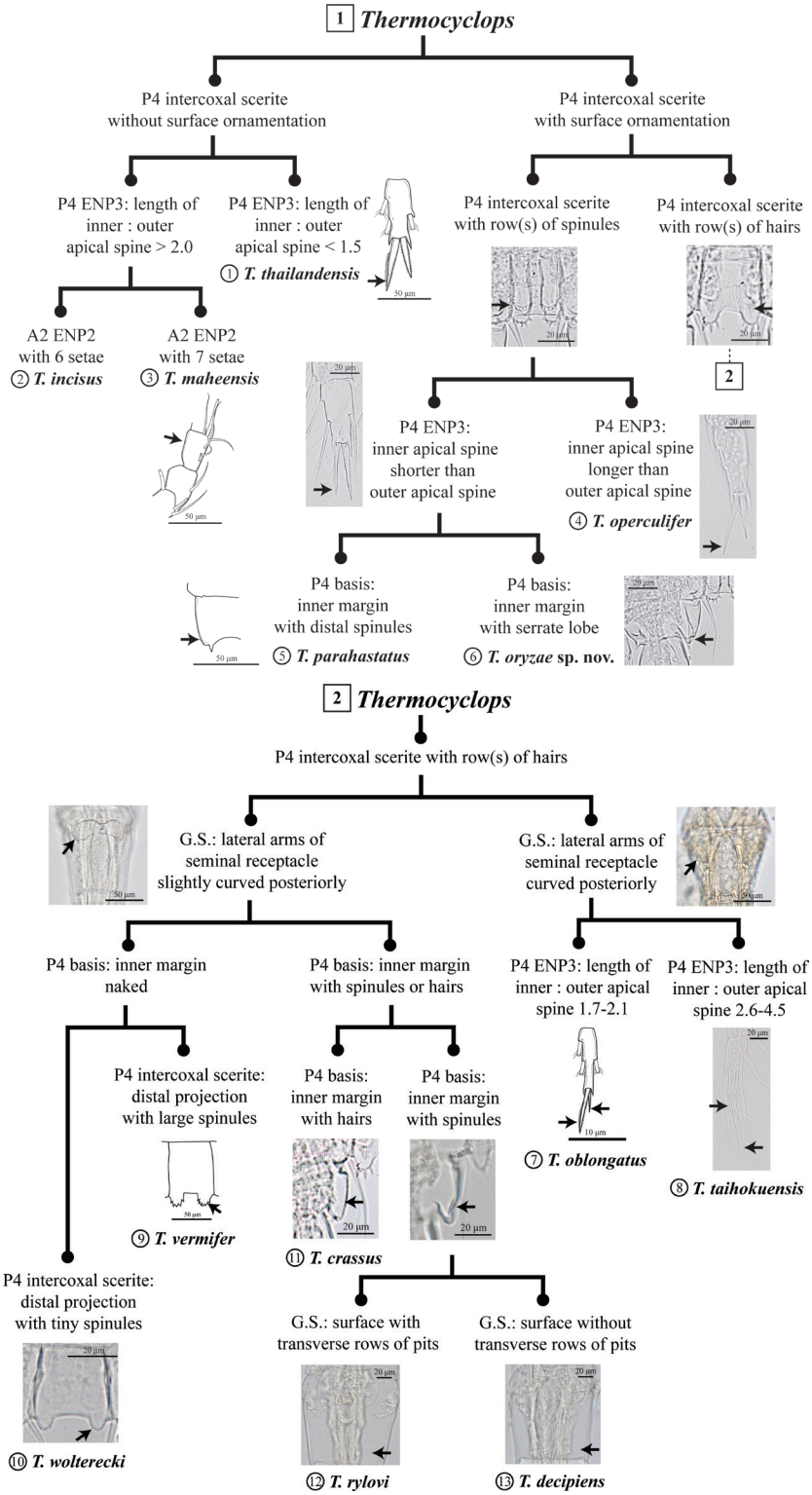

Figure 14. Pictorial key of the adult female of *Thermocyclops* species found in Thailand (*T.* cf. *orientalis* is not included in this figure because its species status needs to be further confirmed; pictures of *T. parahastatus* and *T. thailandensis* were modified from Karanovic et al. 2017; pictures of *T. maheensis* and *T. vermifer* were modified from Chaicharoen et al. 2011; pictures of *T. oblongatus* were modified from Baribwegure et al. 2001).

date: *T. crassus*; *T. decipiens*; *T. incisus* (Kiefer 1932); *T. maheensis* (Lindberg 1941); *T. oblongatus* (G.O. Sars, 1927); *T. operculifer*; *T. rylovi*; and *T. taihokuensis* (Harada 1931); *T. vermifer*; *T. wolterecki*; *T. parahastatus*; and *T. thailandensis*; *T.* cf. *orientalis*; and *T. oryzae* sp. nov. Each species can be found in various types of freshwater habitats, and most can be found in temporary and permanent water bodies (Table 2). In addition, most species are widely distributed in Thailand (Fig. 15), and a few species have a restricted distribution and have been found only in temporary habitats and a few locations.

