



A NEW *ASTEROCHERES* (COPEPODA, SIPHONOSTOMATOIDA)
SYMBIONT OF THE SEA STAR *NIDORELLIA ARMATA* (GRAY, 1840)
(ECHINODERMATA, ASTEROIDEA) IN THE EASTERN TROPICAL
PACIFIC

BY

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ABSTRACT

A new species of the diverse and widely distributed symbiotic copepod genus *Asterocheres* is described from the sea star *Nidorellia armata* (Gray, 1840) in Mexican waters of the Eastern Tropical Pacific. The new species resembles various other congeners by sharing several characters including: (1) a siphon extending to the intersection of the maxilliped, (2) a 21-segmented antennule, and (3) a 2-segmented mandible palp. It can be distinguished by the unique structure and ornamentation of the maxilla, the armature and proportions of the fifth leg, and its body shape.

This is the first documented record of *Asterocheres* from the Mexican Pacific and the first finding of a symbiotic copepod on this sea star host. Males, ovigerous females and copepodites were recorded from the host, thus suggesting a well-established symbiotic association. It is likely that copepods feed on the host's tegument. Further studies will be needed to assess the reproductive traits and seasonality of this copepod as a symbiont.

Key words. — Copepod symbiont, sea star, Mexico

RESUMEN

Se describe una nueva especie del diverso y ampliamente distribuido género de copépodos simbiosntes *Asterocheres*, asociada a la estrella de mar *Nidorellia armata* (Gray, 1840) en aguas mexicanas del Pacífico oriental tropical. La nueva especie es parecida a otros congéneres al compartir varios caracteres que incluyen: (1) un sifón que se extiende hasta la intersección del maxilípido, (2) anténula de 21 segmentos y (3) palpo mandibular de 2 segmentos. La nueva especie se puede distinguir por la estructura y ornamentación única de la maxila, la armadura y proporciones de

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la quinta pata y por la forma del cuerpo. Este es el primer registro documentado de *Asterocheres* del Pacífico mexicano y el primer hallazgo de un copépodo simbiote en esta estrella de mar. Se observaron machos, hembras ovígeras y copepoditos en el hospedero, lo que sugiera una asociación simbiótica bien establecida. Es probable que los copépodos se alimentan del tegumento del huésped, por lo que se necesitan más estudios para evaluar los rasgos reproductivos y la estacionalidad de este copépodo como simbiote.

Palabras clave. — Copepodos simbiotes, estrellas de mar, México

INTRODUCTION

The symbiotic siphonostomatoid copepod genus *Asterocheres* Boeck, 1859 is frequently found in association with sponges (Johnsson, 1998; Boxshall & Halsey, 2004; Varela, 2012) but has also been recorded on bryozoans (Ivanenko & Smurov, 1997), cnidarians (Kim, 2004b), and different groups of echinoderms (Varela, 2010; Kim, 2004a). Kim (2010) revised the generic diagnosis, and other authors provided further taxonomic revisions and descriptions of new taxa (Kim & Min, 2013; Bandera & Conradi, 2014; Bandera, 2015; Kim, 2016). Knowledge on the diversity of *Asterocheres* and other symbiotic copepods associated with benthic invertebrates in the zoogeographic region of the Eastern Tropical Pacific is still lacking; most extant records of siphonostomatoid copepods in the Eastern Pacific region include 34 species of 9 genera of dirivultid siphonostomatoids from deep hydrothermal vents (Gollner et al., 2014). Only three nominal species of *Asterocheres* have hitherto been reported from this region: *A. pilosus* Kim, 2004a from the sea urchin *Eucidaris thouarsii* (Agassiz & Desor, 1846), *A. walteri* Kim, 2004a from the sea star “*Oreaster brevispinis*” (a species of questionable validity: cf. Mah & Foltz, 2011), and *A. urabensis* Kim, 2004a from the scleractinian coral *Pocillopora damicornis* (Linnaeus, 1758), thus contrasting with the nearly 25 species of this genus and 115 other species of symbiotic copepods reported from the adjacent Caribbean Basin in the Northwestern Tropical Atlantic region (Korzhevina et al., 2019). Previous records of *Asterocheres* in the Eastern Tropical Pacific include: all from the Pacific coast of Panama (Kim, 2004a). During the analysis of samples obtained from a biological survey of the benthic invertebrate fauna of the southern Pacific coast of Mexico, we found an asterocherid copepod as a symbiont of the chocolate chip sea star, *Nidorellia armata* (Gray, 1840). The taxonomic examination of these copepods allowed us to recognize them as representing an undescribed species of the genus *Asterocheres*. The new species is herein described and illustrated based on adult male and female specimens and compared with its closest similar congeners.

