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First records with morphological confirmation of invasive *Centropages tenuiremis* (Copepoda: Calanoida: Centropagidae) from the Straits of Malacca

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ABSTRACT

Centropages tenuiremis Thompson I.C. and Scott A., 1903 was described for the first time from the waters of Ceylon (Sri Lanka). However, the current distribution of this invasive species has been recorded from Japanese waters, Korean Peninsula, Taiwan, Andaman Sea, India and also the Arabian Gulf. Of late, *C. tenuiremis* has been recorded from numerous localities of Southeast Asian waters, often with no attempt at justification of identification. *Centropages tenuiremis* was initially discovered in mid-March 2020 in a sample taken during a long-term plankton survey along the west coast of Johor (Straits of Malacca) started. This study aimed to identify the invasive *C. tenuiremis* morphologically to meet the attributes for introduced species which are based on the premise of morphologic accuracy.

Keywords: Straits of Malacca, Zooplankton, Invasive species, Copepoda, *Centropages tenuiremis*

1. INTRODUCTION

Invasive species specifically zooplankton are known to be the second most common cause of species extinctions (Molnar et al., 2008; Bellard et al., 2016) while their ecological impacts can simply propagate along the food web and affect ecosystem services (Gallardo et al., 2016; Walsh et al., 2016). Moreover, with the increase of maritime activities particularly through ballast water and hull fouling during the last decades have facilitated their dispersal into new regions away from their native environments (Geburzi and Mc-Carthy, 2018; Bailey, 2015).

The range extension and the current biogeographic state of the invasive *Centropages tenuiremis* particularly in the Southeast Asia and the neighbouring waters is disquieting (Figure 1A). Apart from Japanese, Taiwan and numerous

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far-eastern coastal regions (Chen and Zhang, 1965; Wu et al., 2007; Xu et al., 2020), this species has already invaded several other sites of the Arabian Gulf (Al-Yamani et al., 2011), India (Krishnaswamy, 1953; Ganapati and Shanthakumari, 1961) and the Andaman Sea (Phukham, 2008). From the literatures, it is now spreading fast also in the Malayan peninsular (Figure 1B) and has been reported in Port Dickson (Rezai et al., 2005), Merambong (Peralta and Yusoff, 2015), Port Klang (Chew and Chong, 2016) as well as Pulau Sibu, east coast of Johor (Metillo et al., 2018; Kassim et al., 2018). Here we report its discovery with simplified morphological identification of the collected specimens from the southwest coast of Johor, further expanding the species' known invasion distribution.

