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The genus *Thermocyclops Kiefer*, 1927 (Copepoda: Cyclopidae) in China

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Abstract

Based on the result of investigations and former records, there are five freshwater species of the genus *Thermocyclops* in China, namely *T. taihokuensis* Harada, 1931, *T. crassus* (Fischer, 1853), *T. vermifer* Lindberg, 1935, *T. dybowskii* (Lande, 1890), and *T. kawamurai* Kikuchi, 1940. Two previously recorded species, *T. brevifurcatus* Harada, 1931 and *T. hyalinus* (Rehberg, 1880) are recognized as synonyms of *Thermocyclops crassus*. Another species, *Thermocyclops mongolicus* Kiefer, 1937, described from China by Tai & Chen, is a synonym of *T. taihokuensis* based on this study. *Thermocyclops orientalis* Dussart & Fernando, 1985 was compared with *Thermocyclops kawamurai* Kikuchi, 1940. It shows conspicuous differences and it seems unlikely that it is a synonym of *T. kawamurai*. The paper presents diagnostic characteristics of each species and a key to five Chinese species of *Thermocyclops*.

Introduction

The genus *Thermocyclops* occurs world-wide, with more than 50 described species and subspecies. In China, the species of *Thermocyclops* occur in any kind of fresh and brackish water biotopes and are frequently predominant in lakes, ponds and potamon sections of rivers, therefore an understanding of their taxonomy and geographical distribution is of particular interest. However, in China incorrect names and out-of-date taxonomy are still used. At present, most limnologists accept Herbst's (1986) taxonomic system. Considering the present confusion, a further study on Chinese *Thermocyclops* Kiefer, 1927 is needed.

Materials and methods

More than 300 samples were collected from a wide range of freshwater habitats in China, using plankton nets with mesh sizes of 112 and 64 μm. All samples were preserved in 4–7% formalin solution. Specimens were dissected in glycerine or PVL under a stereo zoom binocular microscope. A Leitz Laborlux K microscope with a camera lucida was used for identifying, measuring and drawing specimens. Measurements were taken following the method of Kozminski (1936). Mounting was done in glycerine and PVL under a coverslip sealed with nail polish.

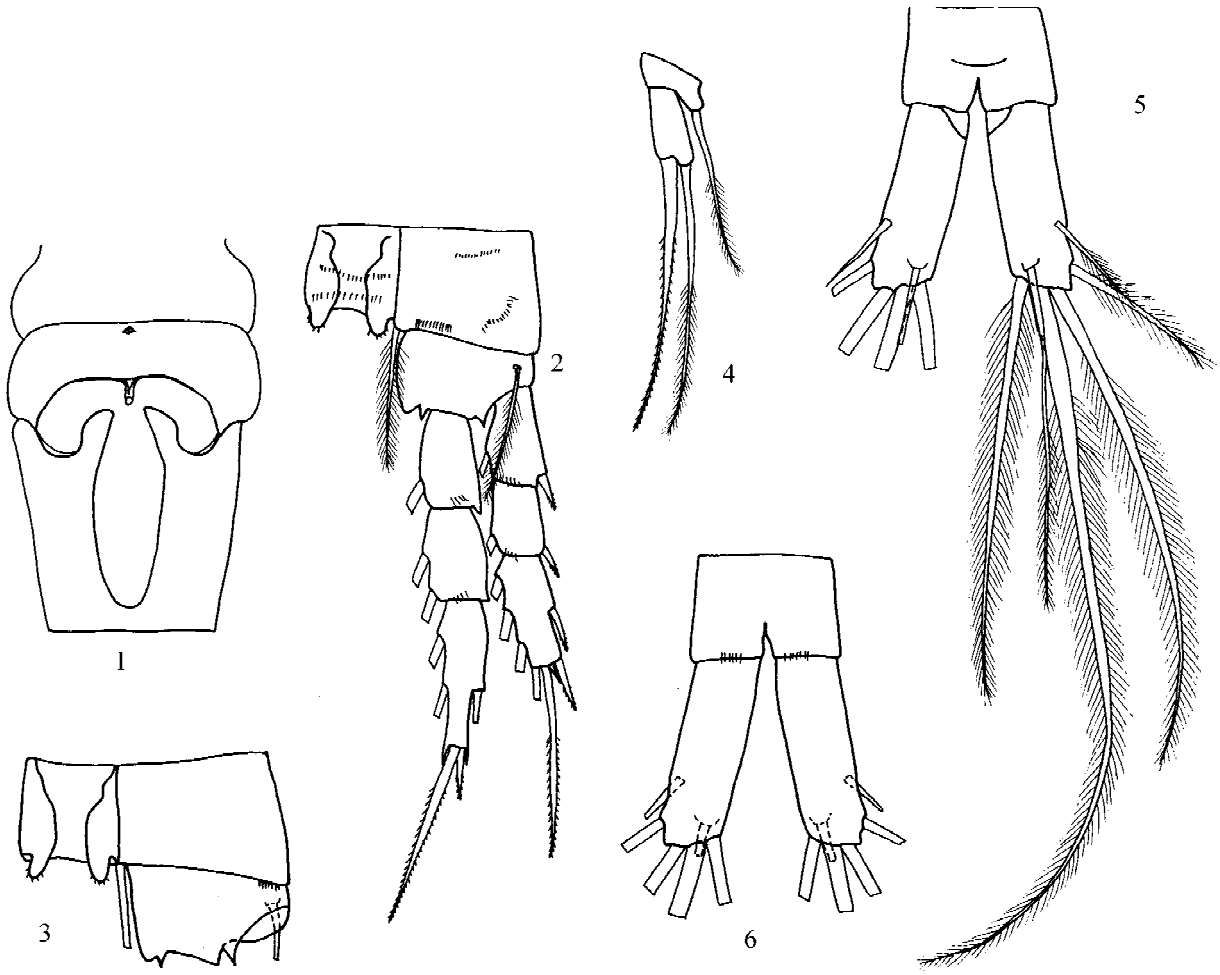
PVL, polyvinyl lactophenol; L, length; W, width; A1, antennula; P1, leg 1; P2, leg 2; P3, leg 3; P4, leg 4; P5, leg 5; Enp, endopodite; Exp, exopodite, R.S., seminal receptacle, Si, terminal internal seta of caudal ramus; Se, terminal external seta of caudal ramus; Sd, dorsal caudal seta.