MATERIAL AND METHODS

Specimens of the host sea star *Nidorellia armata* were collected manually from the intertidal zone of a small cove with coral patches on the Pacific coast of Mexico (Estacahuite Bay, Oaxaca, Mexico: 15°40'4.98"N 96°28'54.6"W) and placed in plastic bags. Copepods were found to be loosely attached to different parts of the host body. In vivo observations of the associated copepods were made under a stereomicroscope. Copepods were sorted, counted and then prepared for further taxonomic examination by placing them in glycerol and lightly staining with methylene blue prior to dissection. Dissected appendages were mounted and observed using the reverse slide method of Humes & Gooding (1964). Taxonomic illustrations were prepared with the aid of a camera lucida mounted on an Olympus BX53 semi-motorized microscope with Differential Interference Contrast (DIC). An adult female specimen was prepared for SEM examination with a JEOL SM-6010 microscope at facilities of ECOSUR in Chetumal, Mexico. The process included dehydration of specimens in progressively higher ethanol solutions (70, 96, 100%), critical point drying, and gold coating following standard methods.

Kim's (2010) descriptive standards and morphologic nomenclature for siphonostomatoid copepods were followed. The copepod's body length was measured from the anterior margin of the rostrum to the posterior margin of the caudal rami, excluding caudal setae. The type specimens are deposited in the collection of zooplankton held at El Colegio de la Frontera Sur (ECOSUR), Chetumal, Quintana Roo, Mexico (ECO-CHZ).

SYSTEMATICS

Order SIPHONOSTOMATOIDA Thorell, 1859

Family ASTEROCHERIDAE Giesbrecht, 1899

Genus *Asterocheres* Boeck, 1859

Asterocheres nidorelliae new species (figs. 1-4)

Material examined.— Holotype adult female (ECO-CH-Z-01038), allotype adult male (ECO-CH-Z-01039), 7 female and 7 male paratypes (ECO-CH-Z-01040; ECO-CH-Z-01041) from the sea star *Nidorellia armata* (Gray, 1840) collected 20 February 2013 in Estacahuite Bay, Oaxaca, southern Pacific coast of Mexico (15°40'4.98"N 96°28'54.6"W) at a sampling depth of 4 m. Collector: C. Nahxieli Reyes-González.

Type locality.— Estacahuite Bay, Oaxaca, southern Pacific coast of Mexico (15°40'4.98"N 96°28'54.6"W).

Description of adult female.— Body (fig. 1A) cycloform, with robust prosome, not flattened dorso-ventrally (fig. 1B), urosome relatively short. Body length = 806 μm (size range = 755-883 μm), maximum width = 454 μm (width