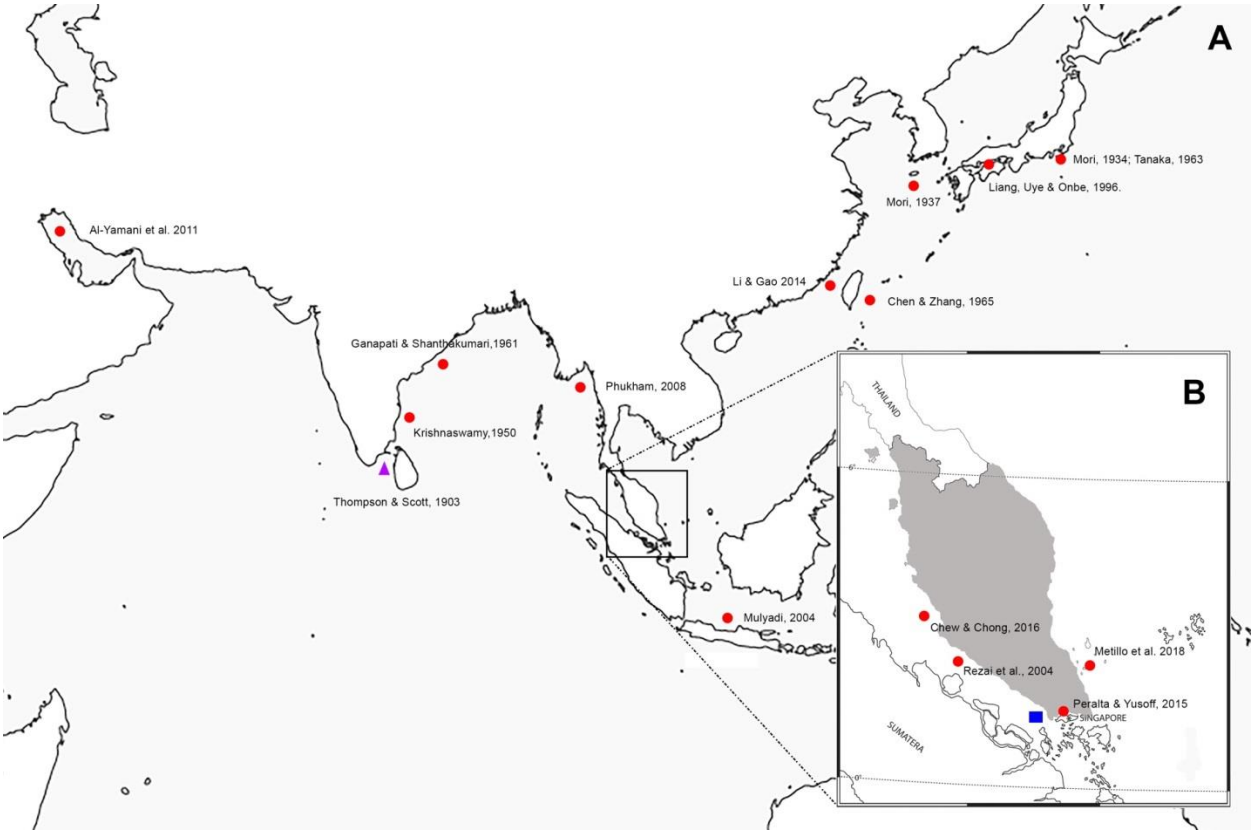

Figure 1 A: Worldwide distribution of *Centropages tenuiremis* Thompson I.C. and Scott A., 1903. Triangle symbol indicates native record. Round symbols, distribution to the introduced regions for worldwide and local distribution; B: Square symbol indicates present study, location of the sampling station off Kukup, Johor, Malaysia, Straits of Malacca.

2. METHODOLOGY

Zooplankton samples were collected from the coastal waters off Kukup, Johor (1°16'08.7" N 103°28'14.1" E) on 14 March 2020 (Figure 1B). Samples were collected by vertical hauls through the whole water column of 140 μm mesh plankton net near the sea surface. Immediately after sampling, specimens for morphological examination were fixed in a 4% formalin-seawater solution. Temperature and salinity in the surface water were measured using a multiparameter water quality meter (Aquaread water monitoring system –AP-2000). During the sampling time, the temperature and salinity off Kukup were 29°C and 34.4°C respectively.

Microscopic examination and dissections were made in diluted glycerol using stereomicroscopes (OLYMPUS SZ61). For detailed observations, specimens were photographed using an OLYMPUS SZX9 microscope with attached Canon-M100 for imaging. Body size of the specimens were measured from the top of the head to the tip of the caudal rami (excluding caudal setae), using an ocular micro meter. Terminology follows Huys and Boxshall, (1991). All materials were lodged at the University Kebangsaan Malaysia Muzium Zoologi (UKMMZ), Malaysia.

