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Ergasilus lyraephorus n. sp. (Copepoda: Cyclopoida: Ergasilidae) parasitic on the Longtail Knifefish *Sternopygus macrurus* (Bloch & Schneider, 1801) (Actinopterygii: Sternopygidae) from Northeast Brazil

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Abstract The cyclopoid family Ergasilidae Burmeister, 1835, is the most common group of parasitic copepods infesting fish in Brazil, and the type-genus *Ergasilus* von Nordmann, 1832 comprises the highest number of species. During a survey of freshwater fish in Northeast Brazil, a new species of *Ergasilus* was found on the gills of the Longtail Knifefish *Sternopygus macrurus* (Bloch & Schneider) (Actinopterygii: Sternopygidae) in the Viana lake system, State of Maranhão. *Ergasilus lyraephorus* **n. sp.** can be distinguished from its closest congeners mainly because it has a lyre-shaped ornamentation on the ventral surface of first pedigerous somite, a feature that has never been reported in the family. In addition, the new species differs from closely related congeners by having a maxillule bearing three elements, by the large spinules on the interpodal plates of legs 1, 2 and 3, and by having leg 5 reduced to a single seta of moderate size. The present study is the first report of an ergasilid parasitizing *S. macrurus*, as well as the first parasitic copepod found on a host belonging to the family Sternopygidae Cope.

Introduction

Ergasilids represents one of the most diverse groups of parasitic copepods worldwide, comprising about 275 species distributed in 31 genera (Walter & Boxshall, 2021; Couto et al., 2023). Members of Ergasilidae Burmeister, 1835 are mainly identified by a robust antenna, modified into a prehensile organ that fertilized females use to attach on the gills, skin, and nostrils, or in the urinary bladder of their mostly

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actinopteryigian hosts, but also occurring on elasmobranchs and bivalve molusks (Boxshall & Halsey, 2004; Boxshall & Defaye, 2008; Rosim et al., 2013; Taborda et al., 2016). Ergasilids have been reported from almost all continents (except Antarctica), but the highest species richness is observed in the Neotropics (Boxshall & Defaye, 2008; Taborda et al., 2016; Narciso & da Silva, 2020). In the Neotropical Region, Brazil has the greatest number of ergasilid species, in which 76 species from 18 genera have been reported so far. Even though Ergasilidae has a remarkable richness in Brazil, some authors affirm that its real diversity and distribution may be unknown, due to an inadequate sampling effort in the country (Luque & Tavares, 2007; Luque et al., 2013; Couto et al., 2023).

Ergasilus von Nordmann, 1832, the type-genus of Ergasilidae, is the most diverse genus in the family, comprising 159 species, 35 of which have been reported on fish hosts from Brazil (Walter & Boxshall, 2021; Marques, 2023). Most congeners are recorded in freshwater, commonly associated with a wide range of fish families, and, less frequently, from planktonic samples (Luque & Tavares, 2007; Luque et al., 2013; Taborda et al., 2016; Varella et al., 2019).

During a parasitological survey of freshwater fish in the State of Maranhão, Northeast Brazil, a species of *Ergasilus* was found on the gills of *Sternopygus macrurus* (Bloch & Schneider) (Gymnotiformes: Sternopygidae). Detailed morphological study of the specimens revealed that they represent a new species, which is described herein.

Materials and methods

Fish were bought dead from local fishermen in the Viana Lake System (3° 1429″ S, 45° 04′ 21″ W), State of Maranhão, Northeast Brazil. Hosts were analyzed mostly fresh, but some specimens were kept frozen at -20°C, prior to parasitological examination. Copepods were collected by washing gill filaments in flowing water or detached using a needle, and fixed and preserved in 80% ethanol. For observation using light microscopy, parasite specimens were cleared in 85% lactic acid and the appendages were dissected and examined using the wooden slide procedure described by Humes and Gooding (1964). Drawings were made using a drawing tube attached to an Olympus CH2 microscope. Light micrographs were taken using a Nikon Eclipse Ei microscope with a PirmeCam Intervision 12 attached. Measurements, in micrometers unless otherwise stated, were taken using an ocular micrometer and are presented as range, followed by mean and standard deviation in parentheses. The descriptive terminology and classification of copepods follow Boxshall and Halsey (2004). Prevalence and intensity terminology is according to Bush et al. (1997). Host identification was based on Hulen et al. (2005) and their nomenclature and classification were updated according to Eschmeyer's Catalog of Fishes (Van der Laan et al., 2023). Type-specimens were deposited in Coleção Carcinológica do Museu de Zoologia da Universidade de São Paulo (acronym MZUSP), Brazil. Access to genetic heritage was registered in the Sistema Nacional de Gestão do Patrimômio Genético e do Conhecimento Tradicional Associado (acronym SisGen), under the number A03E910, according to Brazilian Federal requirements.

