

A review on the parasitic isopod genus *Notophryxus* G. O. Sars, 1883 (Crustacea: Isopoda), and first report of *Notophryxus globularis* G. O. Sars, 1885 from Lakshadweep Sea (Amini Island)

Mukkattu Nazar Suhaana¹, Jaime Gómez-Gutiérrez², Paravanparambil Rajakumar Jayachandran³,
Punnakkal Hari Praved¹, Sivasankaran Bijoy Nandan^{1*}

¹ Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Kochi-Kerala 682016, India

² Departamento de Plancton y Ecología Marina, Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz B.C.S. 23096, Mexico

³ Applied Research Centre for Environment and Marine Studies, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

Received 27 November 2022; accepted 19 April 2023

© Chinese Society for Oceanography and Springer-Verlag GmbH Germany, part of Springer Nature 2024

Abstract

Isopod crustaceans of the family Dajidae are exclusively marine ectoparasites. The genus *Notophryxus* G. O. Sars, 1883 currently includes nine nominal species, which are very rarely reported as the chances for encountering these specimens are unpredictable. Our comprehension of the taxonomy, biology, ecology, and life cycle of species belonging to the *Notophryxus* genus is notably lacking. All nominal species of *Notophryxus* genus are reviewed here to obtain a comprehensive and integrative taxonomic understanding of this genus, in an attempt to address the lacunae. This paper also documents the rediscovery of an ectoparasitic isopod from the genus *Notophryxus* in Indian waters, after 55 years. Adult isopod specimens obtained from the outer reefs of Amini Island in the Lakshadweep archipelago, Southeastern Arabian Sea, display morphological congruence to *Notophryxus globularis* G. O. Sars, 1885. The only previous report on this species dates back to 1885 from G.O. Sars' description of *N. globularis* as an ectoparasite on the euphausiid *Thysanoessa gregaria* G. O. Sars, 1883 in the North Pacific. This discovery represents a range extension of *N. globularis* from the North Pacific to the Arabian Sea. Two cryptoniscid larvae and three adult females of *N. globularis* (with dwarf males) were found attached to four adult mysid specimens of *Siriella aequiremis* Hansen, 1910. The present study provides an improved diagnosis of *N. globularis* with the aid of light microscopy images and line drawings which was not given in the original G. O. Sars, 1885 report. This research also provides a concise description of cryptoniscid larvae from the same sampling location and same host which is most likely to be *N. globularis* larvae.

Key words: Dajidae, Mysid, cryptoniscan larvae, Southeastern Arabian Sea, *Notophryxus*

Citation: Suhaana Mukkattu Nazar, Gómez-Gutiérrez Jaime, Jayachandran Paravanparambil Rajakumar, Praved Punnakkal Hari, Nandan Sivasankaran Bijoy. 2024. A review on the parasitic isopod genus *Notophryxus* G. O. Sars, 1883 (Crustacea: Isopoda), and first report of *Notophryxus globularis* G. O. Sars, 1885 from Lakshadweep Sea (Amini Island). Acta Oceanologica Sinica, 43(8): 142–153, doi: 10.1007/s13131-023-2217-3

1 Introduction

Isopod crustaceans are ubiquitous in all aquatic ecosystems encompassing a large number of species that display parasitic trophic strategies during their life cycle (Rohde, 1982; Rameshkumar and Ravichandran, 2014). All isopods of the family Dajidae G.O. Sars, 1883 are obligate parasites of euphausiids, mysids, and decapods (Shields and Gómez-Gutiérrez, 1996; Williams and Boyko, 2012; Gómez-Gutiérrez et al., 2017). Dajid isopods in larval or juvenile stages are micro-predators developing as obligate ectoparasites or even endoparasites during the adult phase (Field, 1969; Boyko et al., 2013; Gómez-Gutiérrez et al., 2017). The Dajidae currently includes 68 nominal marine species within 22 genera that are mostly ectoparasites of mysid, euphausiid, and decapod crustaceans (Schotte, 1995; Shields and Gómez-Gutiérrez, 1996; Williams and Boyko, 2012; Gómez-Gutiérrez et al., 2017; Boyko et al., 2019).

Dajidae displays a remarkable sexual dimorphism with mor-

phologically modified larger females that contain a large ovigerous sac and typically have one to three dwarf males attached to the marsupium that maintain the isopod characteristic of having a dorso-ventrally compressed body. Adult males are typically seen sheltering in the marsupium or dorso-ventral region of the female's body. Dajidae isopods primarily develop through three motile larval stages: epicaridium, microniscus, and cryptoniscus (Sars, 1899; Coyle and Mueller, 1981; Williams and Boyko, 2012). Cryptoniscus larvae are observed as an ectoparasite on copepods (Sars, 1899; Field, 1969), euphausiids (Gómez-Gutiérrez and Castellanos-Orsorio, 2010; Gómez-Gutiérrez et al., 2017), and occasionally to the body surface or second abdominal somite of the final host (a euphausiid, mysid, or decapod) with an oral sucker (Shimomura et al., 2005; Ohtsuka et al., 2007). The juvenile stages of Dajidae species are rarely observed (Field, 1969; Gatto, 1983; Ariyama et al., 2016). The Dajidae family encapsulates species with high morphological diversity and varying sites

*Corresponding author, E-mail: bijoynandan@yahoo.co.in

of attachment on their crustacean hosts (Gómez-Gutiérrez et al., 2017). Thus, the current Dajidae taxonomy mainly focuses on their attachment site on the host and adult morphology (Shields and Gómez-Gutiérrez, 1996; Williams and Boyko, 2012; Ariyama et al., 2016).

Previous reports of Dajidae species in Indian waters include: *Dajus afromysidis*, *Prodajus gastrosacci*, *Prodajus ovatus*, and *Notophryxus lobatus* reported parasitizing mysids (Pillai, 1964); and *Heterophryxus appendiculatus* and *Branchiophryxus koehleri* reported parasitizing euphausiids (Sebastian, 1970) (Table 1, Fig. 1a).

The genus *Notophryxus* of the family Dajidae currently encompasses nine nominal species (Boyko et al., 2019). *Notophryxus ovoides* G. O. Sars, 1883 is the type species by monotypy of this genus erected in 1883 (G. O. Sars, 1883). *Notophryxus globularis* G. O. Sars, 1885 was the third species to be described from this genus (Boyko et al., 2019). Species of the *Notophryxus* genus possess several morphological diagnostic characteristics: adult females of this genus bear a sac-like body, single pair of brood lamellae, pereopods arranged in the anterior quarter of the body, slightly indicated segmentation, and female body size is considerably larger than males. An adult male is typically elongated and has a well-segmented body. Most *Notophryxus* species are only known from their original description, some of which were reported a century ago, without any novel reports, making this genus an unexplored taxonomic group from the Dajidae family. In this circumstance, there is a significant lacuna in our knowledge regarding the complete description and diagrammatic representation of species belonging to this genus.

The present study provides a brief review of the *Notophryxus* genus, integrating information from all the reports on this genus that are currently available. This study also documents the first record of *Notophryxus* genus from Lakshadweep waters. Light microscopy images along with line drawings of the adult female, male, and cryptoniscid larvae of specimens collected from the Arabian Sea are provided, which displayed morphological characteristics indistinguishable from the original description of *N. globularis*. The only existing report on *N. globularis* is from 139 years ago parasitizing the euphausiid *Thysanoessa gregaria* G. O. Sars, 1883 from the North Pacific (G. O. Sars, 1885). Despite the availability of integrated information on certain genera within the Dajidae family, details regarding the biogeographical distribution, host specificity, and taxonomic characteristics of the *Notophryxus* genus remain scarce (Gómez-Gutiérrez et al., 2017). Hence, comprehensive information on the genus *Notophryxus*

holds a significant scientific value (Fig. 1a) (Boyko and Williams, 2021).

2 Materials and methods

Mesozooplankton samples were collected from the outer reefs of Amini Island (11° 06' 36.072" N, 72° 43' 27.768" E) of Lakshadweep Archipelago located in the Southeastern Arabian Sea (Lakshadweep Sea) (Fig. 1b). The surface water samples were collected from 0.5 m depth using a standard Niskin sampler (General Oceanics, 5 L capacity). Sea water temperature was measured onboard using a standard thermometer with a range of 0°C to 50°C and an accuracy of 0.1°C. The conductivity, pH, and salinity were analyzed using a calibrated multi-parameter water-proof meter (HI98194), Hanna Instruments. Dissolved oxygen concentration (DO) was analyzed from seawater samples using the modified Winkler's method (Strickland and Parsons, 1972). Mesozooplankton samples were collected using a standard Bongo net with a mesh size of 200 µm and mouth of 60 cm diameter attached with a calibrated flowmeter (General Oceanics, model 2030R, 2012) deployed from a motorboat at a fixed speed of 2 km/h for 10 minutes. The zooplankton sample was preserved with a 4% formaldehyde solution buffered with saturated sodium borate immediately after collection. Zooplankton volume was estimated using the displacement volume method. Parasitized mysids from the zooplankton samples were sorted out under a stereomicroscope (Magnus MSZ-TR). Detailed morphological analysis of the mysid host and the ectoparasite was carried out under an epifluorescence microscope Leica DM6 for species taxonomic identification. Morphometry was acquired using the standard method, with Leica Application Suite X (LAS X). The scientific illustration of the specimens was drawn using Adobe Illustrator 2020. One adult female and one adult male were dehydrated in ascending concentrations of ethanol (20 minutes in each of 70%, 80%, 90%, and 100% ethanol concentration), and then ethanol is removed by submerging the specimens in 3 mL of hexamethyldisilazane (HMDS) for 10 minutes. Then the residual HMDS was removed and the specimen was allowed to air dry at room temperature for 18 h in a desiccator (modified from Murtey and Ramasamy, 2016). A scanning electron microscope (VEGA3 TESCAN SEM) was used to obtain images of gold-sputter-coated, dried specimens mounted on an aluminum stub. Unfortunately, the specimens shriveled considerably after SEM preparation; thus, the SEM images were not of great quality, and both specimens were spoiled. Two female specimens with their respective attached males and a mysid specimen with two

