

**THE FRESHWATER COPEPOD GENUS *Mesocyclops*
(Copepoda, Cyclopoida, Cyclopidae) IN VIETNAM**

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ABSTRACT

The freshwater copepod *Mesocyclops* Sar, 1914, a species-rich genus within the family Cyclopidae Rafinesque, 1815, is common in tropical areas. In addition, the genus members are used for the biological control of mosquito larvae (*Anopheles*, *Aedes*) which are vectors for transmitting dengue fever. In Vietnam, a total of 11 *Mesocyclops* species have been recorded in inland freshwater bodies. Of which, one endemic species (*M. sondoongensis* Tran & Holyńska, 2015) and two species were described from Vietnam, namely *M. yena* Holyńska, 1998; *M. ferjemurami* Holyńska & Vu, 2000. Diagnostic characteristics, habitat, and distribution of all 11 species are provided. Additionally, a pictorial key to all Vietnamese *Mesocyclops* is presented.

Keywords: Cyclopidae, *Mesocyclops*, biodiversity, pictorial key, taxonomy, Vietnam.

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INTRODUCTION

In the family Cyclopidae, the genus *Mesocyclops* Sar, 1914 is considered to be a cosmopolitan group, but more dominant in the tropics and more common in eutrophic water bodies. To date, 79 *Mesocyclops* species have been described (Hołyńska, 1997, 2000, 2006; Karanovic, 2006; Hołyńska and Stoch, 2012; Alekseev et al., 2013; Papa and Hołyńska, 2013; Tran and Hołyńska, 2015).

Many studies indicated that *Mesocyclops* species can kill larvae of *Anopheles* spp., *Aedes* spp. (Marten et al., 1989, 1994; Vu Sinh Nam et al., 1998). Thus, they are often used as biological control agents of mosquito larvae which is known as vectors for dengue transmission in Mexico, Brazil, Australia, India and Vietnam (Marten et al., 1989, 1994; Vu Sinh Nam et al., 1998, 2000, 2004).

In Vietnam, based on the species characteristics of the genus *Mesocyclops* as described by Sars (1914), Kiefer (1927) and Rylov (1948), Dang Ngoc Thanh (1977, 1980), Dang Ngoc Thanh et al. (1980, 2002) recorded only one species of *Mesocyclops leuckarti* (Claus, 1857) in inland freshwater bodies of Vietnam. However, Kiefer (1981) indicated that *M. leuckarti* was only distributed in the Palaearctic region including Europe, Russia, North China, South Korea and Japan, not extending to the tropic area. Compared to the diagnosis of *M. leuckarti* proposed by Kiefer (1981), the description and drawings by Dang Ngoc Thanh et al. (1980, 2002) has significant differences in antennule, caudal rami, thoracopod and especially seminal receptacles in females. These differences suggested that the presence of this species in Vietnam could be questionable.

Research on the genus *Mesocyclops* has been conducted in Vietnam on both taxonomic and applied aspects. In a joint project with the Central Institute of Hygiene and Epidemiology in Hanoi on the use of *Mesocyclops* in the biological control of *Aedes* (mosquitoes transmitting dengue fever) in Vietnam, Hołyńska (1997, 1998), and Hołyńska & Vu (2000) recorded 9 species of

the genus *Mesocyclops* in freshwater of Vietnam, including: *Mesocyclops affinis* Van de Velde, 1987; *M. aspericornis* (Daday, 1906); *M. feriemurami* Hołyńska & Vu, 2000; *M. ogunnus* Onabamiro, 1957; *M. pehpeiensis* Hu, 1943; *M. shenzhenensis* Guo, 2000; *M. thermocyclopoides* Harada, 1931; *M. yенаe* Hołyńska, 1998 and *M. woutersi* Van de Velde, 1987. Of which, two were described as new to science: *M. yенаe* Hołyńska, 1998 from Hai Phong City and *M. feriemurami* Hołyńska & Vu, 2000 from Khanh Hoa Province. Hołyńska (1997, 1998, 2000) used the system of diagnostic features of the genus *Mesocyclops* of Van de Velde (1984) which was verified and now widely accepted in the world. Recently, Tran & Hołyńska (2015) described *M. sondoongensis* from the Son Doong cave, Quang Binh Province.

In studies following the diagnostics of the genus *Mesocyclops* proposed by Dang Ngoc Thanh et al., 1980, most specimens collected in Vietnam were identified as *M. leuckarti* (Claus, 1857) or *Mesocyclops* spp. (Hoang Dinh Trung & Phan Doan Dang, 2011; Vo Van Phu & Hoang Dinh Trung, 2012; Phan Doan Dang et al., 2015; Le Thi Nguyet Nga & Phan Doan Dang, 2013, 2015a,b, 2019). This resulted in the confusion and misunderstanding of the zooplankton biodiversity of Vietnam, and could caused mistakes in selecting biological control agents.

The paper aims to provide an updated review and identification key of the genus *Mesocyclops* in Vietnam, which will also facilitate further research on freshwater copepods of Vietnam.

MATERIALS AND METHODS

Freshwater copepod specimens were collected from various localities in Vietnam during the period of 2005–2019, using a 100 µm mesh-sized plankton net. Samples were fixed and stored in 70% ethanol and deposited in the Department of Aquatic Ecology, Institute of Ecology and Biological Resources (IEBR), Ha Noi, Vietnam. The specimens were observed with a differential interference contrast microscope (Nikon Eclipse Ni-U).