Discussion

The new species is confirmed to belong to the genus *Thermocyclops* based on the combination of the characteristics described by Mirabdullayev et al. (2003). The morphological characteristics of *Thermocyclops oryzae* sp. nov. are mostly similar to those of *T. crucis* Holynska 2006 (Table 3), but they differ in the following characteristics: in the female, (i) the ratio of length to width of the caudal ramus is 3.6–4.1 (4.1–4.7 in *T. crucis*), (ii) the dorsal and lateral surfaces of the fifth pedigerous somite have tiny spinules (tiny spinules present only laterodorsally in *T. crucis*), (iii) the medial margin of the basis of P1 has hairs (medial spinules and hairs in *T. crucis*), (iv) the posterior surface of the EXP and ENP of P1–P4 is ornamented with tiny spinules (*T. crucis* has no spinules), (v) the intercoxal sclerite of P4 has two rows of spinules (*T. crucis* has three rows), (vi) the inner margin of the base of P4 has a serrate lobe (group of spinules in *T. crucis*); and (vii) the inner apical spine of ENP3 of P4 is 0.9 times as long as the lateral one (1.0 in *T. crucis*) .

With the discovery of this new species, the number of *Thermocyclops* species recorded in Thailand has increased from 13 to 14, accounting for 21% of global *Thermocyclops* species diversity. Based on previous and present research, most *Thermocyclops* species appear to have a wide distribution, and there are two species, *T. crassus* and *T. decipiens*, that are distributed in all regions of the country. However, recent discoveries of *T. parahastatus* and *T. thailandensis* in Thailand (Karanovic et al. 2017), including the present discovery, indicate that cryptic or semiterrestrial habitats may be home to a diverse *Thermocyclops* fauna, especially in temporary habitats. Therefore, further research, particularly on this type of habitat, is needed.