Table 1. Dajidae isopods reported from the Arabian Sea, parasitizing euphausiids and mysids

Dajidae species	Host species	Sampling location	Site of attachment to the host	References
<i>Branchiophryxus koehleri</i> Nierstrasz & Brendler à Brandis, 1931	<i>Stylocheiron carinatum</i> G. O. Sars, 1883, <i>Stylocheiron affine</i> Hansen, 1910 (euphausiids)	Arabian Sea	Posterior branchia	Sebastian (1970)
<i>Heterophryxus appendiculatus</i> G. O. Sars, 1885	<i>Euphausia sibogae</i> Hansen, 1908 (euphausiid)	Arabian Sea	Dorsal hind end of the carapace	Sebastian (1970)
<i>Dajus afromysidis</i> Pillai, 1964	<i>Afromysis macropsis</i> W. Tattersall, 1922 (mysid)	Inshore waters of the Kerala coast (Trivandrum)	Brood pouch	Pillai (1964)
<i>Prodajus gastrosacci</i> Pillai, 1964	<i>Eurobowmaniella muticus</i> W. Tattersall, 1915 (mysid)	Inshore waters of the Kerala coast (Trivandrum)	Brood pouch	Pillai (1964)
<i>Prodajus ovatus</i> Pillai, 1964	<i>Eurobowmaniella muticus</i> W. Tattersall, 1915 (mysid)	Inshore waters of the Kerala coast (Trivandrum)	Brood pouch	Pillai (1964)
<i>Notophryxus lobatus</i> Pillai, 1964	<i>Rhopalophthalmus tattersallae</i> O. Tattersall, 1957 (mysid)	Inshore waters of the Kerala coast (Trivandrum)	Ventral surface of the abdomen	Pillai (1964)
<i>Notophryxus globularis</i> G. O. Sars, 1885	<i>Siriella aequiremis</i> Hansen, 1911 (mysid)	Lakshadweep, Southeastern Arabian Sea	Postero-dorsal part of the carapace	Present study

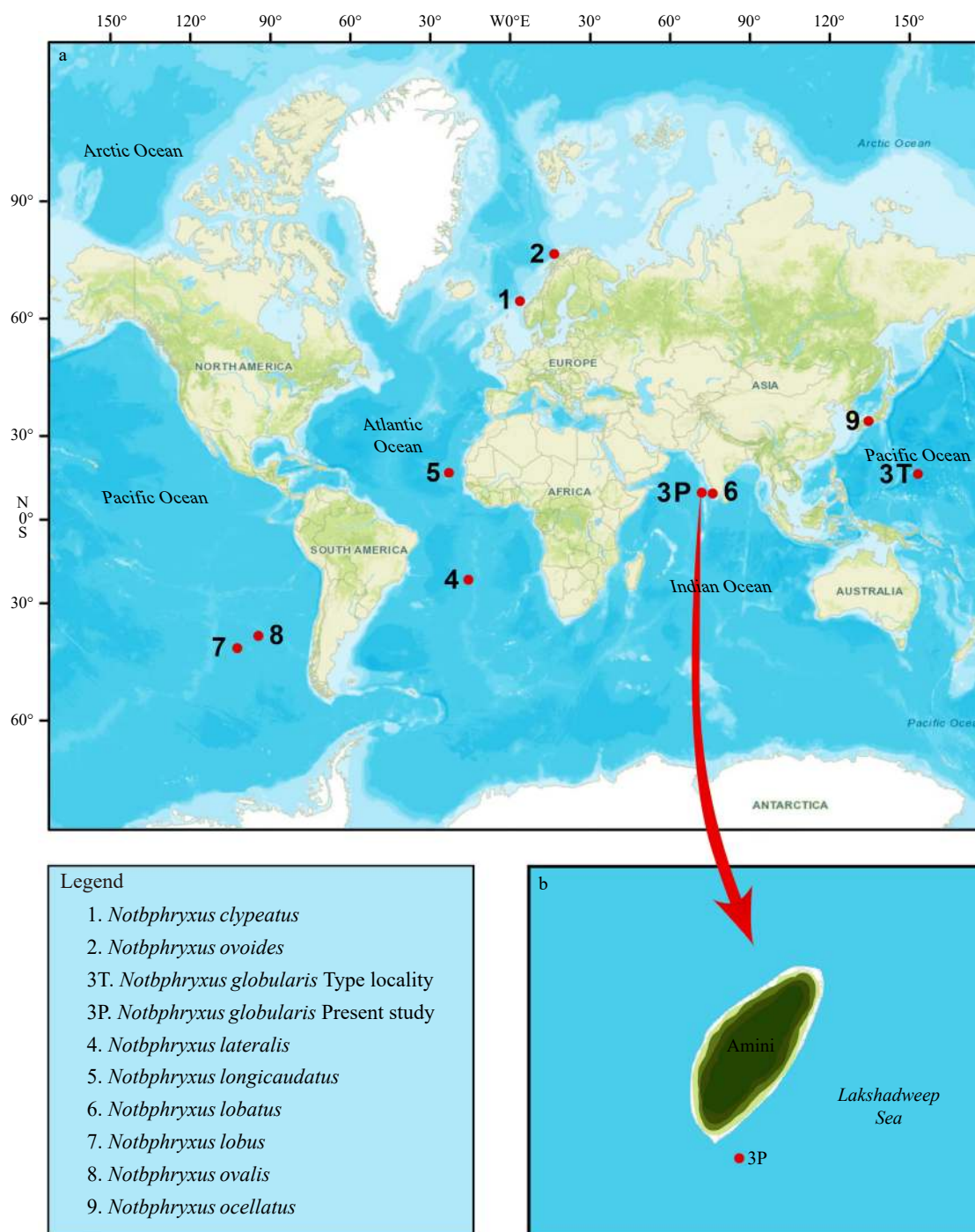


Fig. 1. Map showing the biogeographic distribution of *Notophryxus* (G. O. Sars, 1883) species, in world oceans (a). Study location at Amini Island from where specimens of *Notophryxus globularis*, were collected (b).

cryptoniscid larvae are stored in 2 mL Eppendorf tubes containing 4% formaldehyde solution buffered with saturated sodium borate (voucher no: MB/SBN/SN1-3) in the Marine Biology Museum of the Department of Marine Biology, Microbiology, and Biochemistry, Cochin University of Science and Technology (CUSAT).

3 Results

Four mysid specimens were parasitized with isopods (two larval forms and 3 females with males attached) (Figs 2a–f). The environmental conditions recorded in the sampling station (St. 4,

11° 06' 36.072" N, 72° 43' 27.768" E) of Amini Island were: sea surface temperature of 28.9°C, sea surface salinity of 36.27, pH of 8.02, and sea surface dissolved oxygen concentration of 4.73 mL/L.

The mesozooplankton biovolume recorded at the sampling station was 20 mL/(1 000 m³). Copepods contributed about 64% of the zooplankton biovolume. Mollusc larvae (9%), zoea (5%), mysida (4%), fish egg (3%), and siphonophora (2%) represented other numerically dominant taxonomic groups at this sampling station. Analysis of mysid specimens from the station showed the presence of Dajidae isopod ectoparasite. Approximately, 30

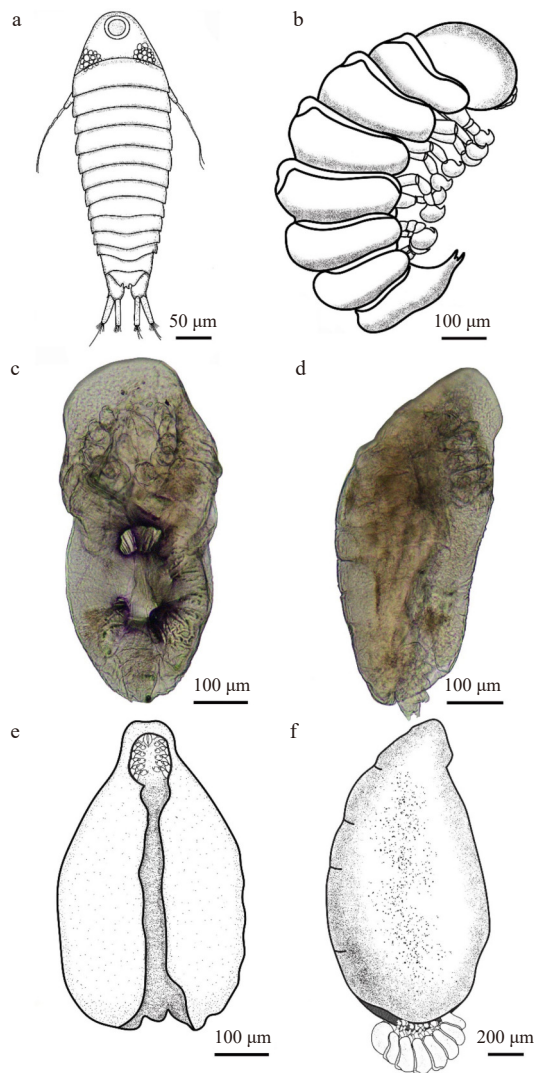


Fig. 2. *Notophryxus globularis*: a. cyprioniscid larvae, habitus, dorsal; b. adult male, habitus, lateral; c. immature female, habitus, ventral; d. immature female, habitus, lateral; e. adult female, habitus, ventral; f. adult female with attached male, habitus, lateral.

mysid specimens were collected from the sampling station, and four adult mysids among them were found to be parasitized with Dajidae isopods. Parasitized mysids were recognized by a prominent bulge in the dorsal part of the carapace and were sorted out from the mesozooplankton sample (Figs 3a and b). The mysid host was identified as *Siriella aequiremis* Hansen, 1910 (Eumalacostraca: Mysida). Three ectoparasite females (with adult males) and two larval forms of the parasite identifiable as *N. globularis* were found attached to the dorsal part of the carapace of the mysid host.