Illustrations were made with the aid of a camera lucida attached to the microscope. The following abbreviations are used, where required, throughout the text and figures: Endp = endopod; Exp = exopod; P1–P5 = swimming legs 1–5.

RESULTS AND DISCUSSION

Species composition

A total of 11 *Mesocyclops* species are recognized from inland freshwater bodies of Vietnam (Table 1). Of which, one species is considered to be endemic to Vietnam, *M. sondoongensis* Tran & Hołyńska, 2015 and two species (*M. yena* Hołyńska, 1998, *M. ferjemurami* Hołyńska & Vu, 2000) were described for the first time from Vietnam's copepod fauna.

Table 1. List of species and distribution of the genus *Mesocyclops* in Vietnam

STT	Taxon	Geographic distribution in Vietnam						
		I	II	III	IV	V	VI	VII
1	<i>Mesocyclops affinis</i> Van de Velde, 1987	+	+	+		+	+	+
2	<i>Mesocyclops aspericornis</i> (Daday, 1906)	+	+	+	+	+	+	+
3	<i>Mesocyclops augusti</i> Papa & Hołyńska, 2013	+						
4	<i>Mesocyclops dissimilis</i> Defaye & Kawabata, 1993	+	+	+				
5	<i>Mesocyclops ferjemurami</i> Hołyńska & Vu, 2000						+	
6	<i>Mesocyclops ogunnus</i> Onabamiro, 1957	+		+			+	+
7	<i>Mesocyclops pehpeiensis</i> Hu, 1943	+	+	+	+	+	+	+
8	<i>Mesocyclops sondoongensis</i> Tran & Hołyńska, 2015*				+			
9	<i>Mesocyclops thermocyclopoides</i> Harada, 1931	+	+	+			+	+
10	<i>Mesocyclops woutersi</i> Van de Velde, 1987	+	+	+	+	+	+	+
11	<i>Mesocyclops yena</i> Hołyńska, 1998	+		+				

Abbreviations: I. Northeast region; II. Northwest region; III. Red River delta and North Central coast regions; IV. North Central mountains region; V. Central highlands region; VI. South Central coast; VII. Mekong River delta; * Species endemic in Vietnam.

Taxonomic part

Order Cyclopoida Burmeister, 1834

Family Cyclopidae Rafinesque, 1815

Subfamily Cyclopinæ Rafinesque, 1815

Genus *Mesocyclops* Sars, 1914

Typ species: *Cyclops leuckarti* Claus, 1857

Synonyms: *Cyclops* (*Mesocyclops*) Gurney, 1933: 286–287; *Mesocyclops* (*Mesocyclops*) Rylov, 1948: 292–293.

Diagnosis: Medium size Cyclopidae, cephalothorax oval or slightly elongated. Genital double-somite trapezoidal, slightly shrunk back. Seminal receptacle “T”-shaped, distal part dilated and almost sac-like. Caudal ramus cylindrical with two rami often parallel. Antennule 17-segmented, last segment ornamented with serrate hyaline membrane, with or without large notch. P1–P4 with 3-

segmented rami. P1 basipodite with or without medial spine. P5 2-segmented, terminal segment with apical long seta and long inner spine.

In Vietnam, 11 species of this genus are currently known to be present.

Mesocyclops affinis Van de Velde, 1987

Mesocyclops affinis Van de Velde, 1987: 151–156, figs 15–27; Hołyńska, 200: 400–405, figs 25–27.

Mesocyclops thermocyclopoides acutus Dussart & Fernando, 1988: 254–255, figs 43–50; Red & Kay, 1992: 340–341, figs 4a–d. Synonymized by Hołyńska (1994).

Mesocyclops thermocyclopoides-Dussart & Fernando, 1988 [partim]: 245–246, figs 8–10.

Type locality: A bomb hole, Madang Province, Papua New Guinea (Van de Velde, 1987).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule pattern of antennary basipodite with an oblique row of tiny spinules starting at distal third of medial rim, group of short spinules near implantation of medial setae, group of relatively large spinules at laterodistal angle, spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base. Frontal surface of maxillary coxopodite bearing a distinct row of spinules. P1 basipodite lacking medial spine; medial expansion of basipodite of P1–P4 with apical hairs; distal margin of P4 coupler with two small obtuse or acute outgrowths. Pediger 5 with only soft pilose laterally. Genital double-somite without hairs. Lateral arms of seminal receptacle wide and short; transverse ducts directed to each other at straight or nearly straight angle (not V-shaped) before connection with copulatory duct; copulatory duct straight or slightly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal setae present or absent and at implantation of lateralmost terminal setae always present; medialmost terminal seta about 2.5–3.5 times as long as lateralmost terminal seta.

Specimens examined: 15 ♀♀, 10 ♂♂ (IEBR-MESO-09-04), Sai Gon river, Ho Chi Minh City, VI. 2009, Tran D.L. leg.; 10 ♀♀, 6 ♂♂ (IEBR-MESO-11-01), a fish pond, Quang Nam Province, VII. 2011, Tran D.L. leg.; 20 ♀♀, 25 ♂♂ (IEBR-MESO-12-05), Cau river, Thai Nguyen Province, VIII. 2012, Tran D.L. leg.; 5 ♀♀, 1 ♂ (IEBR-MESO-15-10), Nhue river, Ha Nam Province, X. 2015, Nguyen T.C. leg.; 14 ♀♀, 5 ♂♂ (IEBR-MESO-19-01), Krong Kmar reservoir, Dak Lak Province, III. 2019, Dang V.D. leg.