3. RESULTS

Taxonomy

Centopages tenuiremis Thompson I.C. and Scott A., 1903

Species synonyms

Centropages arabicus Cleve, 1904 (p.371, figs.); *Centropages yamadai*: Mori, 1937 (1964) (p.59, figs.F, M); Yamazi, 1958 (p.149, Rem.); Tanaka, 1963 (p.11, figs.F, M); Koga, 1968 (p.17, fig.: egg); Itoh, 1970 a (p.4: tab.1); Kasahara et al., 1974 (p.170, fig. egg); Hirota and Uno, 1977 (p.77, fig. egg, seasonal abundance); Hanaoka, 1977 (p.267, 300, abundance); Gricea nd Marcus, 1981 (p.125, Dormant eggs, Rem.: p.133, 135, 137); Kim and al., 1993 (p.269); Kotani al., 1996 (tab.2); Sharaf and Al-Ghais, 1997 (tab.1); Mauchline, 1998 (p.506, tab. 40); El-Serehy, 1999 (p.172, Table 1, occurrence); Ohtsuka and al., 2015 (p.123, Rem.: p.125); *Centropages kroyeri* (M): Mori, 1929; *Centropages orsinii* (F): Mori, 1929 p.174, figs.F)

Species characteristics

Marine

Species diagnosis

Male (Figure 2A–D)

Mean total length 1.653 mm, urosome symmetrical and 5-segmented. Fifth pedigerous somite (Figure 2A) produced into short spinal process and slightly asymmetrical corners. Right antennule (Figure 2C), geniculate between segments XX and XXI (18 and 19). P5 (Figure 2D) biramous, strongly asymmetrical with a 3-segmented; a spinal process stretching from middle part of inner margin forming a chela with "thumb", chela shorter than terminal claw.

Female (Figure 3A–G)

Mean total length 2.124 mm, body (Figure 3F) robust, prosome plump comprising cephalosome and five pedigerous somites; urosome symmetrical and 5-segmented. Genital complex asymmetrical, ventral surface with hook-like process (Figure 3A, 3E). Fifth pedigerous somite (Figure 3B) produced into symmetrical, long, spinal process. P5 asymmetrical (Figure 3C); right leg with 2 exopodal and 3 endopodal segments, inner margin of fused segment with spiniform process, extending backwards; left leg with 3 exopodal and 3 endopodal segments, inner spinal process shorter than the segment, posterior surface of naked (Figure 3G). Caudal rami symmetrical (Figure 3D).

Distribution

Malaysia

Habitat

Marine Coastal/Supratidal. Epipelagic. Neritic, estuarine.

Distribution

Native range

Sri Lanka (Ceylon)

Dispersal and spread

Arabian Sea, Gulf of Oman, Arabian Gulf, UAE coast, Kuwait, Maldive and Laccadive Is., Sri Lanka, India (W, off Cochin, Bombay, Goa, Madras, Cochin, G. of Mannar, Palk Bay, Burhabalanga estuary, Lawson's Bay, Godavari region, Kakinada Bay), Bay of Bengal, Burma (coast), W Malay Peninsula (Andaman Sea), Straits of Malacca, E Malay Peninsula (Pulau Sibu), Singapore, Indonesia (Java: Jakarta- Bay-Seribu Islands, off Tegal, off Surabaya), S Celebes Sea: Manado Bay, Hong Kong, China Seas (Bohai Sea, Yellow Sea, South China Sea, Xiamen Harbour and Bay, Jiaozhou Bay), Taiwan (SW, W, Kaohsiung Harbor, NW, N), S and W Korea, Muan Bay, Asan Bay, Korea Strait, Japan (Tokyo Bay, Tanabe Bay, Onagawa, Seto Inland Sea, south estuaries, Honshu: Suruga Bay), Sea of Japan (Amursky Bay), Korea (Ki-Channel, Bay of Fusan) off mouth of Amour River, S. Sakhalin, S Kuril Is., Pacif. (W equatorial), E Medit. (W Egyptian coast in Zakaria et al., (2016))