3.1 Description of *Notophryxus globularis* specimen from Amini Island

Order: Isopoda

Suborder: Cymothoida

Infraorder: Epicaridea

Superfamily: Cryptoniscoidea

Family: Dajidae G. O. Sars, 1883

Genus: *Notophryxus* G. O. Sars, 1883

Species *Notophryxus globularis* G. O. Sars, 1885

Type location: North Pacific G. O. Sars, 1885, (Pl. XXXVIII, Fig. 1, p. 220). The precise sampling location was not reported (Table 2).

New geographic locality: Amini Island of Lakshadweep Archipelago (11° 06' 36.072" N, 72° 43' 27.768" E), Southeastern Arabian Sea (Fig. 1b).

Dajidae females were found attached to the postero-dorsal part of the cephalothorax of the mysids (Fig. 3a). The mouth of the Dajidae female was directed towards the posterior part of the mysid's body. The female (body length: 1.5 mm, width 0.7 mm) was 3.1 times larger than the adult male that was attached longitudinally to the posterior region of the female marsupium (Fig. 3b).

Female: The adult female had a small, symmetrical, oblong-ovate sac-like body, with a convex dorsal surface and a somewhat flat ventral side. There is a slight indication of three segments in the dorsal margin of the body. The anterior margin of the cephalon is narrower, subtruncate, and slightly bent downwards compared to the posterior body margin (Figs 2e, 2f, 3c–f). Adult female lacks eyes. There is an oral hood situated anteriorly, ventrally this hood contains cephalic appendages and an oral cone (mouth) surrounded by five pairs of pereopods arranged in a semi-circular pattern (Figs 2c–e, 3c–e). Two pairs of antennae are visible in the ventral view. There is a ventral groove starting from the oral cone to the posterior side of the female leading to an anal opening (Figs 2e, 3c, 3e). The mouth morphology facilitates the sucking force necessary for feeding on the haemolymph of the host. Pleopod absent. Single pair of brood lamellae without any eggs.

Ovoid body shape, symmetry, the position of pereopods, their number, and the absence of pleopods, indicate that the Dajidae specimens parasitizing this Mysidae belongs to the genus *Notophryxus* G. O. Sars, 1883. Characteristic features like the attachment site on the host, the presence of a pair of brood lamellae with a male attached to the posterior groove, very slightly indicated dorsal segmentation and detailed observation of the thoracic appendages confirmed specimen Dajidae female was *Notophryxus globularis* G. O. Sars, (1885).

Male: The male specimen of *Notophryxus globularis* was found attached longitudinally to the posterior region of the ventral groove of the female using its specialized hooking appendages. The cephalon of the male was oriented towards the dorsal side of the adult female and the posterior region of the male was directed towards the ventral side of the female (Figs 2c–f, 3a, 3b, 3f). Adult male had a body length of 0.5 mm, body height measured 0.18 mm in length excluding legs, and 0.2 mm including legs, with a body width of 0.16 mm. The body was curved ventrally, having a large cephalon with a convex margin on the anterior side with segmented antennae (Figs 2b; 3f). Eyes are absent. Cephalon appeared to be partly fused with the first pereopod. Pereon is six segmented and Pereon 1–6 has a transverse dorsal ridge (Figs 2b, 3f). Six pairs of pereopods, all uniform in appearance and similar to those of female pereopod but slightly extended in length towards the posterior region. Pleon is unsegmented. Triangular pleotelson with a pair of uropods.

Coloration: Female and male specimens of *N. globularis* preserved in 4% buffered formalin solution were pale yellow in color.

Cryptoniscan larvae: The cryptoniscan larvae were also found parasitizing the mysid *Siriella aequiremis* Hansen, 1910 from the same mesozooplankton sample where the adult females and males of *N. globularis* were collected (a quite rare species not collected since its description in 1885), the parsimony ex-

Table 2. Morphological diagnostic characters of adult females of *Notophryxus* genus. *Notophryxus longicaudatus* female is so far undescribed; * indicates *N. globularis* from the present study; n.d means not described

Morphological characteristics of adult female	Antennae; Antennule	Body segmentation	Distinct cephalon; cephalon's anterior margin	No. of Pereopods	Overall shape and symmetry.	Host	Attachment site on the host	Female head orientation in relation to the host	Pleomere; pleopod; pleotelson; uropod	Eyes	Body length
<i>N. ovoides</i> G. O. Sars, 1883	Antennae-2 pairs	Slightly indicated s egmentation	Yes; Rounded truncated	5 pairs	Ovoid; symmetric	<i>Ambylops abbreviata</i>	Dorsal part of abdomen	Female's head pointed to its host's anterior end	n.d	Absent	3.5 mm
<i>N. ovalis</i> Schultz, 1978	n.d	n.d	Yes; obovate	Not visible	Ovoid	n.d	n.d	n.d	Absent	n.d	2.5–2.6 mm
<i>N. ocellatus</i> Shimomura & Ohtsuka, 2011	Antennae-2 pairs	Slightly indicated s egmentation	Yes; Rounded	5 pairs	Elongate ovate	<i>Rhopalophthalmus orientalis</i>	Ventral thoracic gills/appendages	Female's head pointed to its host's anterior end	3 pleomeres; pleopod - 2 pairs; pleotelson present	1 pair- small eyes	1.4–2.1 mm
<i>N. lobus</i> Schultz, 1977	nd	Slightly indicated s egmentation	Yes; Rounded	3 pairs	Lobular shape	n.d	n.d	n.d	Absent	n.d	1.9–2.6 mm
<i>N. lobatus</i> Pillai, 1964	Antennae-1 pair	No s egmentation	Yes; Sub-truncated	5 pairs	Elongate ovate	<i>Rhopalophthalmus tattersallae</i>	Ventral abdomen	n.d	4 pleons, 3rd pleon- 1 pleopod; 4th pleon - 1 uropod	Absent	1.5 mm
<i>N. lateralis</i> G. O.Sars, 1885	n.d	Slightly indicated s egmentation	Yes; Subtruncated	5 pairs	Sac like body	<i>Hansarsiamegalops, Hansarsia difficilis</i>	Thoracic legs/ penultimate gill	Female's head pointed to its host's posterior end	n.d	Absent	2 mm
<i>N. globularis</i> G. O.Sars, 1885	n.d (Antennae-2 pairs*)	Slightly indicated s egmentation (3 incomplete segments*)	Yes; Rounded-truncated (Rounded truncated*)	5 pairs (5 pairs*)	Ovoid; n.d (Ovoid; Symmetrical*)	<i>Thysanoessa gregaria; (Siriella aequiremis*)</i>	Posterior part of dorsal carapace; (Same*)	Female's head pointed towards host's posterior end; (Same*)	n.d (Pleopod absent*)	n.d (Eyes absent*)	n.d (1.5 mm*)
<i>N. clypeatus</i> G. O.Sars, 1883	Antennae-2 pairs; antennule-1 pair	3 or 4 segments	Yes; Rounded	5 pairs	Oblong -ovate; symmetrical	<i>Pseudomma roseum; Pseudomma truncatum</i>	Dorsal cephalothorax	n.d	Pleonites fused with broad and long pleotelson	Absent	3–5 mm

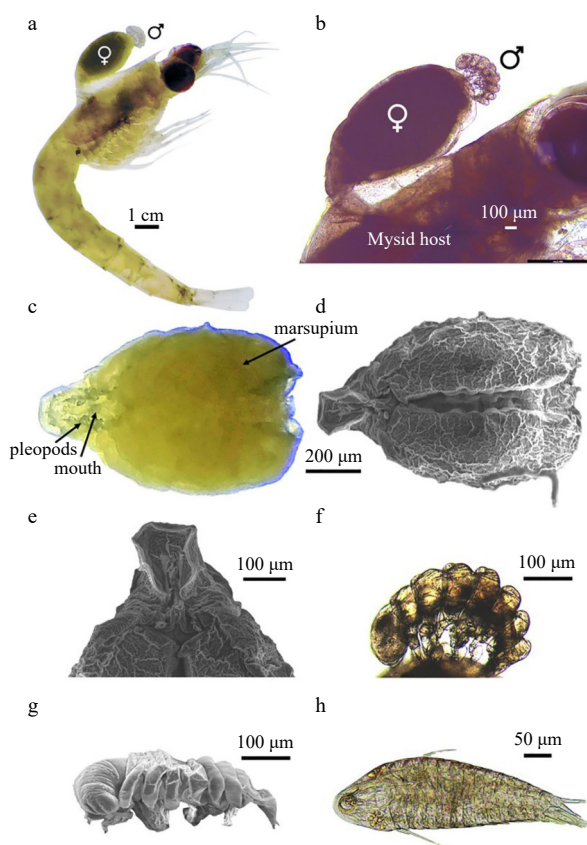


Fig. 3. *Notophryxus globularis*: a. adult female (with a male) attached to the dorsal part of the cephalothorax of the mysid host *Siriella aequiremis*; b. magnified view of an adult female with attached male, habitus, lateral; c. light microscope image of an adult female, habitus, ventral view; d. SEM image of the same adult female, habitus, ventral; e. SEM image of the ventral portion of a female head (appendages lost due to excessive shrinkage of the specimen during SEM preparation); f. light microscope image of adult male, habitus, lateral; g. SEM image of the adult male, habitus, ventro-lateral view; h. light microscope image cryptoniscus larvae parsimoniously identified as *N. globularis*, habitus, ventral.

planation is that these planktonic micropredators are also likely to be *N. globularis* cryptoniscan larvae. The cryptoniscan larva possesses a prominent oral sucking disc (Figs 2a, 3h). Larvae measured 0.48 mm in body length, 0.1 mm in width, and 0.08 mm in height. The cryptoniscan larvae had a narrow body, about three times as long as the maximum width. A total of 13 body segments were present. The cephalon is as wide as pereomere 1, the anterior margin is convex, and the posterior margin is slightly concave. Two pairs of antennae were present. Eyes have assemblages of 6–14 pigment spots situated on the posterior cephalic region (Figs 2a, 3h). Pleotelson tapers posteriorly, and the dorsal plate has two pairs of obtuse teeth on the posterior side. Uropods are equipped with two dorso-distal teeth, two ventro-distal setae, narrow exopod, and endopod of the same length, exopod, with 4–5 distal setae, endopod, with 3–4 distal setae. The oral sucker is 0.02 mm in diameter. Mandible emerging from the pore of the sucker, with bifurcate tip. Oral cone is longer than wider and tapered distally, it has two pairs of long transverse folds and some short folds on the ventral-distal surface.