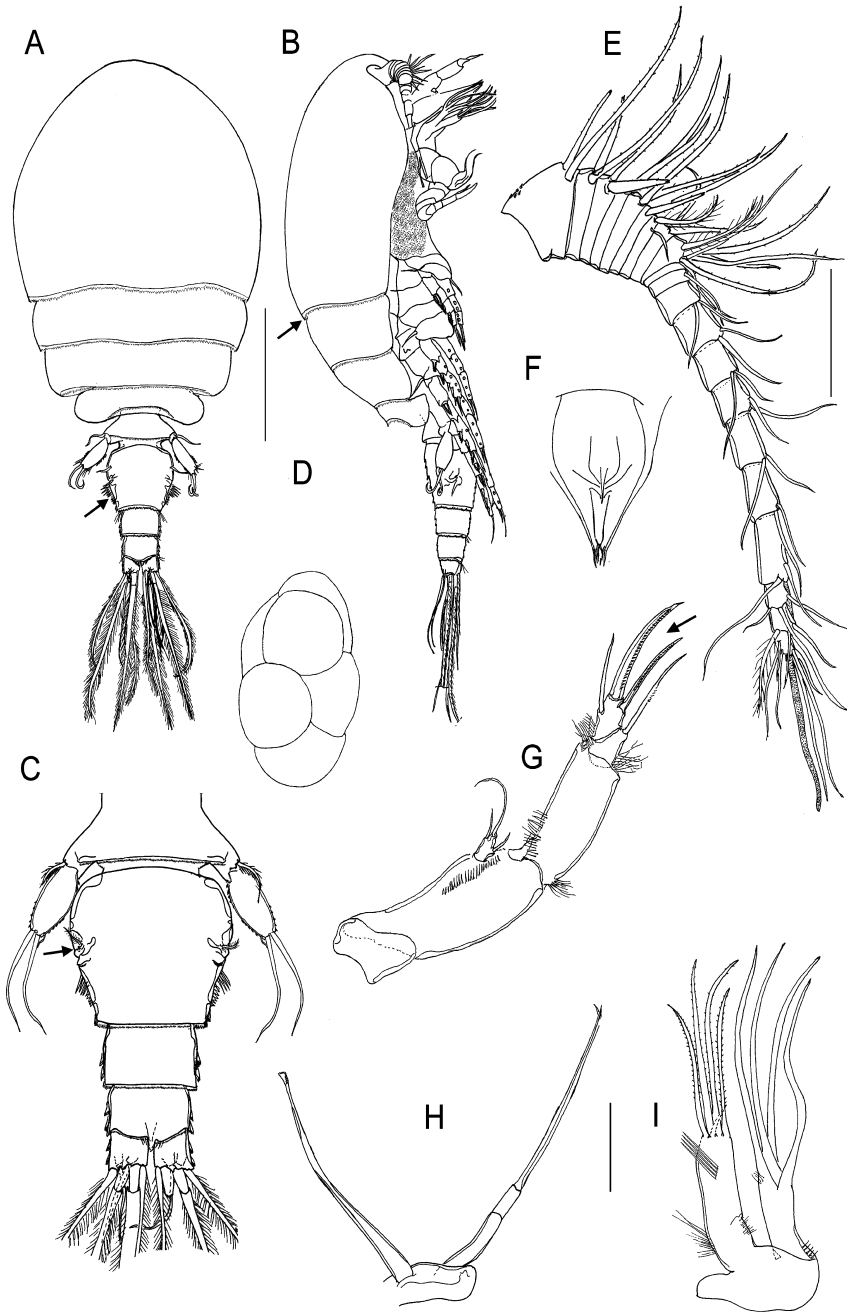


Fig. 1. *Asterocheres nidorelliae* n. sp., female holotype. A, Habitus dorsal view; B, habitus lateral view showing hyaline fringe on posterior margin (arrow); C, urosome with fifth legs, ventral view; D, egg sac; E, antennule; F, siphon; G, antenna showing stout terminal spine (arrow); H, mandible; I, maxillule. Scale bars: A, B = 250 μ m; C, E = 100 μ m; D, F-I = 50 μ m.

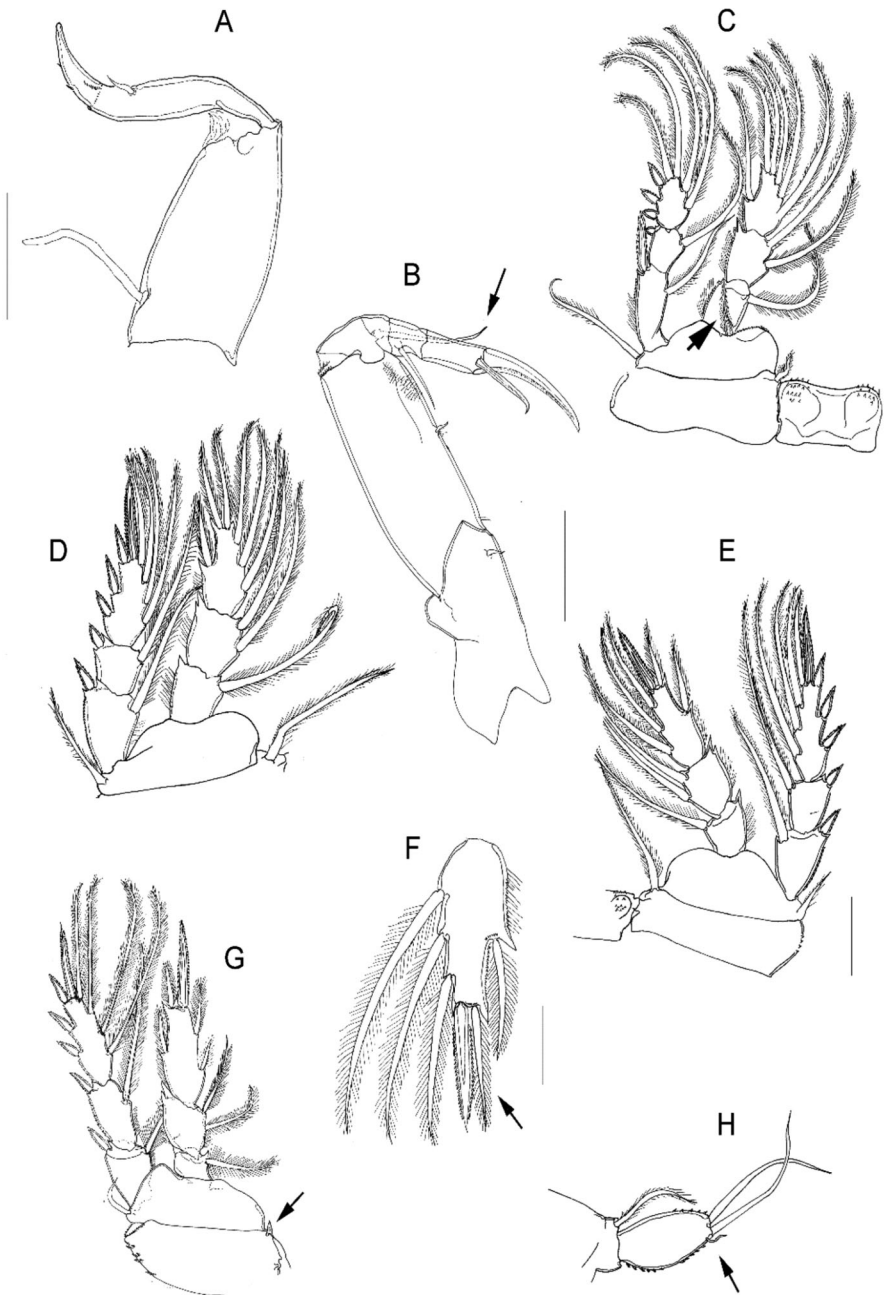


Fig. 2. *Asterocheres nidorelliae* n. sp., holotype female. A, Maxilla; B, maxilliped with long subdistal seta (arrow); C, leg 1 with short basipodal spine (arrow); D, leg 2; E, leg 3; F, third endopodal segment of leg 3 with longer outer distal spine (arrow); G, leg 4 with reduced outer basipodal seta (arrow); H, free segment of leg 5 with accessory element (arrow). Scale bars: A-E, G = 50 μm ; F, H = 25 μm .