Ecology: This species has been found in aquaculture ponds, reservoirs, lakes and rivers.

Records from Vietnam: Lai Chau, Ha Giang, Thai Nguyen, Phu Tho, Ha Nam, Nghe An, Quang Nam, Ninh Thuan, Dak Lak, Ho Chi Minh City, Kien Giang (this study), Bac

Giang, Phu Tho, Hung Yen, Hai Phong, Nam Dinh, Ha Noi, Nghe An, Ha Tinh, Thua Thien-Hue, Da Nang, Khanh Hoa, Ho Chi Minh City, Dong Nai (Vu et al., 2000).

Distribution: Papua New Guinea (Van de Velde, 1987), Indonesia, Malaysia (Hołyńska, 2000).

***Mesocyclops aspericornis* (Daday, 1906)**

Cyclops aspericornis Daday, 1906: 181–184, Pl. 14, figs 1–6.

Mesocyclops aspericornis-Kiefer, 1981: 172–173, Pl. 10; Van de Velde, 1984: 42–45, figs 28–29; Lim & Fernando, 1985: 83, figs 54–56; Hołyńska, 2000: 392–398, figs 20–23; Gutiérrez-Aguirre et al., 2003: 1349–1361, figs 1–6.

Mesocyclops leuckarti-Kiefer, 1938: 60, figs 27–29.

Mesocyclops iranicus Lindberg, 1936: 12–16, figs 17–21. Synonymized by Ghenne & Fiers (2000).

Type locality: Bogor, Indonesia (Daday, 1906).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch at 1/3 distal part. Caudal spinule ornamentation of antennary basipodite with an oblique row of small spines starting at distal third of inner margin, group of tiny spinules near implantation of medial setae, and a group of small spinules between proximal oblique and longitudinal spinule rows. Frontal surface of maxillary coxopodite bearing a distinct row of hair-like spinules. P1 basipodite without medial spine; medial expansion of basipodite of P1–P4 with apical hairs; distal margin of P4 coupler bearing two small, triangular outgrowths. Pediger 5 with soft hairs laterally. Genital double-somite without hairs. Lateral arms of seminal receptacle wide and elongate; transverse ducts directed to each other at acute angle (V-shaped) before connection with copulatory duct; copulatory duct slightly curved. Caudal rami with medial hairs; spinules at implantation of lateral caudal and

lateralmost terminal setae present; medialmost terminal seta about 1.2–1.4 times as long as lateralmost terminal seta.

Specimens examined: 10 ♂♂, 30 ♀♀ (IEBR-MESO-09-02), Cau river, Thai Nguyen Province, IV. 2009, Tran D.L. leg.; 5 ♀♀ (IEBR-MESO-09-03), Nhue river, Ha Nam Province, IV. 2009, Tran D.L. leg.; 20 ♀♀, 15 ♂♂ (IEBR-MESO-09-16), Cai river, Kien Giang Province, XII. 2009, Tran D.L. leg.; 10 ♂♂, 10 ♀♀ (IEBR-MESO-18-07), Tram Chim National Park, Dong Thap Province, IX. 2018, Tran D.L. leg.

Ecology: This species has been found in various freshwaters bodies, such as aquaculture ponds, reservoirs, lakes and rivers, and especially favors the stagnant and eutrophic waters.

Records from Vietnam: Widely distributed.

Distribution: Thailand, Malaysia (Lim & Fernando, 1985), Indonesia (Daday, 1906; Dussart & Fernando, 1985), Philippines (Van de Velde, 1987; Hołyńska, 2000), Papua New Guinea (Van de Velde, 1987), Australia (Brown et al., 1991; Hołyńska & Brown, 2003), Ethiopia, Ghana, Nigeria (Van de Velde, 1984), Mexico, Colombia (Gutiérrez-Aguirre et al., 2003, 2006).

***Mesocyclops augusti* Papa & Hołyńska, 2013**

Mesocyclops augusti Papa & Hołyńska, 2013: 290–312; figs 2–6.

Type locality: Siloton lake, Mindanao, Philippines (Papa & Hołyńska, 2013).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule ornamentation of antennary basipodite with an oblique row of tiny spinules starting at distal third of inner margin, group of medium sized spinules near implantation of medial setae, spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base. Row of spinules present on frontal surface of

maxillary coxopodite. P1 basipodite lacking medial spine; medial expansion of basipodite of P1–P4 with apical hairs; outgrowths small and acute on distal margin of P4 coupler. Pediger 5 pilose laterally, naked dorsally. Genital double-somite without hairs. Lateral arms of seminal receptacle wide and short; transverse ducts directed to each other at obtuse angle (not V-shaped) before connection with copulatory duct; copulatory duct strongly curved. Hindgut on anal operculum with oblique field of short spinules, and 1-1 row of long spinules near anterior margin of caudal rami. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 2.6–2.8 times as long as lateralmost terminal seta.

Specimens examined: 5 ♀♀ (IEBR-MESO-17-06), Xa Huong lake, Tam Dao, Vinh Phuc Province, X. 2017, Nguyen T.C. leg.

Ecology: This species is found only in large freshwater bodies like lakes and reservoirs.