Coloration: The cryptoniscan larvae preserved in 4% buf-

fered formalin are transparent. Their transparent color, thin body shape, and size makes it easier to go unnoticed.

3.2 Morphological comparison among *Notophryxus* species of the family Dajidae

The genus *Notophryxus* currently includes nine nominal species (Boyko et al., 2019): *Notophryxus clypeatus* (G. O. Sars, 1879); *Notophryxus ovoides* G. O. Sars, 1883; *Notophryxus globularis* G. O. Sars, 1885; *Notophryxus lateralis* G. O. Sars, 1885; *Notophryxus longicaudatus* Vanhöffen, 1914; *Notophryxus lobatus* Pillai, 1964; *Notophryxus lobus* Schultz, 1977; *Notophryxus ovalis* Schultz, 1978; and *Notophryxus ocellatus* Shimomura & Ohtsuka, 2011 (Table 2).

Notophryxus clypeatus (G. O. Sars, 1879)

Original name: *Leptophryxus clypeatus* G. O. Sars, 1879

Type description: G. O. Sars, (1879)

Type locality: North Iceland; Norway exclusive economic zone.

Host: *Pseudomma roseum* G. O. Sars, 1870 (Mysidae), *Pseudomma truncatum* S I Smith, 1879 (Mysidae).

Latest reference of description: Brandt, A. (1993)

Female: Description based on G. O. Sars, (1879) and Brandt, A. (1993). Long-oval in shape with a symmetrical body, slightly flattened dorso-ventrally; distinct segmentation in the mid-region, three distinct segments dorsally, frontal segments represented only by mediadorsal seam lines (Fig. 4a1). Head and frontal segments are fused to form a cephalothorax, the head protrudes slightly and has a rounded shape. All of the pleonites are fused with long and wide pleotelson, with a clypeiform margin, and a wide semi-circular caudal shield, where males shelter. Two wide triangular plates are seen meeting inwards anteriorly on the medial line, with the external angle considerably developed and protruding. These might be the first set of antennae (Sars, 1879). The second antennae are visible on both sides of these plates as a pair of differently shaped appendages made up of merged peduncular segments with small scale-like spines with little setules on the sides, four-minute flagellar articles, and five basic distal setae. (Fig. 4a2). Antennules are two small lobe-like structures. Extremely reduced mouthparts with maxillipeds and cone-shaped, protruding mandibles having tiny hooks distally, and a labrum bordered frontally forming a strong sucking tube. Five pairs of pereopods (Fig. 4a2), located on either side of the buccal region, are closely spaced within the anterior third of the entire body length near the mouthparts. The pereopods are all uniform visually, but their length slightly increases along the posterior region, representing incompletely articulated clasping organs. All pereopods are equal in size and have a basis that is wide, quadrangular, and without setae. The ischium in comparison with the basis is slightly shorter and thinner; there are few setules; the merus and carpus are joined and have a triangular form; the propodus has a broad-oval shape; the dactylus is small and has a tiny, claw-like continuation that is joined to the article. No well-developed oostigites; the eggs of the female are contained in two lengthy cuticle flaps on the ventral side. The body's posterior region is devoid of appendages (Table 2).

Color of female: pale yellowish. Length 3.5 mm. The broader pleotelson in this species is the major characteristic that differentiates it from *N. ovoides*.

Male: Males are attached to the ventral abdominal cavity of females and are considerably smaller than females (Fig. 4a2). The body is small, narrow, and distinctly segmented, with a large semicircular head, with deep segments that are unconnected. The head is not fused with the first pereonite, the body has seven pereonite segments, the abdomen is not segmented, and the

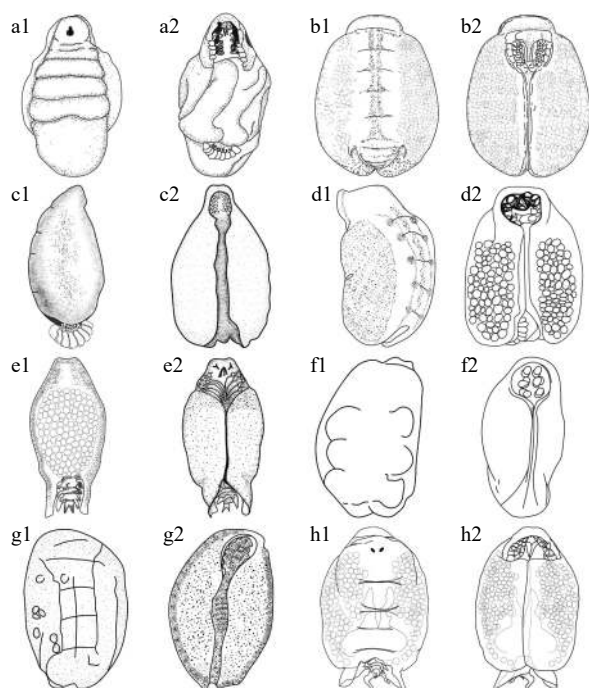


Fig. 4. Morphological comparison of adult females of *Notophryxus* genus: a1, a2. *Notophryxus clypeatus* G. O. Sars, 1879. a1. adult female, habitus, dorsal; a2. adult female with attached male, habitus, ventral (modified from Brandt, 1993); b1, b2. *Notophryxus ovoides* (G. O. Sars, 1883). b1. ovigerous adult female, habitus, dorsal; b2. ovigerous adult female, habitus, ventral (modified from Sars, 1883). c1, c2. *Notophryxus globularis* G. O. Sars, 1885. c1. adult female with attached male, habitus, lateral; c2. adult female, habitus, ventral (present study); d1, d2. *Notophryxus lateralis* G. O. Sars, 1885. d1. adult female, habitus, dorso-lateral; d2. female with attached male, habitus, ventral, (modified from Field, 1969); e1, e2. *Notophryxus lobatus* Pillai, 1964. e1. ovigerous female, habitus, dorsal; e2. ovigerous female, habitus, ventral, (modified from Pillai, 1964); f1, f2. *Notophryxus lobus* Schultz, 1977. f1. gravid female, habitus, dorsal; f2. adult female, habitus, ventral, (modified from Schultz, 1977); g1, g2. *Notophryxus ovalis* Schultz, 1978. g1. gravid female, habitus, ventral; g2. gravid female, habitus, dorsal (modified from Schultz, 1978); h1, h2. *Notophryxus ocellatus* Shimomura and Ohtsuka, 2011. h1. adult female, habitus, dorsal; h2. adult female, habitus, ventral, (modified from Shimomura and Ohtsuka, 2011).

head is slightly smaller than the posterior body. Males had fairly similar appendages to that of the female, but males had seven pereopods; two pairs of thread-like antennae on the head, the first antenna is shorter than the second one; mouthparts are style-like and conically tapering with a small suction tube; and pleotelson devoid of any distinguishing features (male specimen was lost while preparation for SEM) (Table 3).

***Notophryxus ovoides* G. O. Sars, 1883**

Type description: G. O. Sars, (1883)

Type locality: Norway

Host: *Amblyops abbreviatus* G. O. Sars, 1869 (Mysidae).

Female: Symmetrical, ovoid body. Slightly convex dorsally, indistinctly segmented, belly channeled in the middle, broader inflated body, forehead slightly prominent, with rounded-truncate anterior margin. Eyes absent (Fig. 4b1). Large lamelliform antennae are stored under the forehead, 2nd pair of antennae

slightly protruding outside. Five pairs of pereopod are present, situated on the anterior ventral side at the sides of the oral floor (Fig. 4b2). Broodplates absent. Posterior body (pleon), not prominent or small in adults, almost semicircular, without any appendages (Table 2).

Color of female: pale yellowish. Length 3.5 mm.

Male: Narrow distinctly segmented body. The head is fused with the first pereomere with a flattened and arched forehead. The first pair of antennae are rudimentary; second pair of antennae is elongate, setiform, and distinctly articulate (Fig. 5a). The oral parts transformed into a conical tube extending anteriorly. Six pairs of pereopods, prehensile, rather robust, very swollen, with strongly curved claws. The posterior body (Pleon) is composed of a single large and swollen segment, without any appendages (pleopod or uropod). Length 1.0 mm (Table 3).