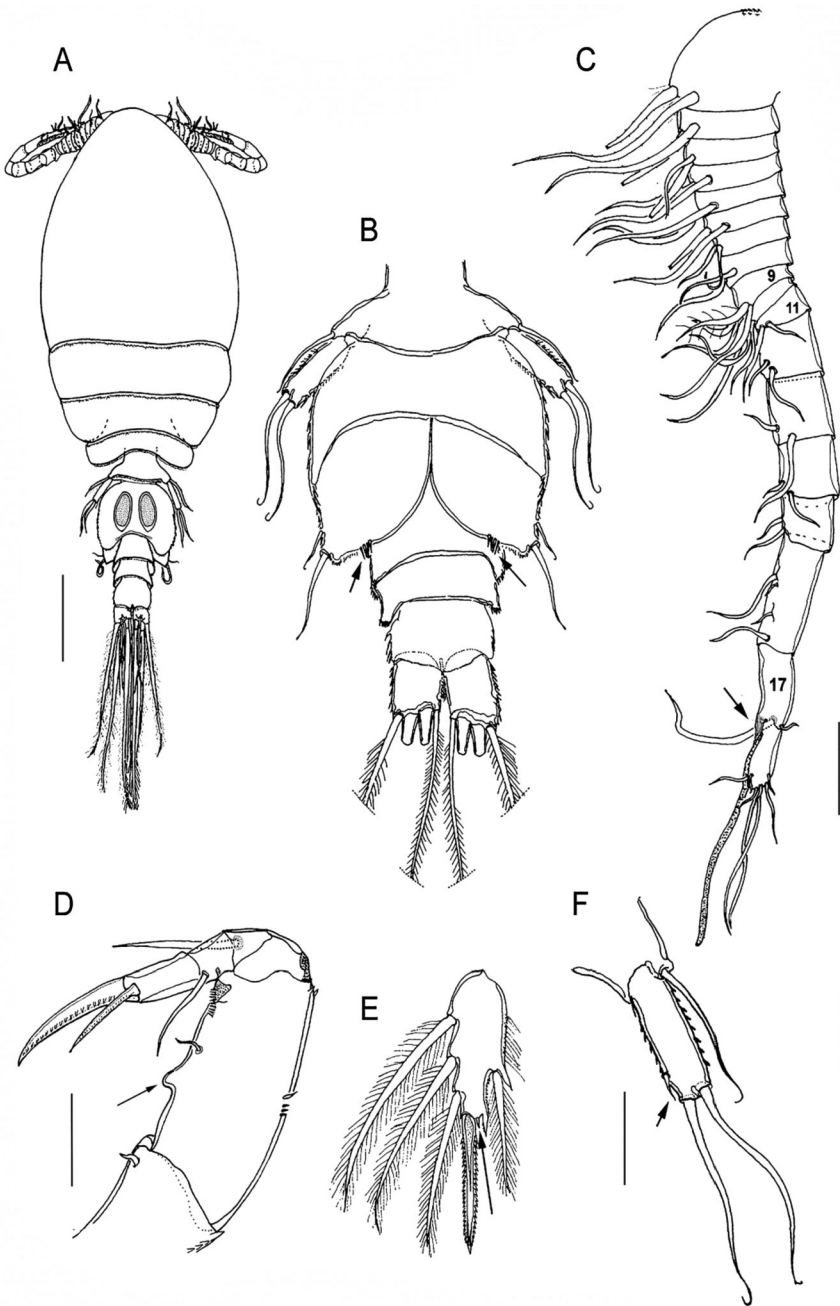


Fig. 3. *Asterocheres nidorelliae* n. sp., allotype male. A, Habitus, dorsal view; B, urosome showing fifth legs, ventral view; C, antennule; D, maxilliped; E, third endopodal segment of leg 3; F, fifth leg free segment. Scale bars: A = 100 μm ; B, C = 50 μm ; D-F, 25 μm .