Records from Vietnam: Vinh Phuc (this study, Papa & Hołyńska, 2013).

Distribution: Philippines (Mindanao) (Papa & Hołyńska, 2013).

***Mesocyclops dissimilis* Defaye & Kawabata, 1993**

Mesocyclops dissimilis Defaye & Kawabata, 1993: 121–126, figs 1–25; Ueda, Ishida & Imai, 1997: 64–66, figs 22–37.

Type locality: Biwa lake, Japan (Defaye & Kawabata, 1993).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with two large notches at distal third of segment. Caudal spinule pattern of antennary basipodite with an oblique row of tiny spinules starting at distal third of inner margin, group of small spinules near implantation of medial setae, large spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral

spinules near base. Row of spinules present on frontal surface of maxillary coxopodite. P1 basipodite lacking medial spine; medial expansion of basipodite of P1–P4 with apical hairs; outgrowths small and acute on distal margin of P4 coupler. Pediger 5 with lateral hairs only. Genital double-somite without hairs. Seminal receptacle with wide and short lateral arms; transverse ducts directed to each other at acute angle (V-shaped) before connection with copulatory duct; copulatory duct strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 2.7–2.9 times as long as lateralmost terminal seta.

Specimens examined: 25 ♀♀, 15 ♂♂ (IEBR-MESO-08-06), Pa Khoang lake, Dien Bien Province, VI. 2008, Tran D.L. leg.; 50 ♀♀, 50 ♂♂ (IEBR-MESO-12-02), Bat Chat lake, Lai Chau Province, V. 2012, Tran D.L. leg.; 6 ♀♀, 6 ♂♂ (IEBR-MESO-13-16), Cau river, Bac Giang, IV, 2013, Nguyen D.T. leg.

Ecology: Aquaculture ponds, lakes and river deltas, hilly and mountainous areas.

Records from Vietnam: Dien Bien, Lai Chau, Thai Nguyen, Hai Duong, Vinh Phuc (this study); Vinh Phu? (Vu et al., 2000).

Distribution: Japan, China (Defaye & Kawabata, 1993; Guo, 2000).

***Mesocyclops ferjemurami* Holyńska & Vu, 2000**

Mesocyclops ferjemurami Holyńska & Vu, 2000: 197–206, figs 1–4.

Type locality: Nha Trang, Khanh Hoa Province, Vietnam (Holyńska & Vu, 2000).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch at distal third of segment. Caudal spinule pattern of antennary basipodite with an oblique row of tiny spinules starting at distal third of inner margin, group of small spinules near implantation of medial setae, a triangular group of spinules between the spinule group at height of medial setae and oblique row of

tiny spinules starting at distal half of medial rim, large spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base. Frontal surface of maxillary coxopodite without spinule ornamentation. P1 basipodite lacking medial spine; medial expansion of basipodite of P1–P4 with apical hairs; distal margin of P4 coupler with two large acute outgrowths. Pediger 5 and genital double-somite without hairs. Lateral arms of seminal receptacle elongated, transverse ducts meet at deep acute angle anterior to copulatory pore (V-shaped), copulatory duct slightly to strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 3.0 times as long as lateralmost terminal seta.

Specimens examined: 6 ♀♀ (IEBR-MESO-11-02), Tra Khuc river, Quang Ngai Province, VII. 2011, Tran D.L. leg.; 37 ♀♀, 12 ♂♂ (IEBR-MESO-18-03), a reservoir in Cu Lao Cham Island, Quảng Nam Province, III. 2018, Tran D.L. leg.

Ecology: Mainly inhabiting fish ponds and rivers in delta areas.

Records from Vietnam: Quang Nam, Quang Ngai (this study); Khanh Hoa (Holyńska & Vu, 2000).

Distribution: Thailand (Alekseev & Sanoamuang, 2006).

***Mesocyclops ogunnus* Onabamiro, 1957**

Mesocyclops ogunnus Onabamiro, 1957: 125–127, figs 7–12; Van de Velde, 1984: 31–36, figs 19–22; Dussart & Fernando, 1988: 250–251, figs 27–30; Reid & Kay, 1992: 338–339, figs 3d–f; Mirabdullayev, 1996: 96, figs 12–17; Holyńska, 1997: 27–30, fig. 4g; Holyńska, 2000: 398–400, figs 24a–f.

Type locality: Ogun river, Abeokuta, Nigeria (Onabamiro, 1957).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule pattern of antennary basipodite with an

oblique row of fine spinules starting at distal third of inner margin, row of large spinules near implantation of medial setae, spinules in longitudinal row near lateral margin, a row of oblique spinules next to long lateral spinules near base. Maxillary palp bearing a row of large spinules. Frontal surface of maxillary coxopodite bearing distinct a row of spinules. P1 basipodite without medial spine; medial expansion of basipodite of P1–P4 with apical hairs; distal margin of P4 coupler with two small obtuse or acute outgrowths. Pediger 5 pilose laterally and dorsally. Genital double-somite without hairs. Lateral arms of seminal receptacle wide and short; transverse ducts directed to each other at obtuse angle (not V-shaped) before connection with copulatory duct; copulatory duct strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal setae present or absent and at implantation of lateralmost terminal setae always present; medialmost terminal seta about 2.6–2.8 times as long as lateralmost terminal seta.