***Notophryxus globularis* G. O. Sars, 1885**

Type description: G. O. Sars, (1885)

Type locality: North Pacific

Host: *Thysanoessa gregaria* G. O. Sars, 1883 (Euphausiidae)

Female: The body is sac-like, has lightly marked segmentation, and has five pairs of clasping legs that are clustered close together in the anterior region of the ventral face, along the sides of the mouth region (Fig. 4c2). The adult female was observed adhering to the posterior region of the dorsal face of the carapace on a euphausiid species, *Thysanoessa gregaria*, which was collected from the North Pacific on July 10, 1875. This species was given the name *Notophryxus globularis* because of its relatively short and thick-set body (Table 2).

Male: Described in the present study.

***Notophryxus lateralis* G. O. Sars, 1885**

Type description: G. O. Sars, (1885)

Type locality: South Atlantic

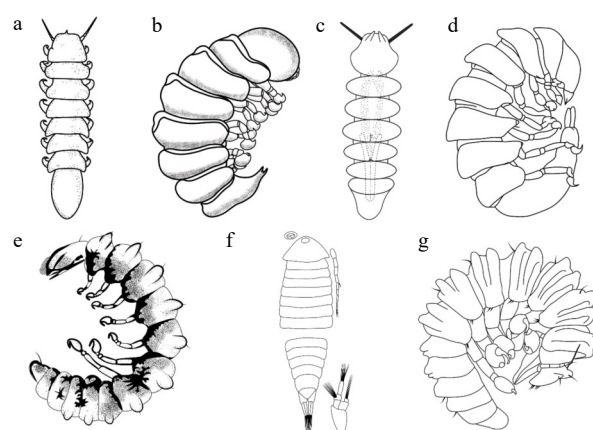


Fig. 5. Morphological comparison of males of *Notophryxus* genus: a. *Notophryxus ovoides* G. O. Sars, 1883 Adult male, habitus, dorsal (modified from G. O. Sars, 1883); b. *Notophryxus globularis* G. O. Sars, 1885 Adult male, habitus, lateral (present study); c. *Notophryxus lateralis* G. O. Sars, 1885 Adult male, habitus, dorsal (modified from Field, 1969); d. *Notophryxus longicaudatus* Vanhöffen, 1914, Adult male, habitus, lateral (modified from Vanhöffen, 1914); e. *Notophryxus lobatus* Pillai, 1964, Adult male, habitus, lateral (modified from Pillai, 1964); f. *Notophryxus lobus* Schultz, 1977 unmetamorphosed male, habitus, dorsal (modified from Schultz, 1977); g. *Notophryxus ocellatus* Shimomura and Ohtsuka, 2011 Adult male, habitus, lateral (modified from Shimomura and Ohtsuka, 2011).

Host: *Hansarsia megalops* G. O. Sars, 1883 and *Hansarsia dif-
ficilis* Hansen, 1911 (Euphausiidae). *Hansarsia* nom. nov. is a
genus replacement name for *Nematoscelis* G. O. Sars, 1883
(Shaw, 2023)

Female: The adult female has a sac-like body with an oral
hood situated anteriorly; ventrally this hood contains an oral
cone (mouth) surrounded by five pairs of pereopods (Fig. 4d2).
The adult female was attached to the coxopodite of one of the
thoracic appendages, of a euphausiid, and extended laterally or
ventrally from the shrimp, among the gills. Adult females are
about 2 mm in body length (Table 2).

Male: The male of *Notophryxus lateralis* is about 0.5 mm long
and exhibits regular segmentation (Fig. 5c). Normally only one
male lives in the brood pouch of a female (Fig. 4d2), although one
female specimen contained two males (Table 3).

***Notophryxus longicaudatus* Vanhöffen, 1914**

Type description: Vanhöffen (1914)

Type locality: Cape Verde, Africa

Host: Unknown

Female: Undescribed

Male: In a vertical catch from a depth of 3 000 m west of Cape
Verde Islands during 1903, a male of *Notophryxus* was obtained,
which differs from the previously known males of this genus with
its long abdomen (pleon) and long style-like uropods. As it is so
well characterized, although the adult female is still unknown

this male specimen was named *Notophryxus longicaudatus*
(Fig. 5d). The body length is about 1 mm (Table 3).

***Notophryxus lobatus* Pillai, 1964**

Type description: Pillai, N. K. (1964)

Type locality: Trivandrum, India

Host: *Rhopalophthalmus tattersallae* N K Pillai, 1961 (Mysid-
ae).

Female (Adult): Long and oval body, with a narrower anteri-
or end. The ventral side is somewhat flat and the dorsal side is
highly convex. Cephalon is somewhat triangular, with its anteri-
or border subtruncate and ventral surface concave. Enlarged and
bulged pereon, devoid of any segmentation trace. From the pos-
terior-lateral region of the pereon, prolongs two substantially big
lamellar lobes that extend beyond the pleon. Pleon has four seg-
ments: the first three are laterally pulled out into thin processes,
while the fourth is apically bifid. Microscopically, the external
borders of pleon segments are hairy. Hypopharynx is cone-
shaped and faces forwards (Fig. 4e1). A pair of stiff backwardly
directed spines represent the reduced antennae. Five pairs of
pereopods are placed laterally on the cephalon, arranged in two
rows. Four pairs of overlapping plates are placed on the ventral
side, just behind the pereopods, and a substantial pair of brood
lamellae that overlap on the ventral-median section is located
behind them (Fig. 4e2). Like the paired plates, the outer border of
the brood lamellae is also hairy. The third segment of the pleon

Table 3. Morphological diagnostic characters of adult males of *Notophryxus* genus

Morphological characteristics of adult male	Number of pereomere	Distinct head	Number of pereopods	Pleon; Pleotelson; Uropod	Attachment to the adult female	Antennae	Dorsal ridges	Body length
<i>Notophryxus ovoidea</i> G. O. Sars, 1883	6	Yes	6 pairs	Pleotelson with no uropod	n.d	2 pairs	n.d	Absent
<i>Notophryxus ocellatus</i> Shimomura & Ohtsuka, 2011	The male contained in the marsupium of one female was cryptoniscid in form with an oral sucker							0.75 mm
<i>Notophryxus longicaudatus</i> Vanhöffen, 1914	7	Yes	7 pairs	Pleotelson without distinct structures; Long style like uropoda	Ventral abdominal concavity of female	2 pairs of filiform antennae	n.d	n.d
<i>Notophryxus lobus</i> Schultz, 1977	7	Yes	Yes; Rounded	Lobular shape	n.d	n.d	n.d	n.d
<i>Notophryxus lobatus</i> Pillai, 1964	7	Yes	7 pairs	Pleon-6 segmented; Pleopod and uropod absent.	Attached to the posterior end of the female's ventral groove Male attached laterally, at the postero-ventral side of the ventral groove	1 pair of antennae	Cephalon without dorsal ridge; pereomeres 1–7 and pleomeres 1–2 each with a single transverse dorsal ridges	1 mm
<i>Notophryxus lateralis</i> G. O. Sars, 1885	6	Yes	n.d	n.d		Present	Absent	0.5 mm
<i>Notophryxus globularis</i> G. O. Sars, 1885	6*	Yes*	6 pairs*	Single segmented pleon without appendages; pleotelson with a pair of uropod*	Attached longitudinally to the posterior region of the ventral groove*	1 pair of antennae*	Cephalon without dorsal ridge; Pereon 1–6 each with a single transverse dorsal ridge; Pleon with a single dorsal ridge*	0.5 mm*
<i>Notophryxus clypeatus</i> G. O. Sars, 1883	7	Yes	7 pairs	Pleotelson without distinct structures; Uropod absent	Ventral abdominal cavity of female	2 pairs of filiform antennae	Absent	n.d

Note: Males of *N. ovalis* Schultz, 1978 and *N. globularis* G. O. Sars, 1885 are so far undescribed; * indicates the description of *N. globularis* male from the Arabian Sea; n.d means not described.

has two large setae with ventral plates; these are most likely the pleopods. Body length 1.5 mm. These lateral prolongations of the third pleon segment of the adult female easily differentiate this species from others.

Immature female: Dorso-median region of the body is well segmented. Complete segmentation is seen in immature females. Brood lamellae that are large and completely open. Just like in adults, pereopods are closely packed. The final pleon segment is split down the middle and bears two biramous uropods.

Male: Long and cylindrical body, with a large cephalon and a large setose hood-like lobe. Triangular buccal mass that extends beyond the cephalon's anterior margin. Antennae are six segmented. Each segment of the seven-segmented pereon features a transverse dorsal ridge. The cephalon and first pereon are only partially fused. Length of the pereopods increases from the first to the seventh. Pleon is six-segmented and devoid of pleopods and uropods. Length 1.0 mm (Fig. 5e).

***Notophryxus lobus* Schultz, 1977**

Type description: Schultz, (1977)

Type locality: Southern Ocean

Host: Unknown

Female: Laterally compressed, bilaterally symmetrical body with indistinctive pereonal segments. The medial ventral groove stretches out the entire body length, with broader margins at the anterior and posterior regions. Three pairs of small pereopods bearing blunt dactyl hooks are observed in the frontal section of the medial ventral seam. The Latin word for “lobus” alludes to the species' lobular shape (Fig. 4f1). The species shows some similarities with *Notophryxus lateralis*, however, it is smaller and has three pairs of pereopods rather than five (Fig. 4f2). Length: 1.9 mm, 2.1 mm, 2.5 mm (Table 2).

Male: One of the females' marsupium carried a cryptoniscid male having an oral sucker (Fig. 5f). 0.75 mm and 2.6 mm in length (Table 3).

***Notophryxus ovalis* Schultz, 1978**

Type description: Schultz, (1978)

Type locality: Central South Pacific

Host: Unknown.