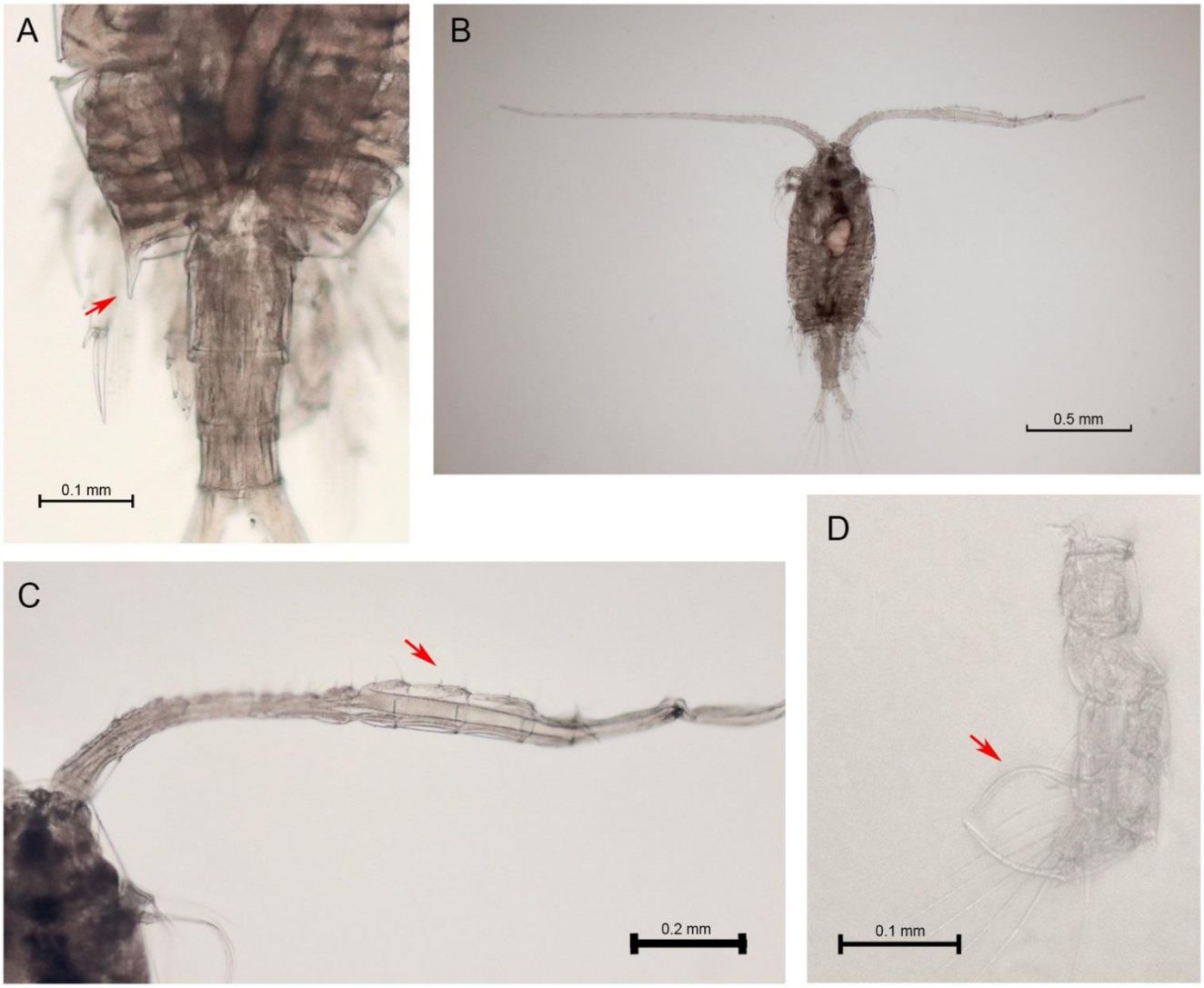

Figure 2 *Centropages tenuiremis*, male. A: Genital complex, dorsal view; (red arrow shows 5 pedigerous somite produced into pointed corner; B: Habitus dorsal view; C: Right antennule, (red arrow shows swollen between segments 13 and 17, geniculate between segments 18 and 19); D: Right 5 leg, (red arrow shows "thumb" of chela shorter than terminal claw)