Specimens examined: 10 ♀♀, 5 ♂♂ (IEBR-MESO-12-01), Nhue river, Ha Nam, IV. 2012, Tran D.L. leg.; 8 ♀♀ (IEBR-MESO-14-07), Han river, Da Nang City, VIII. 2014, Tran D.L. leg.

Ecology: It lives in lakes, ponds and river deltas and hilly areas.

Records from Vietnam: Quang Ninh, Vinh Phuc, Ha Nam, Nghe An, Khanh Hoa, Dong Nai, Kien Giang (this study); Lang Son, Bac Giang, Hai Phong, Nam Dinh, Thua Thien-Hue, Da Dang, Khanh Hoa, Ninh Thuan, Ca Mau (Vu et al., 2000).

Distribution: Nigeria (Onabamiro, 1957; Van de Velde, 1984), Senegal, Mali, Mozambique, Ethiopia, Kenya (Van de Velde, 1984), Brazil (Reid and Pinto-Coelho, 1994), Uzbekistan (Mirabdullayev, 1996), China (Guo, 2000), Malaysia (Holyńska, 2000), Papua New Guinea (Holyńska, 2000), Thailand (Aleksiev & Sanoamuang, 2006).

***Mesocyclops pehpeiensis* Hu, 1943**

Mesocyclops leuckrti pehpeiensis Hu, 1943: 124–126, figs 2–4.

Mesocyclops pehpeiensis-Shen, 1956: 9, pl. 3, figs 26–29; Tai & Chen, 1979: 409–410, figs 247–248; Kawabata & Defaye, 1994: 151–153, figs 6–7; Guo, 2000: 34–35, figs 2–4.

Mesocyclops ruttneri Kiefer, 1981:178–180, fig. 14 (synonymized by Guo, 2000); Reid, 1993: 177–1983, figs 3–5; Mirabdullayev, 1996: 98–99, figs 23–26; Ueda, Ishida & Imai, 1997: 66–68, figs 38–50.

Type locality: Pehpei, Chongqing, China (Hu, 1943; Guo, 2000).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule ornamentation of antennary basipodite with an oblique row of tiny spinules starting at distal third of inner margin, a row of medium sized spinules near implantation of medial setae, large spinules in a longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base. Row of spinules present on frontal surface of maxillary coxopodite. P1 basipodite without medial spine; medial expansion of basipodite of P1–P3 with apical hairs, medial expansion of P4 basis naked; distal margin of P4 coupler with two large acute outgrowths. Pediger 5 and genital double-somite without hairs laterally and dorsally. Lateral arms of seminal receptacle short, transverse ducts meet at deep acute angle anterior to copulatory pore (V-shaped), copulatory duct strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 3.0 times as long as lateralmost terminal seta.

Specimens examined: 7 ♀♀, 3 ♂♂ (IEBR-MESO-06-11), Huong river, Thua Thien-Hue, VI. 2006, Tran D.L. leg.; 30 ♀♀, 20 ♂♂ (IEBR-MESO-10-07), Dak Ha reservoir, Kon Tum Province, VI, 2010, Tran D.L. leg.; 12 ♀♀, 2 ♂♂ (IEBR-MESO-12-08), Boi river, Hoa Binh Province, VII. 2012, Tran D.L. leg.; 40 ♀♀, 15 ♂♂ (IEBR-MESO-12-09), a fish pond, Viet Tri, Phu Tho, IX. 2012, Tran D.L. leg.; 22 ♀♀, 18 ♂♂ (IEBR-

MESO-18-08), Tram Chim National Park, Dong Thap Province, IX. 2018, Tran D.L. leg.; 23 ♀♀, 17 ♂♂ (IEBR-MESO-20-04) Vinh Cuu, Dong Nai Province, V.2020.

Ecology: It lives in lakes, ponds and river deltas and hilly areas.

Records from Vietnam: All provinces.

Distribution: Malaysia, Indonesia, Sri Lanka (Dussart & Fernando, 1985, 1988), India (Hołyńska et al., 2003), China (Hu, 1943; Tai & Chen, 1979; Guo, 2000), Japan (Kawabata and Defaye, 1994; Ueda, Ishida & Imai, 1997), Kazakhstan, Uzbekistan (Mirabdullayev et al., 1995; Mirabdullayev, 1996), Mexico (Suárez-Morales et al., 2005), Cuba (Menéndez Diaz et al., 2006), Thailand (Alekseev & Sanoamuang, 2006), USA (Reid, 1993; Connolly et al., 2019).

***Mesocyclops sondoongensis* Tran & Hołyńska 2015**

Mesocyclops sondoongensis Tran & Hołyńska, 2015: 661–686, figs 2–56.

Type locality: Son Doong cave, Phong Nha-Ke Bang National Park, Quang Binh, Vietnam (Tran & Hołyńska, 2015).

Diagnosis: Serrate hyaline membrane of the last antennular segment proximally extending to implantation of medial seta, without notch. Caudal surface ornamentation of antennal coxobasis with spinules in a longitudinal row along lateral margin not reaching height of insertion of exopodal seta; long curved row present, starting next to implantation of more proximal medial seta. Group of spinules present next to implantation of exopodite seta on frontal surface of antennal coxobasis. No spinules on frontal surface of maxillary coxopodite. P1 basipodite with medial spine; medial expansion of basipodite of P1–P3 with apical hairs, medial expansion of P4 basis naked; distal margin of P4 coupler with two small triangular-shaped outgrowths. Pediger 5 and genital double-somite without hairs laterally and dorsally. Seminal receptacle with narrow lateral arms, transverse ducts directed to each other at obtuse angle next to copulatory pore (not V-

shaped), copulatory duct short and slightly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 2.7 times as long as lateralmost terminal seta.