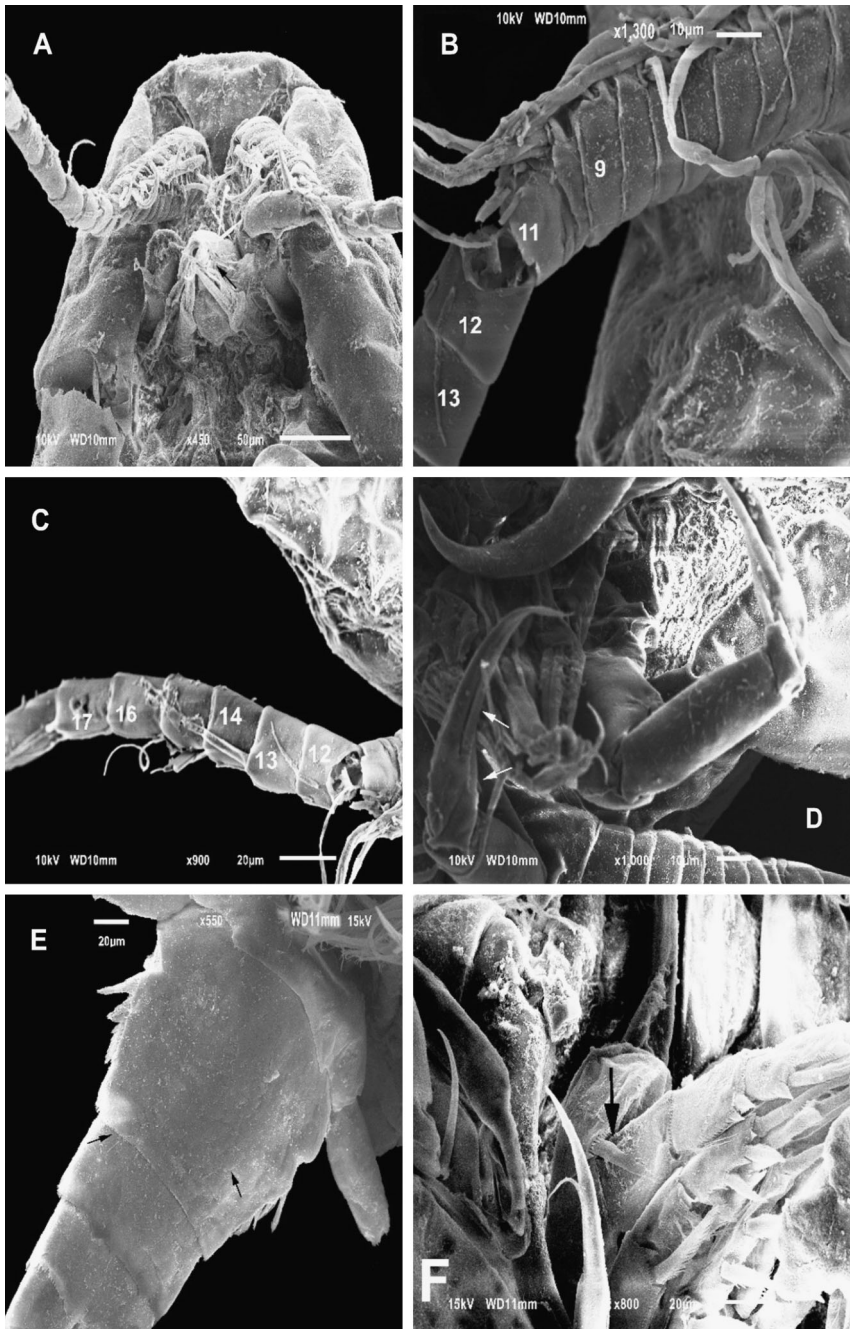


Fig. 4. *Asterocheres nidorelliae* n. sp., SEM-prepared adult female. A, Anterior part of cephalothorax and rostral area, ventral view; B, antennular segments 3-13; C, antennular segments 12-17 showing smooth setae; D, distal elements of antennary basis; E, urosomites with small cuticular scales, dorsal view; F, leg 1 basal seta (arrow).

range = 419-498 μm), $n = 10$. Body length/width ratio = 1.8: 1, thickness = 226 μm . Cephalothorax length = 360 μm incorporating first pedigerous somite, longer than three succeeding free pedigerous somites combined. Epimeral margins of pedigerous somites 2-4 rounded, posterior margins of pedigerous somites ornamented with narrow hyaline frill. Urosome (fig. 1C) with 4 urosomites, comprising short and wide fifth pedigerous somite carrying fifth legs. Genital double-somite subrectangular (119 \times 134 μm), with expanded proximal half. Genital areas located dorsolaterally, armed with single short plumose seta and small adjacent spine. Lateral margins posterior to genital openings with two setule tufts (anterior-most tuft with 5-6 long, slender setules; posterior tuft represented by group of 6-7 small, spinule-like elements). First urosomite measuring 43 \times 81 μm , anal somite 40 \times 72 μm . Caudal ramus subquadrate, 30 \times 32 μm (1 : 1.06), armed with 6 plumose caudal setae. All urosomites with irregularly serrate hyaline frill along posterior margins (small arrows in fig. 4E). Dorsal surface of urosomites irregularly ornamented with small acute cuticular scales (fig. 4E). Egg sac (fig. 1D) 266 \times 162 μm containing 7 or 8 eggs, each egg about 90 μm in diameter.