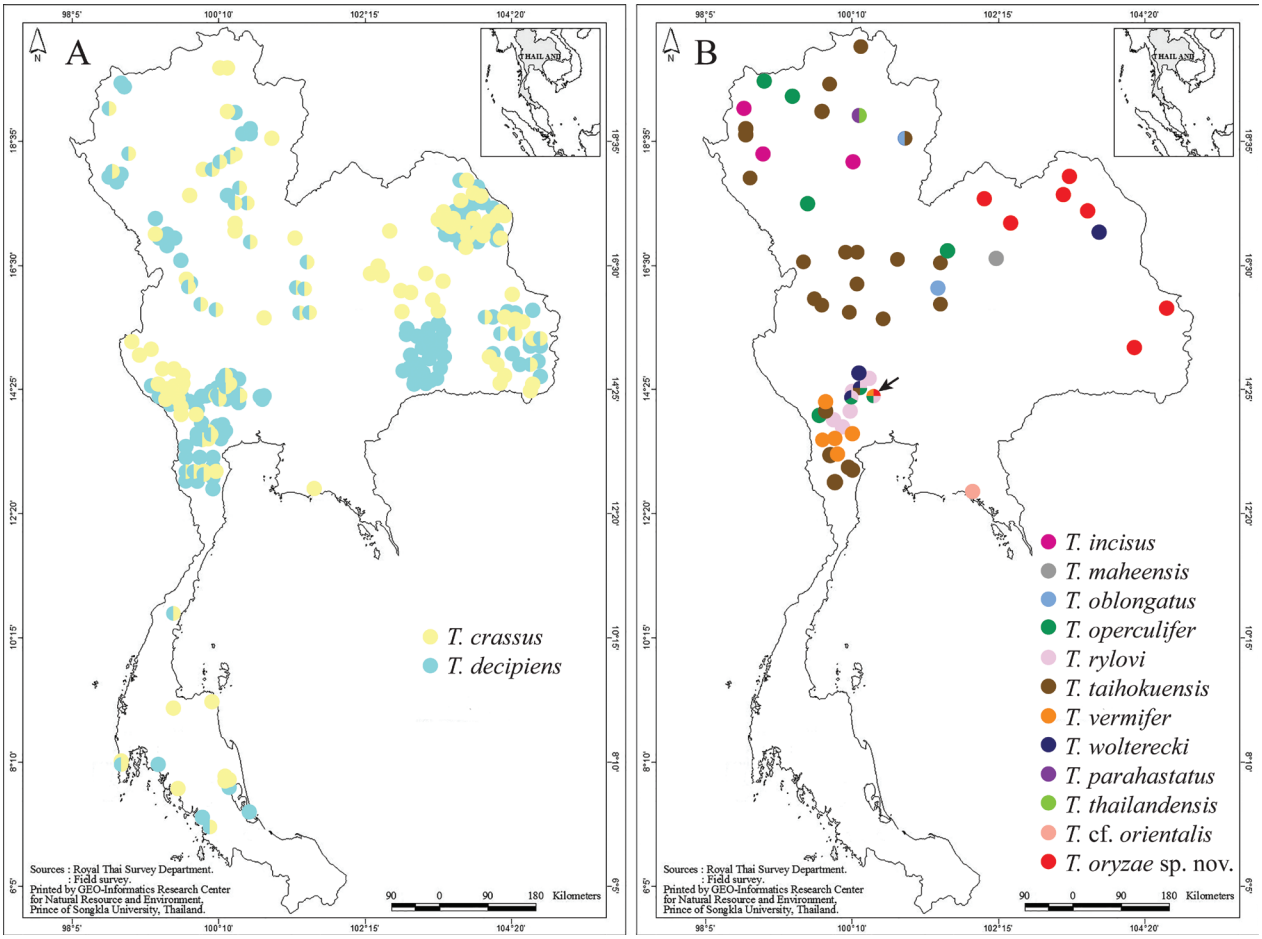

Figure 15. Distribution of *Thermocyclops* species in Thailand. **A.** Species with wide distribution; **B.** Species with restricted distribution (arrow indicates type locality of *T. oryzae* sp. nov.).

Table 2. Co-occurring cyclopoids, habitat information, and general distribution of the *Thermocyclops* species occurring in Thailand.