Female: An adult female has a small, ovoid body. The ventral groove passes longitudinally starting from the posterior region of the body to the anterior concavity encircled by a hood. An oral sucker was observed in the hood depression (Fig. 4g2). At the borders of the hood depression, a semi-transparent integument allows the slight visibility of six or fewer edges of pereonal segments (Fig. 4g2). In the dorsal view, the pereonal segments are exhibited medially (Fig. 4g1). This species varies from others in the genus by having pereonal segment edges rather than pereopod appendages visible in the anterior section of the specimens. Body length 2.5–2.6 mm (Table 2).

Male: Undescribed.

***Notophryxus ocellatus*: Shimomura & Ohtsuka, 2011**

Type description: Shimomura, and Ohtsuka. (2011)

Host: *Rhopalophthalmus orientalis* O. Tattersall, 1957 (Mysidae).

Type locality: Osaka Bay, Japan

Female: Long ovate body, approximately 1.5 times longer than wide. Dorsally arched, with one pair of lateral lamellae that extends beyond the pleon and are loaded with several eggs. The size of the eggs measured between 69.3 µm to 83.7 µm. The frontal margin of the cephalon was rounded while the posterior mar-

gin was imperfectly defined with two small, oval-shaped eyes located dorsally. In the dorsal view pereomeres (Fig. 4b1) are indistinctly defined, with a slight indication of segmentation. Dorsally, pleomeres are distinctly separated (Fig. 4b1) and indistinct in ventral view, each of the first three pleomeres has a lateral plate; 2 pairs of pleopods are present in total. Well-defined pleotelson (Fig. 4b1), having two posterior projections and an open-slit anus. Antenna 1 (Fig. 4b2) constitutes a wide and minute article with a long terminal seta. Second antenna is absent. A conical oral cone surpasses the ventral side of the cephalon (Fig. 4b2). All of the pereopods (Fig. 4b2); are similar in shape; with long setae-less basis; setaeless ischium is only half the length of basis; merus is partially fused with carpus having few tiny setae ventrally; ovate propodus, with some tiny setae ventrally; dactylus is smallest, with a minute claw (Table 2). An adult female of *N. ocellatus* is distinct from *N. lobatus* by the following characteristics: cephalon having 2 small eyes, a rounded frontal margin of the cephalon, imperfectly defined pereomeres dorsally, with segmentation traces.

Male: Ventrally curved body (Fig. 5g), with dorso-laterally scattered setae. Cephalon (Fig. 5g) with a convex anterior margin, devoid of eyes, partially fused with the first pereomere. Seven pereomeres are present, each having a pair of transverse dorsal ridges (Fig. 5g). Six segmented pleon, without uropods. First two pleomeres have a pair of transverse dorsal ridges. Antenna 1 constitutes of a broad article with a lengthy seta. Antenna 2 is formed of 5 articles: The second and third articles are equal in length each bearing a simple medial seta; article 4 is smaller than article 3, with 2 simple distal setae; article 5 with apical aesthetasc and 3 simple setae. The oral cone contains 2 mandibular gnathobases projecting from the mouth. First four pereopods (Fig. 5g) are identical in shape; carpus with small setae ventrally; propodus has long simple seta proximo-ventrally with long protrusion; dactylus arched inward, with a pair of simple ventral setae. Pereopods 5–7 (Fig. 5g) are identical in shape: carpus devoid of setae; protrusion of propodus is small and unpointed; inwardly arched dactylus, with 3 simple ventral setae (Table 3). An adult male of this species can be differentiated from *N. lobatus* by the following characteristics: transverse dorsal ridge on cephalon; a pair of transverse dorsal ridges on each of the 7 pereomeres; the presence of 2 transverse dorsal ridges on pleomeres 1–2, and antenna 2 made of 5 articles.

4 Discussion

4.1 New report of *Notophryxus globularis* from the Arabian Sea

G. O. Sars, (1883) established the family Dajidae and described the first isopod species parasitizing euphausiids (Sars, 1885). The Dajidae species typically have a species-specific attachment site on the crustacean host (Gómez-Gutiérrez et al., 2017) (Tables 1, 2). Females of *N. globularis* have a characteristic attachment site on the dorsal posterior region of the carapace of the host with the female's head facing toward the posterior part of the host (Sars, 1885). This is a distinctive attachment position compared with other species of Dajidae; which prefer attachment positions like the lateral part of the cephalothorax, gills, ovigerous sac, or peduncle of the eyes of the crustacean host (Field, 1969; Shield and Gómez-Gutiérrez, 1996; Gómez-Gutiérrez et al., 2017). These distinct attachment sites form the microhabitats of isopods on their host that are unique for each species of *Notophryxus* genera: (1) *Notophryxus lateralis* G. O. Sars, 1885 usually attaches to the gills or pleopod appendages of the euphausiids *Hansarsia megalops* and *Hansarsia difficilis* reported

from South Atlantic, South Pacific, North Pacific (Field, 1969) including the Gulf of California (Gómez-Gutiérrez et al., 2010, 2017; De Silva-Dávila et al., 2004); (2) *Notophryxus ovoides* G. O. Sars, 1883 attaches to the dorsal abdomen of the mysid host *Amblyops abbreviatus*; with the head of the parasite pointed towards the anterior side of the host (G. O. Sars, 1899).

The present study reports the rediscovery of the Dajidae isopod, *Notophryxus globularis* from the outer reef waters of Amini Island, South Eastern Arabian Sea, ectoparasitizing a new host, mysid *Siriella aequiremis* Hansen, 1910. *Siriella aequiremis* is an oceanic mysid with widespread biogeographic distribution in both tropical and temperate oceanic waters of the Pacific and Indian Oceans from the Arabian Sea to China (Hansen, 1910; Tattersall, 1951; Pillai, 1973). The *N. globularis* specimens collected during this study from the Arabian Sea also exhibited a preference for attaching to the posterior region of the cephalothorax of each adult mysid host. All the adult and larval forms of *N. globularis* were attached to the males of mysid *S. aequiremis* in this mesozooplankton sample, with no female mysids being parasitized. *Notophryxus globularis* was only known to be infesting the euphausiid *Thysanoessa gregaria* in the North Pacific (G. O. Sars, 1885; Gómez-Gutiérrez et al., 2017). *Thysanoessa gregaria* is a transition zone species that is widely distributed in the North Pacific, South Pacific, middle Atlantic, South Atlantic, and Indian Ocean basins (Brinton, 1962; Brinton and Gopalakrishnan, 1973; Brinton et al., 2000). This implies that the present study is a range extension of the type location of *N. globularis* from the North Pacific to the Arabian Sea.

The Dajidae *N. globularis* is likely to infest distinct taxa of small pelagic crustaceans to obtain hemolymph and broaden their biogeographic distribution ranges. Seven Dajidae isopods, parasitizing on euphausiids and mysids, have been reported from the Indian Ocean (Table 1). Dajidae occasionally parasitizes host species with overlapped distribution ranges, thus they also tend to have wide biogeographic ranges. As a result, it is typical for these parasites to have a wider distribution than a particular crustacean host species (Gómez-Gutiérrez and Shields, 1998; Gómez-Gutiérrez and Castellanos-Orsorio, 2010; Gómez-Gutiérrez et al., 2017).

This report features microscopic images and line drawings depicting adult female, male, and cryptoniscian larvae of *N. globularis*, the latter two being previously undocumented in G. O. Sars, (1885). Additionally, it offers an integrative review of the nine nominal species within the *Notophryxus* genus, aiming to streamline species identification in future studies. With only two records of *N. globularis* since 1885 further studies are required to get a complete understanding of the morphology, intraspecific variability, host-specificity, biogeographic distribution, and ecology of this isopod parasite in the Indian Ocean.

The adult females of the genus *Notophryxus* are well-equipped with specialized appendages for attaching to their pelagic crustacean hosts. The comprehension of morphological characteristics and the arrangements of mouthparts in the parasitic Dajidae reinforces the notion that mysids and euphausiids serve as their primary hosts (Williams and Boyko, 2012; Brandt and Janssen, 1994; Wägele, 1992). The Dajidae parasite remains on the host for a prolonged duration of its life span. Thus, imparting a negative impact on the growth and gonad development of the crustacean host (Shield and Gómez-Gutiérrez, 1996). Our understanding of the biology of Dajidae remains rudimentary, primarily due to their infrequent collections stemming from uneven sampling, and a lack of observational effort.

The cryptoniscian larvae secured from the same mesozo-

oplankton sample, infesting the same mysid host, from which the adult females and males of *N. globularis* were obtained suggests that these cryptoniscian larvae are also most likely to be *N. globularis* (as a parsimony explanation). Dajidae larva and juvenile phases have rarely been identified and only represented from specimens collected in California (Field, 1969), Cape Verde Islands, northwest Africa (Gotto, 1983), Gulf of California (Gómez-Gutiérrez et al., 2010, 2017), and Japan (Ariyama et al., 2016).

4.2 *Notophryxus* genus review

The only species of *Notophryxus* previously reported from the Indian Ocean is *Notophryxus lobatus* Pillai, 1964 attached to the ventral surface of the abdomen of the specimen *Rhopalophthalmus tattersallae* Pillai, 1961 from Trivandrum. Female *N. lobatus* is distinguished from *N. globularis* by the presence of four segmented pleon; the third pleon segment having a pair of large setose ventral plates (pleopods) and an apically bifid fourth pleon segment (uropod). *Notophryxus globularis* males have six pereomeres each with a pair of pereopods and a single segmented pleon, while *N. lobatus* male has seven pereomere each with a pair of pereopods and six segmented pleon. When it comes to the presence of dorsal ridges, *N. globularis* has a single transverse dorsal ridge on each of its six pereons, whereas, *N. lobatus* males have a single transverse dorsal ridge seen on cephalon followed by two transverse dorsal ridges in each of the seven pereomeres and pleomeres 1 and 2. The isopod specimen collected in this study showed a slight similarity to *N. lateralis* described by Field (1969), but both *N. lateralis* and *N. globularis* have completely different attachment sites on the host, the latter being attached to the posterior end of dorsal carapace rather than to the coxopodite of thoracic appendages/penultimate gill as in the case of *N. lateralis* (Field, 1969). *Notophryxus globularis* female is smaller and has a thicker set body than *N. lateralis*.