Specimens examined: 1 ♀ (holotype, IEBR-COP3410), 1 ♂ (allotype, IEBR-COP3411), 3 ♀♀ (paratypes, IEBR-COP3412–3414), 3 ♂♂ (paratypes, IEBR-COP3415–3417) and 25 ♀♀, 13 ♂♂ (IEBR-COP-AED04.13.025), Son Doong cave, Quang Binh Province, IV. 2013; Tran D. L. leg.; 46 ♀♀, 28 ♂♂ (IEBR-COP-AED04.13.026), Va cave, Quang Binh Province, IV. 2014, Tran D. L. leg.

Ecology: Living in underground water bodies in cave.

Records from Vietnam: Quang Binh (Son Doong cave, Va cave, Phong Nha-Ke Bang National Park, Quang Binh).

Distribution: Only known from Vietnam.

***Mesocyclops thermocycloides* Harada, 1931**

Mesocyclops thermocycloides Harada, 1931: 161–162, figs 23–25; Kiefer, 1981: 153, 162–165, fig. 2, fig. 5; Van de Velde, 1987: 156, figs 28–30; Hołyńska, 1994: 100–109, figs 1–5; Ueda & Ishida, 1997: 46–48, figs 4–5; Hołyńska, 2000: 431–436, figs 47a–e, figs 48a–d, fig. 49a; Gutiérrez-Aguirre et al., 2003: 352–363, figs 1–6.

Mesocyclops cf. thermocycloides-Dahm & Fernando, 1993: 9–18, figs 5–6.

Mesocyclops thermocycloides acutus Dussart & Fernando, 1988: 254, figs 43–50; Reid & Kay, 1992: 340–341, fig. 4.

Type locality: Candidius lake, Taiwan (Harada, 1931).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule ornamentation of antennary basipodite with an oblique row of tiny spinules starting at distal half of medial rim, a row of large spinules

near implantation of medial setae, large spinules in longitudinal row near lateral margin, a row of oblique spinules next to long lateral spinules near base. Frontal surface of maxillary coxopodite bearing a distinct row of spinules. P1 basipodite without medial spine; medial expansion of basipodite of P1–P4 with apical hairs; outgrowths of P4 coupler small, obtuse. Pediger 5 with dorsal and lateral soft hairs. Genital double-somite with dorsal hairs in anterior half. Seminal receptacle with lateral arms wide and short; transverse ducts directed to each other at straight or nearly straight angle (not V-shaped) before connection with copulatory duct; copulatory duct varies from slightly to strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae absent; medialmost terminal seta about 3.0 times as long as lateralmost terminal seta.

Specimens examined: 13 ♀♀, 5 ♂♂ (IEBR-MESO-08-11) temporary pond, Ninh Tru, Ninh Thuan, XI. 2008, Nguyen D.T. leg.; 50 ♀♀, 50 ♂♂ (IEBR-MESO-11-03), West lake, Ha Noi, VII. 2011, Tran D.L. leg.; 15 ♀♀, 5 ♂♂ (IEBR-MESO-13-19), Cau river, Thai Nguyen Province, IV. 2013, Nguyen D.T. leg.

Ecology: Wide variety of habitats, such as aquaculture ponds, reservoirs, lakes and rivers.

Records from Vietnam: Dien Bien, Phu Tho, Thai Nguyen, Quang Ninh, Ha Noi, Nghe An, Da Nang, Ninh Thuan, Can Tho (this study); Lang Son, Quang Ninh, Bac Ninh, Bac Giang, Hung Yen, Phu Tho, Ha Noi, Nam Dinh, Ha Tinh, Da Nang, Ninh Thuan, Khanh Hoa, Dong Nai, Can Tho, Kien Giang (Vu et al., 2000).

Distribution: Taiwan (Harada, 1931), Myanmar, Malaysia, Indonesia (Holyńska, 1994, 2000); Japan (Ueda & Ishida, 1997), Thailand (Sanoamuang, 2002); China (Guo, 2000), Mexico (Gutiérrez-Aguirre et al., 2003).

***Mesocyclops woutersi* Van de Velde, 1987**

Mesocyclops woutersi Van de Velde, 1987: 156–157, figs 31–44; Holyńska, 2000: 414–418, figs 35–37.

Mesocyclops guangxiensis Reid & Kay, 1992: 332–338, figs 1–2 (Synonymized by Holyńska, 1997).

Type locality: Coral gravel-pit, Madang Province, Papua New Guinea (Van de Velde, 1987).

Diagnosis: Serrate hyaline membrane on last antennular segment extending far beyond implantation of medial seta of segment, with one large notch. Caudal spinule pattern of antennary basipodite with an oblique row of tiny spinules starting at distal third of inner margin, group of short spinules near implantation of medial setae, large spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base. Frontal surface of maxillary coxopodite bearing distinct a row of spinules. P1 basipodite lacking medial spine; medial expansion of basipodite of P1–P4 with apical hairs; distal margin of P4 coupler with two small obtuse or acute outgrowths. Pediger 5 with lateral hairs only. Genital double-somite without hairs. Seminal receptacle with wide and short lateral arms; transverse ducts directed to each other at acute angle (V-shaped) before connection with copulatory duct; copulatory duct strongly curved. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae absent; medialmost terminal seta about 3.0 times as long as lateralmost terminal seta.