Results

Species description (female) and remarks

Thermocyclops taihokuensis *Harada, 1931*

Mesocyclops (*Thermocyclops*) *taihokuensis* Harada, 1931
Mesocyclops (*Thermocyclops*) *asiaticus* Kiefer, 1932; (Rylov, 1948)
Thermocyclops mongolicus Tai & Chen, 1979
Thermocyclops taihokuensis Kiefer, 1938 (Kawabata

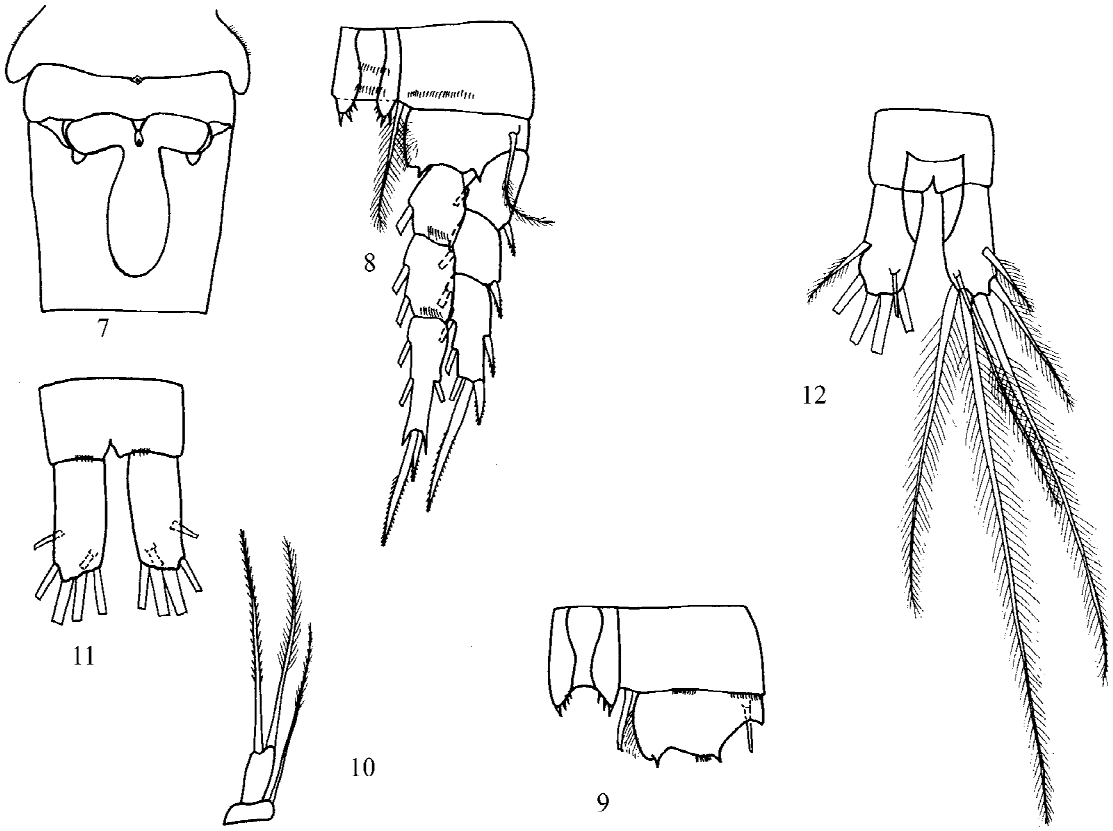


Figures 1–6. Thermocyclops tahokuensis. Female: (1) pediger 5 and genital somite; (2) right P4 with connecting plate (caudal); (3) connecting plate, Coxopodite and basipodite of P4 (frontal); (4) P5; (5) anal somite and caudal rami with setae (dorsal); (6) anal somite and cadal rami (ventral).