Rostrum weakly developed, subtriangular in ventral view (fig. 4A). Antennule (fig. 1E) 347 μm long, 21-segmented, each segment armed with 2 setae (s), except for 7s on segment 9 (fig. 4B), 2s + aesthetasc on segment 18 and 3s, 3s, 6s, on three distal segments (19-21), respectively (fig. 4C); first segment with row of small spinules on anterior surface; several setae on proximal segments apically branched and several other antennular setae lightly pinnate. Antennule segments 7, 9, and 20 each with single plumose seta. Antenna (figs. 1G, 4D) biramous; coxa short, unarmed; basis subrectangular (78 \times 34 μm), gradually expanding distally, with row of small spinules near insertion of exopodal ramus. Exopod 1-segmented, subquadrate (11 \times 8 μm), with 1 subdistal and 2 unequally long terminal setae. Endopod 3-segmented; first segment subrectangular (48 \times 23 μm), distal half furnished with small spinules on outer margin; distal inner half with 6 spinules. Second endopodal segment short, with long inner distal seta (fig. 4D); third endopodal segment armed with 2 setae; terminal claw 58 μm long; distal setae and claw with serrate inner margin (arrow in fig. 1G).

Oral cone (fig. 1F) short (167 \times 100 μm), robust, reaching insertion of maxilliped (fig. 4A). Mandible (fig. 1H) consisting of elongate slender stylet (156 μm long) furnished with 10 small distal teeth inserted on the siphon channel, formed by fusion of labrum and lip. Mandibular palp slender, 2-segmented, proximal segment of palp = 48 μm , distal segment = 19 μm , with two equally long (114 μm) terminal setae reaching beyond tip of mandible. Maxillule (fig. 1I) bilobed, inner lobe subrectangular (67 \times 19 μm), with subdistal row of setules and 5 terminal setae, four of these subequally long (69, 72, 85 and 99 μm), lightly serrate; fifth seta short, smooth. Outer maxillary lobe smaller (42 \times 16 μm),

armed with 4 subequally long smooth setae (128, 133, 114 and 121 μm). Maxilla (fig. 2A) 2-segmented, proximal segment robust, armed with proximal aesthetasc-like element; distal claw conical, short, weakly curved, with single antero-medial seta; lateral margin with subdistal minute setule and two spinules on convex margin. Maxilliped (fig. 2B) elongate, 6-segmented. First segment subrectangular ($51 \times 44 \mu\text{m}$) armed with single small distal seta, second segment longer ($105 \times 48 \mu\text{m}$) than first, with single inner seta and 1 outer spinule plus subdistal patch of small spinules; third segment short ($15 \times 22 \mu\text{m}$), armed with long subdistal seta reaching distal margin of fifth segment (arrow in fig. 2B).

Legs 1-4 (fig. 2C-G) biramous, with 3-segmented rami. Armature formula (Arabic numerals = setae, Roman numerals = spines) as follows:

Formula of setae and spines of legs 1-4 in *Asterocheres nidorelliae* new species

Leg	Coxa	Basis	Exopod	Endopod
Leg 1	0-1	1-1	I-1; I-1; III,2,2	0-1; 0-2; 1,2,3
Leg 2	0-1	1-0	I-1; I-1; III, I-1,3	0-1; 0-2; 1,2,3
Leg 3	0-1	1-0	I-1; I-1; III, I-1,3	0-1; 0-2; 1,1-I,3
Leg 4	0-1	1-0	I-1; I-1; III, I-1,3	0-1; 0-2; 1,1-I,2

Outer distal corner of second endopodal segment of legs 1-4 forked (fig. 2C-E, G); outer spine on leg 1 first exopodal segment stout, longest of ramus (52 μm), leg 1 inner basipodal seta short, spiniform, barely reaching distal margin of first endopodal segment (figs. 2C, 4F). Leg 2-4 outer basipodal seta short, barely reaching distal margin of first exopodal segment. Inner coxal seta of legs 2-3 plumose, that on legs 1 and 4 remarkably short. Legs 1-4 with cuticular denticles on distal and lateral margins of coxa and basis, intercoxal plate of legs 1-4 with thick lateral setules, plates ornamented with rows of small spinules (fig. 2C). Leg 3 third endopodal segment with equally long distal elements (fig. 2F). Leg 5 free segment (fig. 2H), cylindrical ($64 \times 26 \mu\text{m}$) furnished with spinules along posterior and anterior margins; armed with 2 long apical subequally long setae. Leg 6 represented by plumose seta and 1 spiniform element on genital area (arrow in fig. 1C).

Male.— Body shape as in female (fig. 3A), relatively smaller: body length = 597 μm (length range = 521-648 μm), maximum width 296 μm (range = 259-359 μm) $n = 10$. Urosome 5-segmented (fig. 3B), fifth pedigerous somite shorter than wide ($29 \times 85 \mu\text{m}$). Genital somite robust, $88 \times 119 \mu\text{m}$; succeeding two urosomites and anal somite measuring 21×57 , 18×56 , and $24 \times 53 \mu\text{m}$, respectively. Caudal rami subquadrate ($20 \times 25 \mu\text{m}$).