Specimens examined: 20 ♀♀, 12 ♂♂ (IEBR-MESO-09-05), Nui Coc reservoir, Thai Nguyen Province, VI. 2009, Tran D.L. leg.; 20 ♀♀, 20 ♂♂ (IEBR-MESO-12-13), Bien Ho lake, Gia Lai Province, X. 2012, Tran D.L. leg.; 50 ♀♀, 30 ♂♂ (IEBR-MESO-14-03), Son river, Quang Binh Province, IV. 2014, Tran D.L. leg.; 10 ♀♀, 6 ♂♂ (IEBR-MESO-16-06), ricefield, Tu Ki, Hai Duong Province, X. 2016, Dang V.D. leg.; 20 ♀♀, 7 ♂♂ (IEBR-MESO-18-09), Tram Chim National Park, Dong Thap Province, IX. 2018, Tran D.L. leg.

Ecology: This species has been found in various freshwaters bodies, such as

aquaculture ponds, reservoirs, lakes and rivers, and especially favors the stagnant and eutrophic waters.

Records from Vietnam: All provinces.

Distribution: Papua New Guinea (Van de Velde, 1987; Hołyńska, 2000), Laos (Reid & Kay, 1992), China (Guo, 2000), Japan, Australia (Hołyńska & Brown, 2003).

***Mesocyclops yena* Hołyńska, 1998**

Mesocyclops yena Hołyńska, 1998: 337–347, figs 1–26.

Mesocyclops cf. yena Hołyńska, 2000: 382–385, figs 14–15, figs 49b–c.

Type locality: Thua Thien-Hue, Viet Nam (Hołyńska, 1998).

Diagnosis: Serrate hyaline membrane on last antennular segment extending beyond implantation of medial seta of segment, with one large notch. Caudal spinule pattern of antennary basipodite with large spinules in longitudinal row near lateral margin and a row of oblique spinules next to long lateral spinules near base; lacking oblique row of tiny spinules starting at distal third of inner margin. No spinules on frontal surface of maxillary coxopodite. P1 basipodite without medial spine; medial expansion of basipodite of P1–P3 with apical hairs, medial expansion of P4 basis naked; distal margin of P4 coupler with two large acute outgrowths. Pediger 5 and genital double-somite without hairs laterally and dorsally. Lateral arms of seminal receptacle elongated and curved backward; transverse ducts directed to each other at straight or nearly straight angle (not V-shaped) before connection with copulatory duct; copulatory duct straight. Caudal rami without medial hairs; spinules at implantation of lateral caudal and lateralmost terminal setae present; medialmost terminal seta about 3.5–4.0 times as long as lateralmost terminal seta.

Specimens examined: 6 ♀♀, 2 ♂♂ (IEBR-MESO-16-09), Truoi lake, Thua Thien-Hue, X. 2016, Tran D.L. leg.; 3 ♀♀, 1 ♂♂ (IEBR-MESO-11-02) a fish pond Duy Xuyen, Quang Nam Province, VII, 2011, Tran D.L. leg.; 4 ♀♀ (IEBR-MESO-17-02),

temporary pond, Thuy Nguyen, Hai Phong Province, III, 2017, Dang V.D. leg.

Ecology: Mainly inhabiting aquaculture pond, lake and river in delta area.