& Defays, 1994; Mirabdullayev & Kuzmetov, 1997; Shen & Tai, 1961; Tai & Chen, 1979)

Average length to the end of caudal rami 0.94 mm (*n*=20); range 0.85–1.05 mm. Antennulae reaching middle of prosomal somite 3. Lateral sides of pediger 5 without setules (Figure 1). Connecting plate of P4 bearing two rows of setules on the caudal surface. Both outgrowths on distal margin of connecting plate of P4 prominent, rounded and ornamented with three to six spinules. Caudal armature of P4 coxopodite presenting a row of spinules (7–12) near the medial distal rim, an oblique row of spinules (9–15) inserted on lateral distal part and a row of minute spinules near the proximal rim (Figure 2). A row of spinules (6–8) on the frontal surface of P4 coxopodite inserted on the lateral distal rim (Figure 3). The medial edge of P4 basipodite without hairs, whereas P1–P3 with hairs. Enp3 P4 2.80–3.1 times as long as wide, the medial apical spine 3.25–4.5 times as long as the lateral one and longer than the segment (Figure 2). Lateral arms of the R.S. slender and strongly curved backwards (Figure 1). The medial spine and lateral seta on the terminal segment of P5 with similar length (Figure 4). The L/W ratio of caudal rami 2.58–3.3. The lateral and external terminal setae of caudal rami without spinules at their base (Figures 5 and 6).

Remarks: Thermocyclops taihokuensis is common and widespread in China except for the Qinghai–Tibet Plateau and easily distinguished from other species of *Thermocyclops* by its unique lateral arms of R.S., the ratio of apical spines of Enp3P4 and the connect-



Figures 7–12. Thermocyclops crassus. Female: (7) pediger 5 and genital somite; (8) right P4 with connecting plate (caudal); (9) connecting plate, coxopodite and basipodite of P4 (frontal); (10) P5; (11) anal somite and caudal rami (ventral); (12) anal somite and caudal rami with setae (dorsal).

ing plate, coxopodite and basipodite of P4. Variations mainly displaying the proportion of caudal rami and apical spines of Enp3 P4. Although *Thermocyclops mongolicus* Kiefer, 1937 synonymized with *Thermocyclops vermifer* (Lindberg, 1935) by Lindberg (1961), this species described by Tai & Chen (1979) is not *T. vermifer* but *T. taihokuensis*. Based on the description and the figures of *T. mongolicus* (Tai & Chen, 1979), the lateral arms of the R.S. are slender and strongly curved backwards, connecting plate of P4 with two rows of setules on caudal surface and the proportions of the apical spines of Enp3 P4 and caudal rami are 2.45–2.84 and 2.73–3.00 respectively. All of these features are typical of *T. taihokuensis*. Ueda et al (1997) also mentioned a description of *T. mongolicus* by Tai & Chen (1979), which apparently is within the range of variation of *T. taihokuensis* as described by Kawabata & Defaye (1994), such as the proportions of the caudal rami and the apical spines of the Enp3 P4.

Remarks: Thermocyclops *crassus (Fischer, 1853)*

Cyclops crassus Fischer, 1853

Cyclops hyalinus Rehberg, 1880

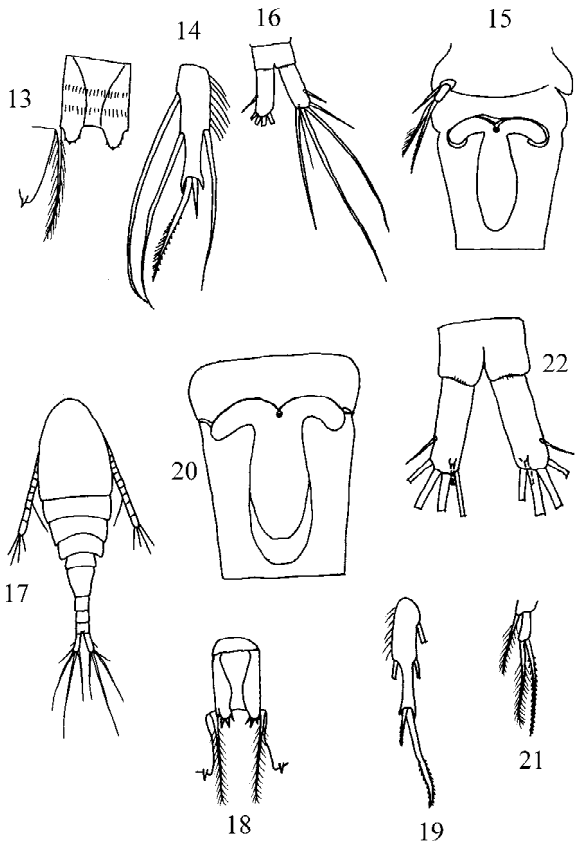
Mesocyclops (*Thermocyclops*) *brevifurcatus* Harada, 1931