Rostrum as in female. Antennule (fig. 3C) 18-segmented; each segment with 2 setae (s), except for 7s on segment 9, 4s on segment 16 and 8s on last segment.

Anterodistal corner of penultimate segment 17 produced into acute process (arrow in fig. 3C), with aesthetasc. Antenna, oral cone and mouthparts as in female. Maxilliped resembling that of female except for showing medial conical process on inner margin of second segment (arrow in fig. 3D). Legs 1, 2 and 4 as in female; leg 3 third endopodal segment with outer distal seta distinctly reduced (arrow in fig. 3E), thus diverging from condition found there in female (fig. 2F). Leg 5 cylindrical, with small subdistal accessory seta on inner margin (arrow in fig. 3F). Leg 6 represented by posteroventral flap on genital somite bearing 2 unequal setae, plus row of spinules on each side (arrows in fig. 3B).

Etymology.— The specific epithet refers to the host from which this symbiotic copepod was obtained. The suffix thus is a feminine noun in the genitive singular.

Remarks.— The specimens examined were identified as belonging to *Asterocheres* by their possession of the following diagnostic characteristics (Boxshall & Halsey, 2004; Kim, 2010): (a) maxillule bilobed with 5s on inner lobe and 4s on outer lobe, (b) maxilliped 6-segmented, with armature formula 1, 1 (or 0) 2, 1, 1, 1 + claw, and (c) third endopodal segment of leg 1-2: 1,2,3; for leg 3: 1,1 + I,3 and leg 4: 1,1 + 1,2.

Our comparative analysis of the known species of the genus showed that the new species *A. nidorelliae* shares the following combination of characters with a reduced group of congeners: (1) siphon extending to intersection of maxilliped, (2) 21-segmented antennule, (3) 2-segmented mandible palp, (4) caudal ramus short, subquadrate. This set of characters is also present in: *A. flustrae* Ivanenko & Smurov, 1997, *A. jeanyeatmanae* Yeatman, 1970, *A. complexus* Stock, 1960, and *A. nudicoxus* Kim, 2010. The new species *A. nidorelliae* differs from both *A. complexus* (as redescribed by Bandera & Conradi, 2014) and *A. flustrae* by the armature of the fifth leg, with two long and one short smooth setae in the new species vs. three long setae present in both *A. flustrae* (cf. Ivanenko & Smurov, 1997, fig. 2B, C) and *A. complexus*. Also, the new species differs from both *A. flustrae* and *A. complexus* in the structure of the second maxillary segment. In the new species this segment is conical, relatively short (i.e., shorter than the preceding segment), whereas the same structure is slender, elongate (i.e., as long as or longer than the preceding segment) in both *A. flustrae* (cf. Ivanenko & Smurov, 1997, fig. 5D) and *A. complexus* (cf. Bandera & Conradi, 2014, fig. 1B). Also, in *A. flustrae*, the urosome cuticular scales are distinctively strong and conspicuous, arranged in defined rows (Ivanenko & Smurov, 1997, fig. 10D), thus diverging from the small, scattered, weakly developed scale pattern found in the new species (fig. 4E).

Asterocheres jeanyeatmanae differs from the new species by: (1) the shape of the pedigerous somites 2-4 pleural processes, subacute in *A. jeanyeatmanae* and

rounded in the new species. In addition, the second segment of the maxilla is unarmed in *A. jeanyeatmanae* vs. maxilla armed with a strong seta and a distal row of spinules found in *A. nidorelliae*. *A. jeanyeatmanae* can be easily distinguished from the new species *A. nidorelliae* by the shape of the body; in the former species it is distinctively flattened dorsoventrally, with very wide tergites, not cyclopiform as in *A. nidorelliae* and other similar species like *A. complexus* (cf. Bandera & Conradi, 2014). The presence of an aesthetasc on the syncoxa of the new species is a character shared by several other species of *Asterocheres* and even by other asterocherid genera (Ivanenko & Smurov, 1997; Bandera & Conradi, 2014); its taxonomic value is yet to be explored among asterocherids.

The new species can be readily distinguished from *A. nudicoxus*, which has a remarkably elongate fifth leg, its free segment with a length/width ratio = 6.0 and armed with three long distal setae, thus diverging from the clearly shorter (length/width ratio = 2.5) fifth leg of *A. nidorelliae* n. sp. and armed with two long and one-minute distal setae.

Ecological comments.— The live colour of the copepod body was variable from orange to reddish, partially resembling the colours of the host's body surface. The detritivorous sea star *Nidorellia armata* is distributed in the Eastern Tropical Pacific but is considered rare in this region (Luna-Salguero & Reyes Bonilla, 2010). The specimens of *N. armata* examined had an average of 70 symbiotic copepods per individual, including ovigerous females, adult males and copepodites, thus suggesting a well-established symbiotic association.