Species	Co-occurring species in Thai water bodies	Distribution in Thai water bodies	Geographical distribution
1. *T. crassus* (Fischer, 1853)	*Cryptocyclops* sp., *Ectocyclops phaleratus*, *E. polyspinosus*, *Eucyclops euacanthus*, *E. serrulatus*, *Halicyclops* cf. *thermophilus*, *Mesocyclops affinis*, *M. aspericornis*, *M. dissimilis*, *M. ferjemurami*, *M. kayi*, *M. ogunnus*, *M. pilosus*, *M. thermocyclopoides*, *Microcyclops* sp., *Paracyclops fimbriatus*, *Thermocyclops decipiens*, *T. incisus*, *T. oblongatus*, *T. operculifer*, *T. rylovi*, *T. taihokuensis*, *T. vermifer*, *T. wolterecki*, *Tropocyclops prasinus*	Several types of habitats including canal, cave, floodplain, irrigation canal, lake, man-made lake, permanent and temporary pond, reservoir, rice field, river, roadside pond, swamp in central, eastern, northern, northeastern, southern and western Thailand [1, 2, 4, 5, 6, 8, 9, 10, 11, 13, 15, 16, 18, 20, 21, 22].	Americas, Australia, Bangladesh, Cambodia, China, Ethiopia, India, Indonesia, Japan, Philippines, Russia, Uzbekistan, and widely distributed in Europe (Defaye et al. 1987; Defaye 1988; Ueda et al. 1997; Guo 1999; Ishida 2002; Mirabdullayev et al. 2003; Hołyńska 2006; Mirabdullayev and Kuzmetov 2007; Chaicharoen et al. 2011; Lopez et al. 2017; Islam et al. 2022; Stamou et al. 2022; Nowakowski and Sługocki 2024)
2. *T. decipiens* (Kiefer, 1929)	*Cryptocyclops linjanticus*, *Ectocyclops phaleratus*, *Eucyclops arcanus*, *E. serrulatus*, *Halicyclops* cf. *thermophilus*, *Macrocyclops fuscus*, *Mesocyclops affinis*, *M. aspericornis*, *M. ferjemurami*, *M. kayi*, *M. ogunnus*, *M. thermocyclopoides*, *Metacyclops* sp., *Microcyclops* cf. *karvei*, *Paracyclops affinis*, *P. fimbriatus*, *Thermocyclops crassus*, *T. incisus*, *T. operculifer*, *T. rylovi*, *T. taihokuensis*, *T. vermifer*, *T. wolterecki*, *Tropocyclops confinis*, *T. prasinus*	Several types of habitats including canal, cave, floodplain, irrigation canal, lake, peat swamp, permanent and temporary pond, reservoir, rice field, river, roadside canal, swamp in central, northern, northeastern, southern and western Thailand [1, 3, 5, 7, 8, 9, 10, 11, 12, 13, 15, 18, 20, 21, 22].	Circumtropical (Defaye et al. 1987; Defaye 1988; Mirabdullayev et al. 2003; Hołyńska 2006; Chaicharoen et al. 2011; Lopez et al. 2017)
3. *T. incisus* (Kiefer, 1932)	*Ectocyclops phaleratus*, *E. polyspinosus*, *Mesocyclops aspericornis*, *M. thermocyclopoides*, *Paracyclops fimbriatus*, *Thermocyclops crassus*, *T. decipiens*	Pond, reservoir, roadside canal, temporary pond in northern Thailand [10].	Africa: Ghana, Guinea, Mali, Nigeria, Senegal and Uganda (Mirabdullayev et al. 2003)
4. *T. maheensis* (Lindberg, 1941)	*Eucyclops euacanthus*, *Microcyclops rubellus*, *Mesocyclops aspericornis*, *M. thermocyclopoides*, *Thermocyclops rylovi*	River in northeastern Thailand [7].	Cambodia and India (Mirabdullayev et al. 2003; Chaicharoen et al. 2011)
5. *T. oblongatus* (G.O. Sars, 1927)	*Mesocyclops aspericornis*, *M. thermocyclopoides*, *Thermocyclops crassus*, *T. decipiens*, *T. taihokuensis*	Permanent pond and reservoir in central and northern Thailand [10].	Algeria, Angola, Congo, Egypt, Ethiopia, Greece, India, Italy, Kenya, Madagascar, Portugal, Rwanda, South Africa, Tanzania, Tunisia, Uganda and Yemen (Pesce and Pace 1984; Defaye 1988; Mirabdullayev et al. 2003)
6. *T. operculifer* (Kiefer, 1930)	*Cryptocyclops* sp., *Eucyclops serrulatus*, *Mesocyclops affinis*, *M. aspericornis*, *M. kayi*, *M. ogunnus*, *M. thermocyclopoides*, *Microcyclops* sp., *Thermocyclops crassus*, *T. decipiens*, *T. wolterecki*	Cave, irrigation canal, rice field river, roadside canal, temporary pond in central, northern and western Thailand [14, 15, 20, 21, 22].	Australia, Cambodia, Indonesia, Philippines and Vietnam (Defaye et al. 1987; Mirabdullayev et al. 2003; Hołyńska 2006)
7. *T. rylovi* (Smirnov, 1928)	*Cryptocyclops* sp., *Eucyclops euacanthus*, *Microcyclops rubellus*, *Mesocyclops affinis*, *M. aspericornis*, *M. kayi*, *M. thermocyclopoides*, *Thermocyclops crassus*, *T. decipiens*, *T. maheensis*, *T. operculifer*, *T. taihokuensis*, *T. wolterecki*	Canal, permanent and temporary pond, reservoir, rice field, river and swamp in central, northeastern and western Thailand [7, 13, 20, 22].	Afghanistan, Australia, Cambodia, Ethiopia, Kazakhstan, India, Iran, Pakistan, Russia, Tajikistan, Uganda and Uzbekistan (Defaye et al. 1987; Mirabdullayev et al. 2003; Hołyńska 2006; Chaicharoen et al. 2011)
8. *T. taihokuensis* (Harada, 1931)	*Cryptocyclops* sp., *Mesocyclops aspericornis*, *M. kayi*, *M. thermocyclopoides*, *Microcyclops* sp., *Thermocyclops crassus*, *T. decipiens*, *T. rylovi*	Lake, permanent and temporary pond, reservoir, rice field, river, roadside canal, swamp in central, northern and western Thailand [1, 10, 13, 20].	China, Japan, Kazakhstan, Korea, Philippines, Russia, Taiwan, Tajikistan, Uzbekistan and Vietnam (Ueda et al. 1997; Guo 1999; Ishida 2002; Mirabdullayev et al. 2003; Lopez et al. 2017; Lazareva and Zhdanovaa 2023)
9. *T. vermifer* (Lindberg, 1935)	*Cryptocyclops* sp., *Ectocyclops* sp., *Mesocyclops affinis*, *M. aspericornis*, *M. ogunnus*, *M. thermocyclopoides*, *Microcyclops* sp., *Thermocyclops decipiens*, *T. rylovi*	Canal, irrigation canal, rice field, permanent and temporary pond, river in central, northern and western Thailand [13, 20, 21, 22].	Afghanistan, Azerbaijan, Cambodia, China, India, Kazakhstan, Pakistan, Tajikistan, Turkmenistan and Uzbekistan (Guo 1999; Mirabdullayev et al. 2003; Chaicharoen et al. 2011)
10. *T. wolterecki* Kiefer, 1938	*Cryptocyclops linjanticus*, *Eucyclops arcanus*, *E. serrulatus*, *Macrocyclops fuscus*, *Mesocyclops affinis*, *M. aspericornis*, *M. kayi*, *M. ogunnus*, *M. thermocyclopoides*, *Microcyclops* cf. *karvei*, *Paracyclops affinis*, *Thermocyclops crassus*, *T. decipiens*, *T. operculifer*, *T. rylovi*, *Tropocyclops prasinus*	Lake, rice field and roadside canal in central, northern and northeastern Thailand [7, 10, 20, 22].	Cambodia, Papua New Guinea and Philippines (Defaye et al. 1987; Mirabdullayev et al. 2003; Chaicharoen et al. 2011; Lopez et al. 2017)
11. *T. parahastatus* Karanovic, Koomput & Sanoamuang, 2017	*Thermocyclops thailandensis*, *Elaphoidella intermedia*, *Parapseudoleptomesochra phayaoensis*	Cave in northern Thailand [17, 19].	Endemic to Thailand (Karanovic et al. 2017; Koompoot and Sanoamuang 2021)
12. *T. thailandensis* Karanovic, Koomput & Sanoamuang, 2017	*Thermocyclops parahastatus*, *Elaphoidella intermedia*, *Parapseudoleptomesochra phayaoensis*	Cave in northern Thailand [17, 19].	Endemic to Thailand (Karanovic et al. 2017; Koompoot and Sanoamuang 2021)
13. *T.* cf. *orientalis*	No co-occurring species	Peat swamp in eastern Thailand [18].	-
14. *T. oryzae* sp. nov.	*Cryptocyclops* sp., *Mesocyclops affinis*, *M. aspericornis*, *M. ogunnus*, *M. thermocyclopoides*, *Microcyclops* sp., *Thermocyclops crassus*, *T. decipiens*, *T. operculifer*, *T. rylovi*, *T. vermifer*, *T. wolterecki*	Rice field, temporary roadside canal and temporary pond in central and northeastern Thailand [22].	Endemic to Thailand