Thermocyclops crassus Löffler, 1961 (Dussart, 1969; Mirabdullayev & Kuzmetov, 1997)

Thermocyclops hyalinus Tai & Chen, 1979

Thermocyclops brevifurcatus Tai & Chen, 1979

The average length to the end of caudal rami 0.88 mm (*n*=20); range 0.78–0.98 mm. Antennulae reaching the distal margin of prosomal somite 2. The pediger 5 with a longitudinal row of minute spinules on both of lateral sides (Figure 7). Connecting plate of P4 with two rows of setules on caudal surface. Well developed outgrowths on the distal margin of the connecting plate of P4 prominent and ornamented with two to six relatively large spinules. A row of spinules (about 20) inserted on medial distal part of P4 coxopodite caudally (Figure 8) and intermittent rows of



Figures 13–22. Thermocyclops vermifer. Female: (13–17 copy from Mirabdullayev & Kuzmetov, 1997) (13) connecting plate of P4 (caudal); (14) Enp3 P4; (15) pediger 5 with P5 and genital somite; (16) anal somite and caudal rami with setae (ventral); (17) habitus. (18–22 copy from Lindberg 1942) (18) connecting plate of P4; (19) Enp3 P4; (20) genital somite; (21) P5; (22) anal somite and caudal rami (ventral).

spinules inserted on distal rim frontally (Figure 9). The medial edge of P1–P4 coxopodite with hairs. Enp3 P4 3.00–3.23 times as long as wide, the medial apical spine 1.88–2.25 times as long as the lateral one and shorter than the segment (Figure 8). The lateral arms of R.S. broad and hardly curved backwards (Figure 7). The medial spine on the terminal segment of P5 1.05–1.16 times as long as the lateral seta (Figure 10). The L/W ratio of caudal rami 2.18–2.49. The lateral and external terminal setae of caudal rami without spinules at their base (Figures 11 and 12).

Remarks: *Thermocyclops hyalinus* (Rehberg, 1880) and *Thermocyclops brevifurcatus* (Harada, 1931) have been affirmed as a synonyms of *Thermocyclops crassus* (Fischer, 1853) (Herbst, 1986). *T. crassus* is common and widespread in any aquatic habitat of China except for Qinghai–Tibet plateau. It also occurs in other countries of Asia, Europe, Africa, North America. Many researchers (Dussart, 1969, 1982; Dussart & Defays, 1985; Herbst, 1986; Jeje, 1988; Kiefer, 1978; Lim & Fernando, 1985; Löffler, 1961; Mirabullayev & Kuzametov, 1997; Ueda et al., 1997) described this species. It is easy to distinguish *T. crassus* from other species of *Thermocyclops* by the combination of the following characteristics morphology of the R.S., both sides of pediger 5 with minute spinules, both outgrowths on the connecting plate of P4 armed with several large spinules, medial edge of coxopodite of P4 with hair-setae.