Our live observations allowed us to detect the presence of tight copepod aggregations on the dorsal surface of the sea star (fig. 5A). Using their antennae, maxillae and maxillipeds as grasping appendages, copepods were found to be attached to the surface between the grooves of the tegumental granules of *N. armata* (fig. 5B, C) and actively moved around the bases of the papulae during our observations (fig. 5D).

DISCUSSION

Röttger et al. (1972) and Mariani & Uriz (2001) stated that symbiotic copepods can obtain their body coloration from their food, particularly when they feed on their host's tegumental pigments. In some symbiotic species females tend to be homochromous with the host tegument (Dumont et al., 2004). Therefore, the observed partially homochromous coloration of female individuals of *Asterocheres nidorelliae* n. sp. and their distribution on the host's body surface suggests that this species feeds on the host tissues.

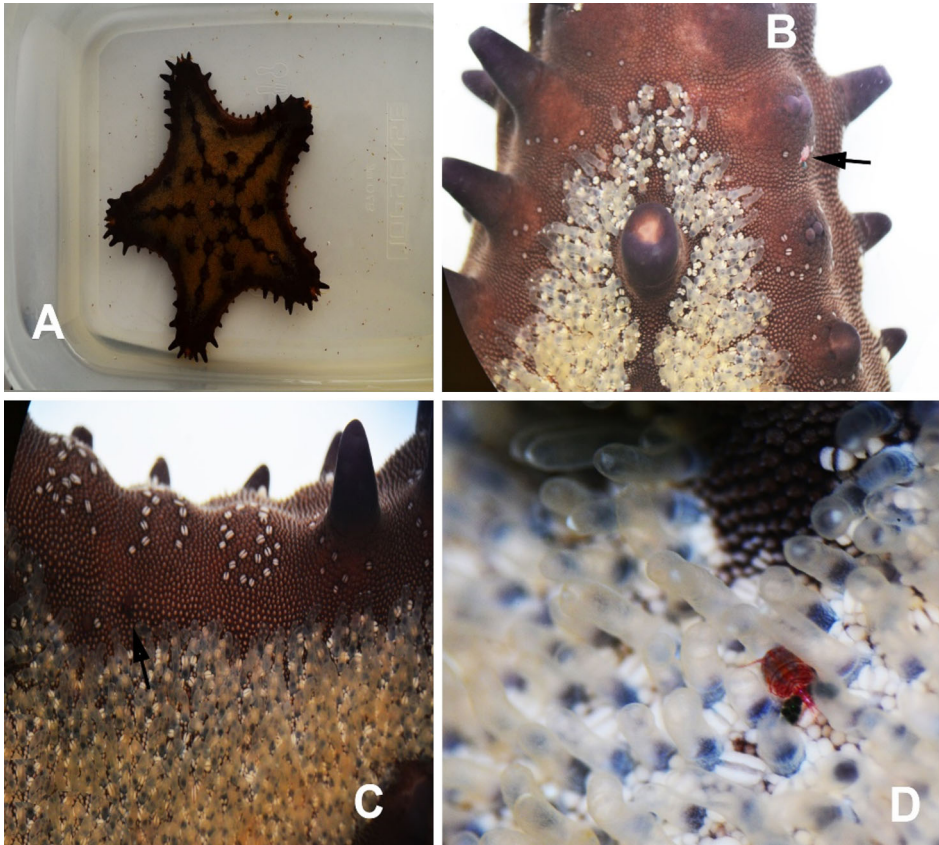


Fig. 5. A, Upper (dorsal) view of an infected individual of the sea star *Nidorellia armata* (Gray, 1840) from the Mexican Pacific; B-C, clusters of the symbiotic copepod *Asterocheres nidorelliae* n. sp. among granules of host tegument; D, female individual (with reddish pigmentation) of *A. nidorelliae* attached to papulae of the sea star *N. armata*.

Our finding of this new species represents the first record of the genus *Asterocheres* in the Mexican Pacific (Suárez-Morales & Gasca, 1998) and the first symbiotic copepod species known from the sea star *Nidorellia armata*. In many symbiotic copepods, the first copepodid stage is considered to be chiefly infective; the subsequent stages, including immature stages and adult males and females, typically establish a full symbiotic association with the host organism (Ohtsuka et al., 2018). The presence of ovigerous females, males and copepodite stages of *A. nidorelliae* in the host sea star suggests that this is a well-established symbiotic association. Further studies will be needed to assess the reproductive and infection traits and the seasonality of this copepod as a symbiont on this sea star.

ACKNOWLEDGEMENTS

The authors deeply appreciate the support and help provided by Dr. Ma. Socorro García-Madrigal (UMAR) during the development of this work. This contribution is part of the first author's (C. N. R.-G.) Master's degree requirements. Dr. Francisco Benítez-Villalobos (UMAR) provided the necessary support to obtain the specimens of *Nidorellia armata* and allowed us to examine the associated copepods. Copepods were deposited and catalogued in the ECOSUR collection of Zooplankton by Rosa Ma. Hernández-Flores.

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