(1) Sanoamuang 1999; (2) Athibai 2002; (3) Yindee 2002; (4) Lekchan 2003; (5) Tungpunyaporn 2003; (6) Wongrat and Pipatcharoenchai 2003; (7) Alekseev and Sanoamuang 2006; (8) Boonsit 2006; (9) Sanoamuang and Faitakum 2005; (10) Proongkiat 2006; (11) Wansuang and Sanoamuang 2006; (12) Chittapun et al. 2009; (13) Koompoot 2010; (14) Watiroyram 2012; (15) Boonyanusith 2013; (16) Saetang and Maiphae 2015; (17) Karanovic et al. 2017; (18) Maiphae 2017; (19) Koompoot and Sanoamuang 2021; (20) Maiphae et al. 2023; (21) Soe and Sanoamuang 2023 (22) this study.

Table 3. Morphological comparisons between *Thermocyclops oryzae* sp. nov. and the morphologically most similar species, *T. crucis* (character states pertain to females; the main diagnostic character is indicated in bold).

Morphological characters	*Thermocyclops oryzae* sp. nov.	*T. crucis*
Caudal ramus: ratio of L:W	3.6–4.1	4.1–4.7
P1: ornamentation on inner margin of basis	hairs	spinules and hairs
P4: number of spinule rows on posterior surface of intercoxal sclerite	2	3
P4: ornamentation on inner margin of basis	**serrate lobe**	group of spinules
P4: apical spines of ENP3, inner:outer	0.9	1
P1–P4: surface ornamentation of EXP and ENP	tiny spinules	no spinules

Acknowledgements

We would like to thank the editor and the reviewer for their time and effort in reviewing the manuscript. We sincerely appreciate all the valuable comments and suggestions that have helped us improve its quality. We would also like to thank Kasetsart University for research funding through the Biodiversity Center Kasetsart University (BDCKU). This research was approved by the Institutional Animal Care and Use Committee, Kasetsart University, Thailand (approval no. ACKU67-SCI-010).

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