Remarks: Thermocyclops *vermifer (Lindberg, 1935)*

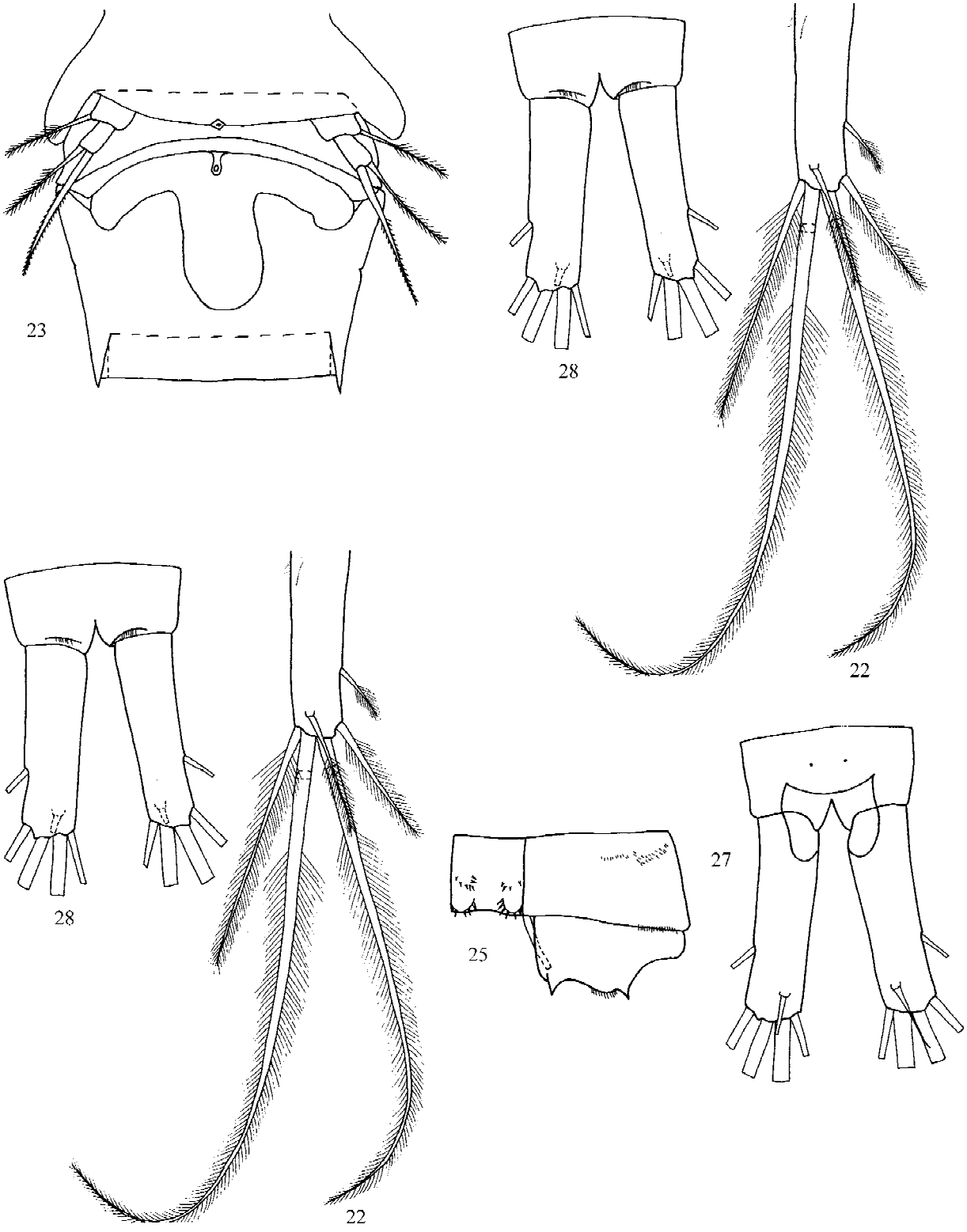
Mesocyclops rylovi var *vermifer* Lindberg, 1935
Mesocyclops vermifer Lindberg, 1938, 1939
Mesocyclops (*Thermocyclops*) *vermifer* Lindberg, 1942
Thermocyclops rylovi vermifer Lindberg, 1950, 1959
Thermocyclops rylovi cf. *vermifer* Löffler, 1961
Thermocyclops vermifer Tai & chen, 1979

Average length to the end of caudal rami 0.92 mm (*n*=28); range, 0.78–1.08 mm (Figure 17). Connecting plate of P4 with two rows of setules on caudal surface (Figure 13). Both outgrowths on the distal margin of the connecting plate of P4 prominent, rounded and ornamented with three to seven spinules (Figures 13 and 18). Enp3 P4 2.32–4.00 times as long as wide, the medial apical spine 1.89–2.83 times as long as the lateral one (Figures 14 and 19). Lateral arms of R.S. are relatively slender and slightly curved backwards (Figures 15 and 20). The medial spine on the terminal segment of P5 0.96–1.40 times as long as the lateral seta (Figures 15 and 21). The L/W ratio of caudal rami 2.48–3.32 and the internal seta (Si) is mostly 2.7–3.0 times as long as external seta (Se) (Figures 16 and 22).

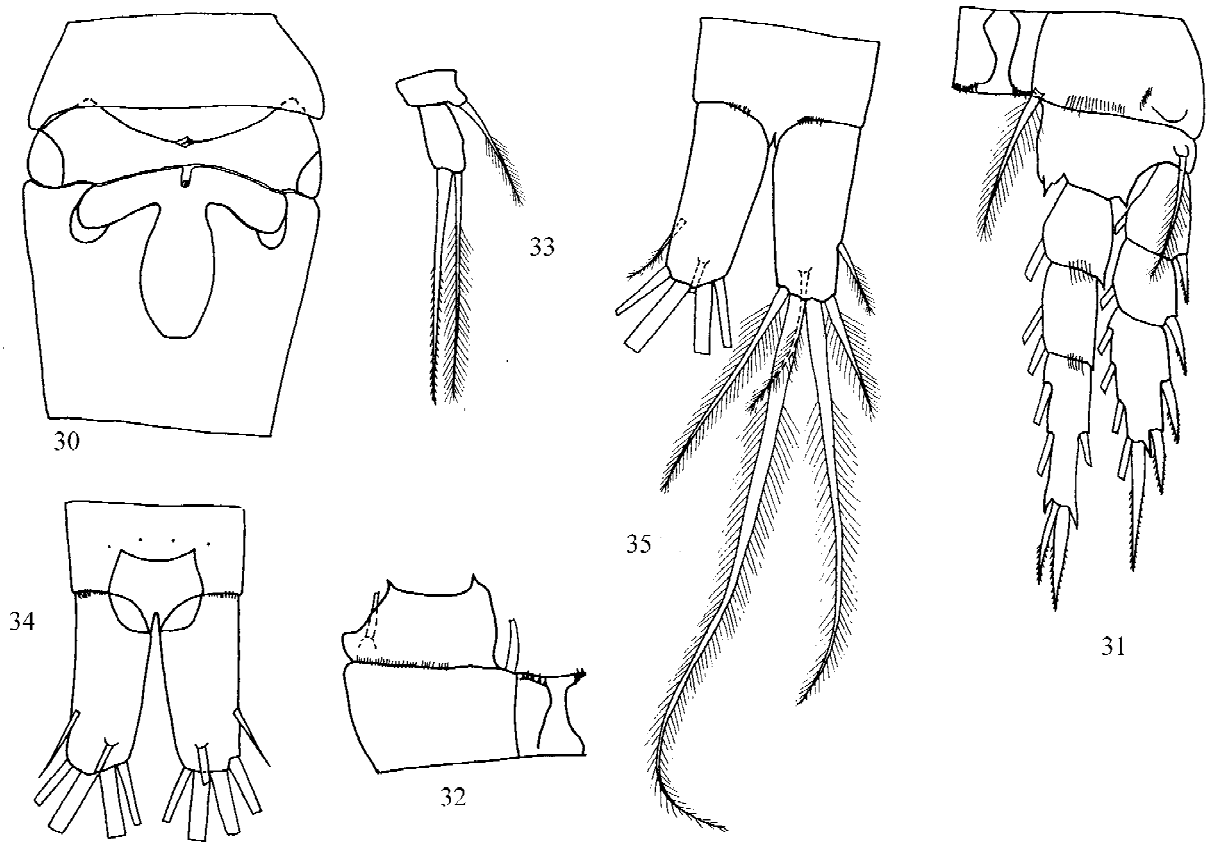
Remarks: This species has not been observed by the author. The above description is based on Lindberg (1935, 1938, 1942) and Mirabdullayev & Kuzmetov (1997). According to Tai & Chen (1979), this species was recorded from Sichuan, Yunnan, Hunan, Jiangxi, Zhejiang, Hubei, Shandong, Hebei and Tianjin of China.