Newly reported occurrences

Materials

a. Straits of Malacca; Country: Malaysia; State: Johor; locality: Kukup; Depth: 15.6 m; Coordinates: 1 15′54.7″ N 103 28′39.92″ E; Sampling Protocol: Vertical tow (depth: 15.6 m) of 140 μm mesh plankton net; Date: 14 March 2020; Time: Night. B.L.: 1.58–1.75 mm; type: Three males; Institution ID: UKMMZ T2103.

b. Straits of Malacca; Country: Malaysia; State: Johor; locality: Kukup; Depth: 15.6 m; Coordinates: 1 15′54.7″ N 103 28′39.92″ E; Sampling Protocol: Vertical tow (depth: 15.6 m) of 140 μm mesh plankton net; Date: 14 March 2020; Time: Night; B.L.: 1.58–1.75 mm; type: 7 females; Institution ID: UKMMZ T2106.

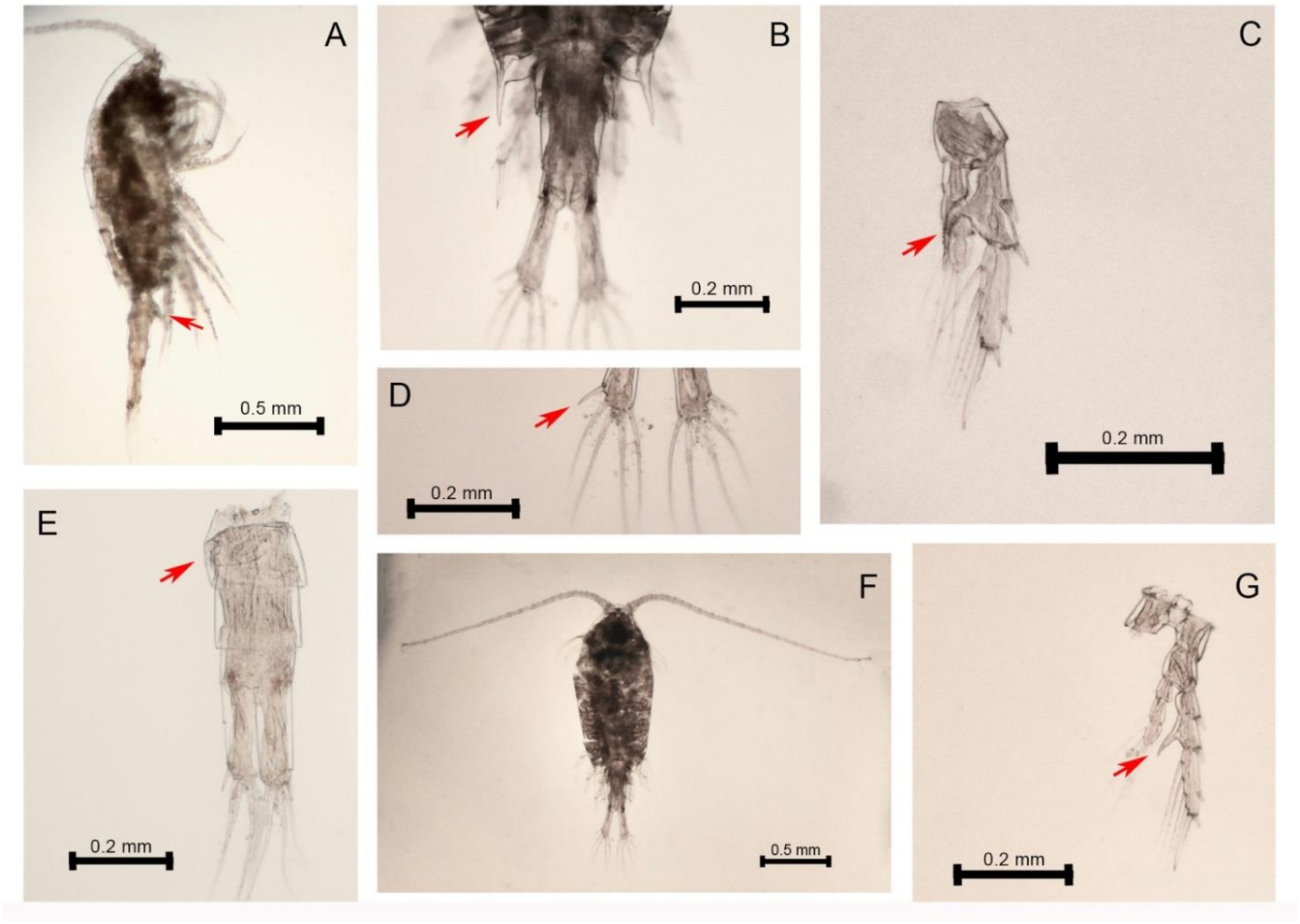

Figure 3 *Centropages tenuiremis*, female. A: Habitus lateral view (red arrow shows genital complex with hook-like process); B: Genital complex, dorsal view (red arrow shows 5 pedigerous somite produced into long, spinal process); C: Right 5 leg, (red arrow shows 1 stout spinal process, extending backwards; D: Caudal rami symmetrical, dorsal view (red arrow shows short seta); E: Urosome, dorsal view with irregular surface outline swelling; F: Habitus dorsal view; G, left 5 leg, (red arrow shows exopod 2 with strong spinal process)

4. DISCUSSION

Although the zooplankton community of the Malaysian waters has been intensively studied during the last decade (Balqiah and Rahim, 2021; Nakajima et al., 2014; Yoshida et al., 2012; Rezai et al., 2009), records on the occurrence of 'exotic, invasive or pest' zooplankton species is still inadequate, possibly due to taxonomic impediment. The synonymy for *C. tenuiremis* is unfeasible to determine. The majority of citations do not provide illustrations and where figures are provided many are not of sufficient detail to confirm or refute the record.