Comparing the morphology of adult females of all nine nominal species belonging to the *Notophryxus* genera revealed that, eyes were only present in *Notophryxus ocellatus*. Pleopod was only present in *N. ocellatus* and *N. lobatus*. Uropod was only observed in *N. lobatus*. Adult females of eight nominal species had 5 pairs of pereopods, except *N. lobus* which has only three pairs of pereopods. Adult female of *N. longicaudatus* is undescribed so far, as only a male specimen was collected and described. Most of the species of the genus *Notophryxus* possessed an ovoid sac-like body, a pair of antennae, distinct cephalon, slightly indicating body segmentation; but vary in the distinct site of attachment to the host. All adult males belonging to this group showed a typical isopod characteristic of having a narrow segmented body. Most adult males were only one-third the size of their females. Males had 6 or 7 pereomeres and pereopods, distinct heads, and a pair of antennae. Dorsal ridges and well-developed pleon were only seen in *N. ocellatus* and *N. lobatus*. Adult males of *N. globularis*, *N. lobus*, and *N. ovalis* were undescribed due to a lack of specimens. The observation of *N. globularis* male specimens in the present study revealed that they also possessed single transverse dorsal ridges on each of its six pereons, along with six pairs of pereopod, distinct heads, and a single segmented pleon.

5 Conclusions

The present study reports the presence of Dajidae isopod, *Notophryxus globularis* in the outer reef waters of Amini Island, South Eastern Arabian Sea, ectoparasitizing a new mysid host *Siriella aequiremis* Hansen, 1910. This parasite was only previously known to ectoparasite the euphausiid *Thysanoessa gregaria* in the North Pacific. *Thysanoessa gregaria* is a transition zone spe-

cies that is widely distributed in the North Pacific, South Pacific, middle Atlantic, South Atlantic, and Indian Ocean basins (Brinton, 1962; Brinton and Gopalakrishnan, 1973). *Siriella aequiremis* is an oceanic mysid with widespread biogeographic distribution in both tropical and temperate oceans including the Pacific and Indian Oceans extending from the Arabian Sea to China (Hansen, 1910; Tattersall, 1951; Pillai, 1973). Thus, the parasite could also have a wide biogeographic distribution as has been demonstrated for other Dajidae species (Gómez-Gutiérrez and Shields, 1998; Gómez-Gutiérrez and Castellanos-Osorio, 2010; Shimomura and Ohtsuka, 2008; Gómez-Gutiérrez et al., 2017). This implies our report is a range extension of the geographic distribution of this isopod from the North Pacific to the Indian Ocean. Unfortunately, an adult female and male specimen got disfigured during the SEM preparation, thus the quality of SEM images was not up to the standard quality. However, since there are currently no accessible SEM images or light microscopy images of these specimens, the provided images may still prove valuable morphological details for future reference regarding the basic taxonomic characters of *N. globularis*.

Notophryxus includes species that are rarely collected from the world's Oceans, typically discovered by serendipity. All nine nominal species in this genus have only been reported a few times from several regions of the world. As a result, the information on each species of this genus is highly fragmented. Several of the articles were written centuries ago in the Latin language. In the present study, we aimed to present an integrative review of all nominal species within this genus by compiling data from all published articles to date and improving the quality of the drawings to attain comprehensive information on genus *Notophryxus* (Figs 4 and 5).

Notophryxus globularis shows specificity in the attachment site on the host (to the posterior region of the cephalothorax). Notably, all three adult females of *N. globularis* collected in present study were exclusively found attached to male mysids. Further studies are required to confirm whether *N. globularis* exhibits specificity in terms of the host's sex, which is most unlikely based on all previous reports. We assume that the cryptoniscan larvae encountered from the same mesozooplankton sample infesting the same host, from which the adult females and males of *N. globularis* were obtained indicates these zooplanktonic larvae are also likely to be *N. globularis* which is not previously reported in the original description of the species by G. O. Sars, (1885).

Acknowledgments

The authors are grateful to the Head of the Department of Marine Biology, Microbiology, and Biochemistry, Cochin University of Science Technology for providing the necessary facilities and research funding for the present study. The help from the Sophisticated Analytical Instrument Facility at Sophisticated Test and Instrumentation Centre, Kochi for SEM analysis is acknowledged. The authors are thankful to Aravind E. H. and Vishnudattan N.K. for their help with the line drawings of Dajidae species. The first author is thankful to the Council of Scientific and Industrial Research (CSIR), New Delhi for the award of Junior Research Fellowship (JRF, 09/239(0555)/2019-EMR-I).

References

- Ariyama H, Saito N, Shimomura M. 2016. *Heterophryxus pacificus*, a new species of dajid isopod from the central North Pacific. *Crustacean Research*, 45: 29–35, doi: [doi:10.18353/crustacea.45.0_29](https://doi.org/10.18353/crustacea.45.0_29)
- Boyko C B, Moss J, Williams J D, et al. 2013. A molecular phylogeny of Bopyroidea and Cryptoniscoidea (Crustacea: Isopoda). *Systematics and Biodiversity*, 11(4): 495–506, doi: [10.1080/14772000.2013.865679](https://doi.org/10.1080/14772000.2013.865679)
- Boyko C B, Bruce N L, Hadfield K A, Merrin K L, et al. 2019. World Marine, Freshwater and Terrestrial Isopod Crustaceans database in the Catalogue of Life. <https://www.marinespecies.org/aphia.php?p=taxdetails&id=147041> [2022-11-10], doi: [10.15468/gnc33i](https://doi.org/10.15468/gnc33i)
- Boyko C B, Williams J D. 2021. A review of the genus *Zonophryxus* Richardson, 1903 (Crustacea: Isopoda: Dajidae) with recognition of *Colypurus agassizi* Richardson, 1905 (Crustacea: Isopoda: Colypuridae) as a synonym of *Zonophryxus similis* Searle, 1914 and the requisite sinking of Colypuridae. *Proceedings of the Biological Society of Washington*, 134(1): 243–264, doi: [10.2988/0006-324X-134.1.243](https://doi.org/10.2988/0006-324X-134.1.243)
- Brandt A. 1993. Redescription of *Notophryxus clypeatus* G. O. Sars, 1885. a parasitic isopod of mysidaceans from the Kobeinsey Ridge, north of Iceland. *Sarsia*, 78(2): 123–127, doi: [10.1080/00364827.1993.10413529](https://doi.org/10.1080/00364827.1993.10413529)
- Brandt A, Janssen H H. 1994. Redescription of *Zonophryxus quinquedens* Barnard, 1913 (Crustacea, Isopoda, Dajidae) from the Weddell Sea, Antarctica, with notes on its biology and zoogeography. *Polar Biology*, 14(5): 343–350, doi: [10.1007/BF00238450](https://doi.org/10.1007/BF00238450)
- Brinton E. 1962. The distribution of Pacific euphausiids. *Bulletin of the Scripps Institution of Oceanography*, 8(2): 21–270, <https://escholarship.org/uc/item/6db5n157>
- Brinton E, Gopalakrishnan K. 1973. The distribution of Indian Ocean euphausiids. In: Zeitzschel B, Gerlach S A, eds. *The Biology of the Indian Ocean*. Berlin: Springer, 357–382, doi: [10.1007/978-3-642-65468-8_31](https://doi.org/10.1007/978-3-642-65468-8_31)
- Brinton E, Ohman M D, Townsend A W, et al. 2000. Euphausiids of the World Ocean. In: *World Biodiversity Database CD-ROM Series*, Window version 1, ISBN: 3-540-14770-5
- Coyle K O, Mueller G J. 1981. Larval and juvenile stages of the isopod *Holophryxus alaskensis* (Epicarida, Dajidae) parasitic on decapods. *Canadian Journal of Fisheries and Aquatic Sciences*, 38(11): 1438–1443, doi: [10.1139/f81-190](https://doi.org/10.1139/f81-190)
- De Silva-Dávila R, Palomares-García R, González-Rodríguez E, et al. 2004. Varamiento de *Nematoscelis difficilis* en la Bahía de La Paz, Baja California Sur, México. In: Hendrickx M, ed. *Contributions to the Study of East Pacific Crustaceans*. México: Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, 3: 1–9
- Field L H. 1969. The biology of *Notophryxus lateralis* (Isopoda: Epicaridea), parasitic on the euphausiid *Nematoscelis difficilis*. *The Journal of Parasitology*, 55(6): 1271–1277, doi: [10.2307/3277273](https://doi.org/10.2307/3277273)
- Gómez-Gutiérrez J, Shields J D. 1998. Range extension for *Oculophryxus bicaulis* Shields & Gómez, 1996 (Isopoda, Dajidae) in the South China Sea. *Crustaceana*, 71(2): 167–170, doi: [10.1163/156854098x00149](https://doi.org/10.1163/156854098x00149)
- Gómez-Gutiérrez J, Castellanos-Osorio I. 2010. *Heterophryxus appendiculatus* G. O. Sars, 1885 (Isopoda, Dajidae): Extension of its known range in the northeast Pacific and Caribbean Sea (Mexico) that indicates inter-ocean zoogeographic distribution. *Crustaceana*, 83(10): 1221–1230, doi: [10.1163/001121610X527004](https://doi.org/10.1163/001121610X527004)
- Gómez-Gutiérrez J, Robinson C J, Kawaguchi S, et al. 2010. Parasite diversity of *Nyctiphanes simplex* and *Nematoscelis difficilis* (Crustacea: Euphausiacea) along the northwestern coast of Mexico. *Diseases of Aquatic Organisms*, 88(3): 249–266, doi: [10.3354/dao02155](https://doi.org/10.3354/dao02155)
- Gómez-Gutiérrez J, Morales-Ávila J R, Kawaguchi S. 2017. *Global Diversity and Ecological Function of Parasites of Euphausiids*. Cham: Springer, 17–38, doi: [10.1007/978-3-319-41055-5](https://doi.org/10.1007/978-3-319-41055-5)
- Gotto R V. 1983. A hitherto undescribed juvenile stage of a female dajid isopod. *Journal of Crustacean Biology*, 3(4): 629–635, doi: [10.1163/193724083X00292](https://doi.org/10.1163/193724083X00292)
- Hansen, H. J. (1911) The genera and species of the order Euphausiacea, with an account of remarkable variation. *Bulletin del'Institut Océanographique de Monaco*, 210, 1–54.
- Murtey M D, Ramasamy P. 2016. Sample preparations for scanning