Thermocyclops kawamurai *(Kikuchi, 1940)*

Mesocyclops (*Thermocyclops*) *kawamurai* Kikuchi, 1940



Figures 23–29. Thermocyclops kawamurai. Female: (23) pediger 5 and genital somite; (24) right P4 with connecting plate (caudal); (25) connecting plate, coxopodite and basipodite of P4 (frontal); (26) P5; (27) anal somite and caudal rami (dorsal); (28) anal somite and caudal rami (ventral); (29) right caudal ramus with setae (dorsal).



Figures 30–35. Thermocyclops dybowskii Female: (30) pediger 5 and genital somite; (31) right P4 with connecting plate (caudal); (32) connecting plate, coxopodite and basipodite of P4 (frontal); (33) P5; (34) anal somite and caudal rami (dorsal); (35) Anal somite and caudal rami with setae (ventral).

Thermocyclops kawamurai Tai & Chen, 1979

Average length to the end of caudal rami 1.06 mm (*n*=10); range, 0.92–1.22 mm. The antennulae reaching the distal margin of prosomal somite 2. Both sides of pediger 5 without setules (Figure 23). Connecting plate of P4 bearing a rows of spinules (9–11) on the caudal surface (Figure 24) and intermittent group of spinules (3–4 + 5–7) on the frontal surface (Figure 25). Both outgrowths on the connecting plate of P4 ornamented with five to eight relatively large spinules and not reaching beyond the distal margin (Figures 24 and 25). Caudal armature of P4 coxopodite presenting a row of spinules (9–11) near the medial distal rim, a row of spinules (6–8) is inserted on lateral distal corner and two rows of spinules near the lateral proximal part (Figure 24). On the frontal surface of P4 coxopodite, an irregular row of minute spinules are inserted on the lateral distal part and a row of spinules on the lateral distal rim (Figure 25). The medial edge of P4 basipodite without hairs. Enp3 P4 3.00–3.24 times as long as wide, the medial apical spine equal to or slightly longer than the lateral one and shorter than the segment (Figure 24). Relatively long lateral arms of R.S. curved posteriorly (Figure 23). The medial spine on the terminal segment of P5 1.3–1.4 times as long as the lateral seta (Figure 26). The L/W ratio of caudal rami 3.21–3.54. The lateral and external terminal setae of caudal rami without spinules at their base (Figures 27 and 28). The Si 1.93 times as long as the Se and 2.20 times as long as the Sd. The Se 1.14 times as long as the Sd (Figure 29).

Remarks: Thermocyclops kawamurai is easily distinguished by its connecting plate of P4, the proportion of apical spines of Enp3 P4 and the caudal rami. This species lives mainly in lakes and ponds with freshwater, temporary water, brackish or alkaline water of northern China such as Heilongjiang, Jilin, Inner Mongolia, Ningxia, Shanxi, Shaanxi, Hebei, Xinjiang. According to Tai & Chen (1979), this species was