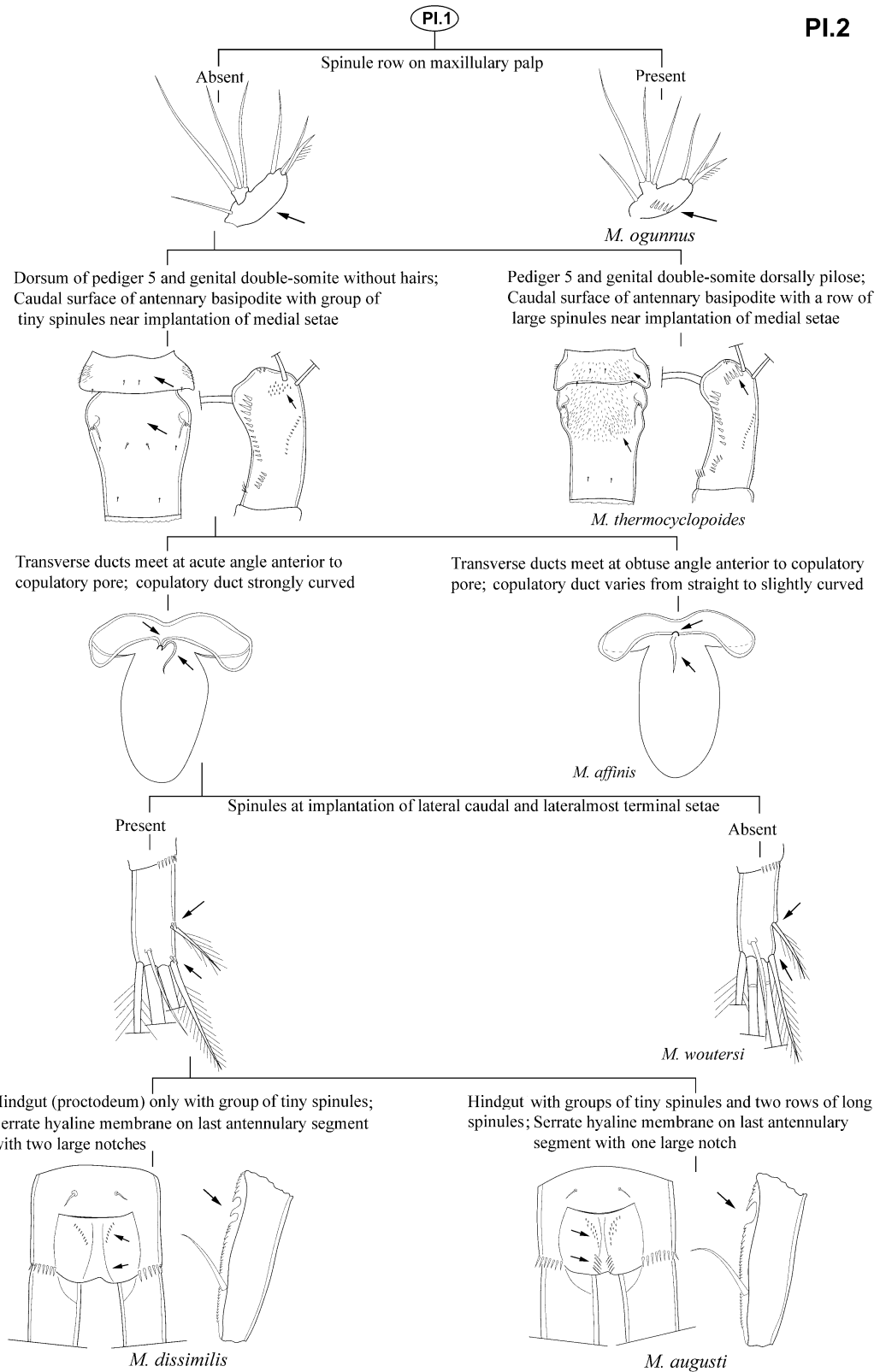
Records from Vietnam: Hai Phong, Thua Thien-Hue, Quang Nam (this study); Thua Thien-Hue (Hołyńska, 1998); Thua Thien-Hue, Hai Phong (Vu et al., 2000).

Distribution: Papua New Guinea (Hołyńska, 2000).

DISCUSSION

Previously, Dang Ngoc Thanh (1980), and Dang Ngoc Thanh et al. (1980, 2002) recorded only *Mesocyclops leuckarti* (Claus, 1857) in inland freshwater bodies of Vietnam. However, only Dang Ngoc Thanh et al. (1980) provided the description of this species based on Vietnamese specimens. Accordingly, *M. leuckarti* in Vietnam was recognized as: antennule with a comb-shaped hyaline plate, with a deep notch at 1/3 of distal part; caudal rami nearly parallel, length 3.0–3.5 times width, outer margin smooth; medialmost terminal seta of caudal ramus not exceeding half of the inner terminal seta; seminal receptacle T-shaped, distal part large, sac-like; lateral arms wide and straight; anterior margin of proximal part concave in the middle; P4 Endp-3 elongated, two apical spines approximately same length; intercoxal plate with two small process-like knobs; P5 2-segmented, distal segment with a long apical seta and a medial spine, apical seta 2.0 times as long as medial spine.

In the description of Dang Ngoc Thanh et al. (1980), there were some comments as follows: 1) “Intercoxal plate of P4 with two small process-like knobs, with small spine in tip” however, in *M. leuckarti*, intercoxal plate of P4 with two large acute outgrowths; 2) “Seminal receptacle T-shaped, anterior margin of proximal part concave in the middle” but figure 187-1 (page 319) of Dang Ngoc Thanh et al. (1980) do not exhibit this feature; 3) “Apical seta on distal segment of P5 2.0 times as long as medial spine” while the illustration in figure 187-5 showed the apical seta of P5 about 1.1 times as long as



medial spine; 4) There were no detailed descriptions or illustrations of the basopodite of antenna, copulatory pore, copulatory duct and seminal receptacle of female, which are important identifying features of this genus.

From above comparison, the identification of *M. leuckarti* collected in Vietnam might be incorrect. This could be due to the quality limitation of microscope when Dang Ngoc Thanh et al. (1980) did this work. This kind of misidentifications has also been found in Shen and Tai (1979) for *Mesocyclops* species in China as reported by Guo (2000). The species “*M. leuckarti*” in Vietnam is, therefore, more likely to be a different species of the genus *Mesocyclops*, and need to have further examination to confirm its taxonomic status.

Pictorial key to species of the genus *Mesocyclops* in Vietnam (Pl.1 and Pl.2)

CONCLUSION

To date, 11 copepods species of the genus *Mesocyclops* have been recorded in freshwater waters of Vietnam. Of these, one species is endemic to the Vietnam fauna (*Mesocyclops sondoongensis* Tran & Hołyńska, 2015) and two species, *Mesocyclops yenaе* Hołyńska, 1998, *Mesocyclops feriemurami* Hołyńska & Vu, 2000) were described for the first time from Vietnam's copepod fauna.

Mesocyclops leukarti (Claus, 1857) is now removed from the list of known copepod species in Vietnam. The pictorial key to all *Mesocyclops* species in Vietnam are also presented and updated.

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