- electron microscopy–life sciences. In: Janacek E, Kral R, eds. *Modern Electron Microscopy in Physical and Life Sciences*, ISBN: 9789535150633, 9535150634
- Ohtsuka S, Harada S, Shimomura M, et al. 2007. Temporal partitioning: dynamics of alternating occupancy of a host microhabitat by two different crustacean parasites. *Marine Ecology Progress Series*, 348: 261–272, doi: [10.3354/meps07096](https://doi.org/10.3354/meps07096)
- Pillai N K. 1961. Additions to the Mysidacea of Kerala. *Bull. Centr. Res. Inst. Univ. Kerala, Trivandrum*, 8: 15–35
- Pillai N K. 1964. Isopod parasites of Indian mysids. *Annals and Magazine of Natural History*. 13(6): 739–743, doi: [10.1080/00222936308651423](https://doi.org/10.1080/00222936308651423)
- Pillai N K. 1965. A review of the work on the shallow-water Mysidacea of the Indian waters. In: *Proceedings of the Symposium on Crustacea*. Ernakulam: Marine Biological Association of India, 1681–1728
- Pillai K N. 1973. Mysidacea of the Indian Ocean. handbook to the International Zooplankton Collections 4; p. 1–125; Indian Ocean Biological Centre; Kerala state, India
- Rameshkumar G, Ravichandran S. 2014. Problems caused by isopod parasites in commercial fishes. *Journal of Parasitic Diseases*, 38(1): 138–141, doi: [10.1007/s12639-012-0210-4](https://doi.org/10.1007/s12639-012-0210-4)
- Rohde K. 1982. *Ecology of Marine Parasites*. St. Lucia: University of Queensland Press, doi: [10.5555/19840814613](https://doi.org/10.5555/19840814613)
- Sars G O. 1869. Undersøgelser over Christiania-fjordens Dybvans-fauna anstillede paa en i Sommeren 1868 foretagen Zoologisk Reise. *Nyt Magazin for Naturvidenskaberne*. 16: 305–362
- Sars, G. O. 1870. Carcinologiske Bidrag til Norges Fauna. I. Monographi over de ved Norges Kyster forekommende Mysider. Pt. 1 Christiania, K. Norske Videnskab. Trondhjem. 64 pp, pls. I–V.
- Sars G O. 1879. Crustacea et Pycnogonida nova in itinere 2do et 3tio expeditionis Norvegicae anno 1877 & 78 collecta (prodromus descriptionis). *Archiv for Mathematik og Naturvidenskab*, 4: 427–476, ISSN 0365-4524
- Sars G O. 1883. Oversigt af Norges crustaceer med foreløbige bemærkninger over de nye eller mindre bekjendte Arter. *Forhandlinger i Videnskabs-Selskabet i Christiania*, 18: 1–124, pls. 1–6, Source id: 5661
- Sars G O. 1885. Report on the Schizopoda collected by HMS Challenger during the years 13 (3): 1873–1876, *Zoology*. 13 (part 37): 1–228, pl. 1–38
- Sars G O. 1899. An account of the Crustacea of Norway, with short descriptions and figures of all the Species, 2. Universitets-forlaget, ISBN: 9781359115287
- Schotte M. 1995. *Gnathia arabica*, n. s. First record of a gnathiid from the Arabian Sea, and new records of isopods (Crustacea; Isopoda) from Pakistan in collections of the Smithsonian Institution. In: Thompson M F, Tirmizi N S, eds. *The Arabian Sea, Living Resources and the Environment*. Lahore: Vanguard Press, 111–118
- Schultz G A. 1977. Bathypelagic Isopod Crustacea from the Antarctic and Southern Seas. *Antarctic Research Series, Biology of the Antarctic Seas*. 23(3): 69–128, Source id: 47006
- Schultz G A. 1978. More planktonic isopod crustaceans from sub-antarctic and Antarctic Seas. In: Pawson D L, ed. *Biology of the Antarctic Seas VII*. Washington: The American Geophysical Union, 27: 69–89, Source id: 47007
- Sebastian M J. 1970. On two isopod parasites of Indian euphausiids. *Journal of Natural History*, 4(2): 153–158, doi: [10.1080/00222937000770161](https://doi.org/10.1080/00222937000770161)
- Shaw J J. 2023. *Hansarsia* nom. nov. , a replacement name for *Nematoscelis* G. O. Sars, 1883 (Crustacea: Euphausiidae: Shawae), a junior homonym of *Nematoscelis* Wollaston, 1867 (Coleoptera: Staphylinidae: Aleocharinae). *Zootaxa*, 5256(1): 84–86, doi: [10.11646/zootaxa.5256.1.6](https://doi.org/10.11646/zootaxa.5256.1.6)
- Shields J D, Gómez-Gutiérrez J. 1996. *Oculophryxus bicaulis*, a new genus and species of dajid isopod parasitic on the euphausiid *Stylocheiron affine* Hansen. *International Journal for Parasitology*, 26(3): 261–268, doi: [10.1016/0020-7519\(95\)00126-3](https://doi.org/10.1016/0020-7519(95)00126-3)
- Shimomura M, Ohtsuka S, Naito K. 2005. *Prodajus curviabdominalis* n. sp. (Isopoda: Epicaridea: Dajidae), an ectoparasite of mysids, with notes on morphological changes, behaviour and life-cycle. *Systematic Parasitology*, 60(1): 39–57, doi: [10.1007/s11230-004-1375-8](https://doi.org/10.1007/s11230-004-1375-8)
- Shimomura M, Ohtsuka S. 2008. New record of a euphausiid ectoparasitic isopod, *Heterophryxus appendiculatus* GO Sars, 1885 (Crustacea: Dajidae) from Japan. *Proceedings of the Biological Society of Washington*, 121(3): 326–330, doi: [10.2988/07-09.1](https://doi.org/10.2988/07-09.1)
- Shimomura M, Ohtsuka S. 2011. Two new species of ectoparasitic isopods (Isopoda, Dajidae) from mysids in Japan. In: Asakura A, ed. *New Frontiers in Crustacean Biology*. Boston: Brill, 23–30, doi: [10.1163/ej.9789004174252.i-354.24](https://doi.org/10.1163/ej.9789004174252.i-354.24)
- Smith, S. I. 1879. The stalk-eyed crustaceans of the Atlantic coast of North America north of Cape Cod. *Transactions of the Connecticut Academy of Arts and Sciences*. 5(2): 27–138, pls. 8–12, doi: [10.5962/bhl.title.10046](https://doi.org/10.5962/bhl.title.10046)
- Strickland J D H, Parsons T R. 1972. *A Practical Handbook of Seawater Analysis*. Ottawa: Fisheries Research Board of Canada, doi: [10.25607/OBP-1791](https://doi.org/10.25607/OBP-1791)
- Tattersall W M. 1951. The mysidacea of the United States National museum. *Bulletin of the United States National Museum*, 201: 1–292, doi: [10.5479/si.03629236.201.1](https://doi.org/10.5479/si.03629236.201.1)
- Tattersall O S. 1957. Report on a small collection of Mysidacea from the Sierra Leone estuary together with a survey of the genus *Rhopalophthalmus* Illig and a description of a new species of *Tenagomysis* from Lagos, Nigeria. *Proceedings of the Royal Society London*. 129: 81–128, doi: [10.1111/j.1096-3642.1957.tb00282.x](https://doi.org/10.1111/j.1096-3642.1957.tb00282.x)
- Vanhöffen E. 1914. Die Isopoden der Deutschen Spdpolar-Expedition, 1901–1903. *Deutschen Südpolar Expedition*, 7: 447–598, crid: 1573105974301575552
- Wägele J W. 1992. Co-evolution between Fishes and Crustaceans. *Acta Zoologica Lituanica*, 73(5): 355–356, doi: [10.1111/j.1463-6395.1992.tb01107.x](https://doi.org/10.1111/j.1463-6395.1992.tb01107.x)
- Williams J D, Boyko C B. 2012. The global diversity of parasitic isopods associated with crustacean hosts (Isopoda: Bopyroidea and Cryptoniscoidea). *PLoS One*, 7(4): e35350, doi: [10.1371/journal.pone.0035350](https://doi.org/10.1371/journal.pone.0035350)
- Williams J D, Boyko C B. 2021. Out on a limb: novel morphology and position on appendages of two new genera and three new species of ectoparasitic isopods (Epicaridea: Dajidae) infesting isopod and decapod hosts. *Zoosystema*, 43(4): 79–100, doi: [10.1371/journal.pone.0035350](https://doi.org/10.1371/journal.pone.0035350)