Despite this lack of sufficient taxonomic information to identify this non-indigenous copepod, *C. tenuiremis* has been cited 5 times around the waters of Peninsular Malaysia (based on taxonomic literature). Rezai et al., (2005) first reported *C. tenuiremis* from the Straits of Malacca with material from Port Dickson. Peralta and Yusoff, (2015) recorded *C. tenuiremis* from a sea grass area of southern Johor (Merambong), followed by Chew and Chong, (2016) from the waters of Port Klang and the most recent from Pulau Sibu, east coast of Johor (Metillo et al., 2018). All with no illustrations of material provided. Further taxonomic and genetic studies are warranted for this species to confirm disjunct distributions, understand when populations became separated and if possible, determine a point of origin for this highly successful invasive species. Ballast water is known to be the primary vector for marine invasive species, especially invertebrates such as planktonic copepods, facilitating their dispersal into new regions away from their indigenous environments (Bailey, 2015). Globalization of maritime activities that has increased during the last decades further exacerbate this phenomenon particularly of this area in the vicinity of three major ports in Southeast Asia (Port of Klang, Port of Singapore and Port of Tanjung Pelepas). This paper reports the presence of *C. tenuiremis* off Kukup, with their vital diagnostical

characters. Consequently, this ease-of-use information can shed light to potential researchers and policymakers on future occurrence of *C. tenuiremis* in their waters.

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Author contributions
Muhammad Harith Mohd Hamdan: Field sampling, analysed the data, prepared figures, authored and reviewed drafts of the paper.
Azman Abdul Rahim: Conceived and designed the study, field sampling and prepared figures, authored and reviewed drafts of the paper and approved the final draft.

Informed consent
Not applicable.

Ethical approval
The Animal ethical guidelines are followed in the study for species observation & identification.

Conflicts of interests
The authors declare that there are no conflicts of interests.

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Data and materials availability
All data associated with this study are present in the paper.

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