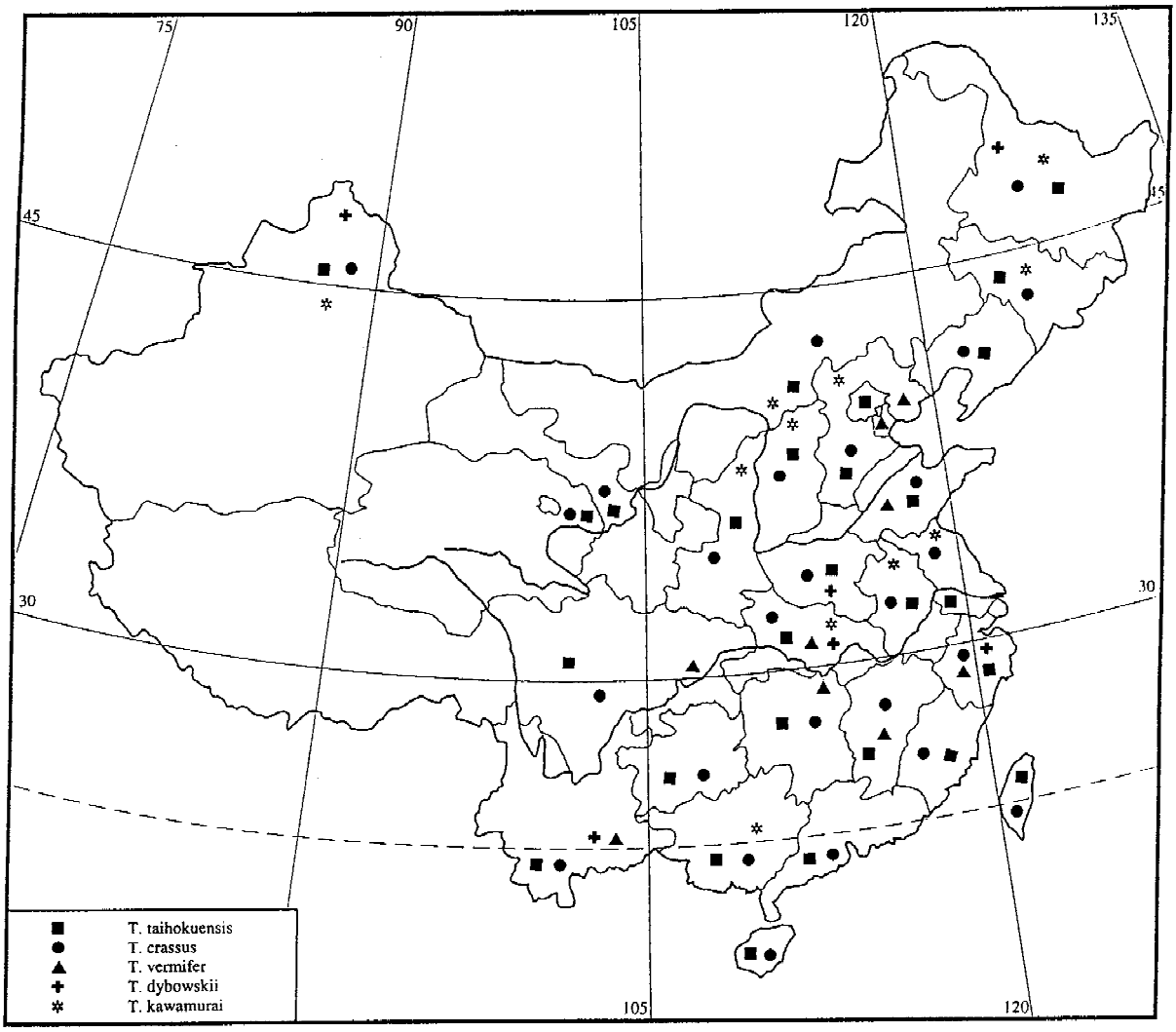


Figure 36. Distribution of *Thermocyclops* in China

recorded from southern China such as Hubei, Anhui, Jiangsu. The author recently also obtained this species from Guangxi province.

Remarks: Thermocyclops dybowskii *(Lande, 1890)*

Cyclops dybowskii Lande, 1890

Mesocyclops dybowskii Sars, 1918

Mesocyclops (*Thermocyclops*) *dybowskii* Kiefer, 1929

Thermocyclops dybowskii Kiefer, 1960, 1978; Einsle, 1970; Dussart, 1969; Tai & Chen, 1979

The average length to the end of caudal rami 0.98 mm (*n*=10); range, 0.90–1.19 mm. The antennulae reaching the middle of prosomal somite 2. Both sides of pediger 5 without setules (Figure 30). Connecting plate of P4 without setules. Both outgrowths on the connecting plate of P4 ornamented with five to six large spinules and not reaching beyond the distal margin (Figures 31 and 32). Caudal armature of P4 coxopodite presenting a row of spinules (16–18) near the distal rim and an oblique row of spinules (6–8) inserted on lateral distal part (Figure 31). On the frontal surface of P4 coxopodite, a row of spinules is inserted on the distal margin (Figure 32). The medial edge of P4 basipodite without hairs. Enp3 P4 3.25–3.40 times as long as wide, the lateral apical spine 1.25–1.40 times as long as the medial one and shorter than the segment (Figure 31). Relatively long lateral arms of R.S. curved posteriorly (Figure 30). The medial spine on the terminal segment of P5 is mostly as long as the

lateral seta (Figure 33). The L/W ratio of caudal rami 2.35–2.50. The lateral and external terminal setae of caudal rami without spinules at their base (Figures 34 and 35).

Remarks: Thermocyclops dybowskii is closely related to *Thermocyclops kawamurai* but easily distinguished by the apical spines of Enp3 P4, where the lateral spine is longer than the medial one. This species occurs in Heilongjiang, Xinjiang, Henan, Hubei, Zhejiang, Yunan.

Remarks: Identification key for females of Thermocyclops

(1) P4 connecting plate: both outgrowths reach beyond distal margin 2
P4 connecting plate: both outgrowths not reaching beyond distal margin 4

(2) Receptaculum seminis (R.S.): lateral arms strongly curved backwards and medial apical spine of Enp3 P4 more than three times as long as lateralone ..... *T. taihokuensis* Harada, 1931
Receptaculum seminis (R.S.): lateral arms not or only slightly curved backwards and medial apical spine of Enp3 P4 less than three times as long as lateral one 3

(3) Receptaculum seminis (R.S.): lateral arms broad and almost not curved backwards, and medial apical spine of Enp3 P4 1.8–2.2 times as long as lateral one ..... *T. crassus* (Fischer, 1853)
Receptaculum seminis (R.S.): lateral arms relatively slender and slightly curved backwards and medial apical spine of Enp3 P4 1.89–2.83 times as long as lateral one ..... *T. vermifer* (Lindberg, 1935)

(4) The medial apical spine of P5 longer than the lateral apical seta and medial apical spine of Enp3 P4 equal to or slightly longer than the lateral one .. *T. kawamurai* Kikuchi, 1940
The medial apical spine of P5 as long as the lateral apical seta or slightly shorter and the lateral apical spine of Enp3 P4 about 1.2 times as long as the medial one ..... *T. dybowskii* (Lande, 1891)

Discussion

Thermocyclops are mainly identified on females. The usual taxonomic characters are: size and shape of receptaculum seminis (R.S.); outgrowths of the connecting plate of P4 and their armature; armature of connecting plate, coxopodite and basipodite of P4; the third segment of endopodite of P4 (Enp3 P4); pediger 5; the appendages of P5; the proportion of the terminal spines of Enp3 P4 and of the caudal rami; relative length of caudal setae.

The present study of *Thermocyclops* of China shows that *T. taihokuensis*, *T. crassus*, *T. kawamurai* and *T. dybowskii* can be confirmed, whereas *T. vermifer* has not been seen by the author so far. *T. vermifer* has been recorded from India, Afghanistan, Iran, Uzbekistan, Tadjikistan and southern Russia (the delta of the River Volga). *T. asiaticus* Kiefer, 1932 from Manchuria has been found to be a synonym of *T. taihokuensis* Harada, 1931 (Dussart & Defaye, 1985; Shen et al., 1979). Another species, *T. oithonoides* Sars, 1863, was recorded from Wuli lake, Jiangsu province of China (no record from Hebei, China) by Shen & Tai (1962) and Shen & Sung (1965). However, based on my examination, I never found this species in Wuli lake where only *T. taihokuensis* and *T. crassus* exist. Likewise, Shen et al. (1979) also did not record this species in China (Figure 36).

Dussart & Fernando (1985) described *Thermocyclops orientalis* from Sri Lanka as a new species. Subsequently, Defaye et al. (1987) considered it as a synonym of *Thermocyclops kawamurai*. However, a comparison of both species shows several conspicuous differences, for example, Enp3 P4 is long, narrow and 3.00–3.24 times as long as broad in *T. kawamurai*, whereas this segment in *T. orientalis* is short, broad and only 2.0 times as long as broad; the two species have different proportions of the caudal setae such as: the internal (Si) versus the external (Se) and the dorsal (Sd). According to Tai & Chen (1979), the structure of male P6 of *T. kawamurai* is also different from that of *T. orientalis*, with a medial spine 2 times as long as the median seta and with similar length as the lateral seta in *T. kawamurai*, whereas *T. orientalis* has a medial spine of similar length with the median seta and the medial spine is about half as long as the lateral seta. Other structures between both species are probably different such as P5, the proportion of apical spines of Enp3 P4, the armatures of the connecting plate and coxopodite of P4. Based on this comparison, it is im-

possible to consider *T. orientalis* as the synonym of *T. kawamurai*.

Reid (1989) remarked that at least in mesotrophic and eutrophic conditions, some species of *Thermocyclops* may maintain high populations relative to those of other herbivorous copepods by gaining a significant portion of their food from blooms of blue-green algae which most other cyclopoid and calanoid copepods are unable to exploit. *T. taihokuensis* and *T. crassus* not only occur over a wide range of habitats, but they are frequently abundant in eutrophic lakes and fish ponds. In contrast to these species, *T. kawamurai* and *T. dybowskii* have a limited distribution and occur at low densities. Coexistence of *Thermocyclops* species was not frequently encountered, with rare two species coexisting in the same environment. Usually, only one species is present.

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