Systematics

Order Cyclopoida Burmeister, 1834
Family Ergasilidae Burmeister, 1835
Genus Ergasilus von Nordmann, 1832
Type-species: *Ergasilus sieboldi* von Nordmann, 1835 by original designation.
***Ergasilus lyraephorus* n. sp.**
Type host: Longtail Knifefish *Sternopygus macrurus* (Bloch & Schneider) (Actinopterygii: Sternopygidae).
Prevalence: 100% (4 fish infested out of 4 examined).
Mean intensity: mean of 19.7 copepods per infected fish (range 5–35).
Site on host: Gills.
Type locality: Viana Lake System, State of Maranhão, Brazil (3°14'29"S, 45°04'21"W).
Specimens deposited: Holotype female (MZUSP-44975) and 9 paratype females (MZUSP-44976).
ZooBank registration: urn:lsid:zoobank.org:act:44B13ED3-22AA-4E68-9FD8-57EA9C5FC8F9
Etymology: The specific name "*lyraephorus*", from the Latin "carrying a lyre", refers to the

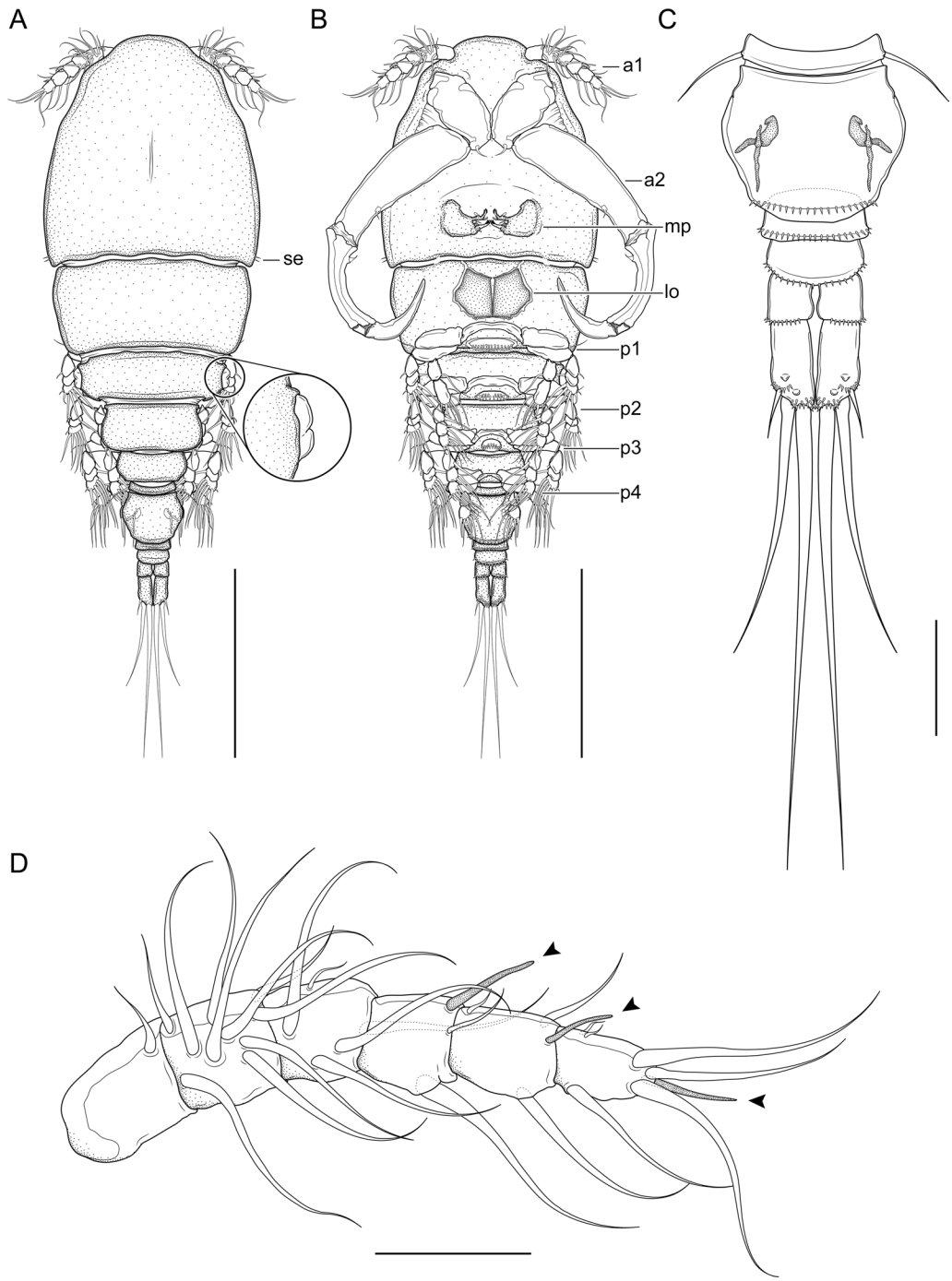

Fig. 1 *Ergasilus lyraephorus* **n. sp.** (adult female). **A** habitus, dorsal, with detail of integumental window, se = sensillum; **B** habitus, ventral, a1= antennule, a2= antenna, mp= mouthparts, lo= lyre-shaped ornamentation, p1= leg 1, p2= leg 2, p3= leg 3, p4= leg 4, p5= leg 5; **C** fifth pedigerous somite, abdomen and caudal rami, ventral; **D** antennule, ventral, arrows pointing aesthetascs. Scale bars: **A**–**B** = 200 µm; **C** = 40 µm; **D** = 30 µm

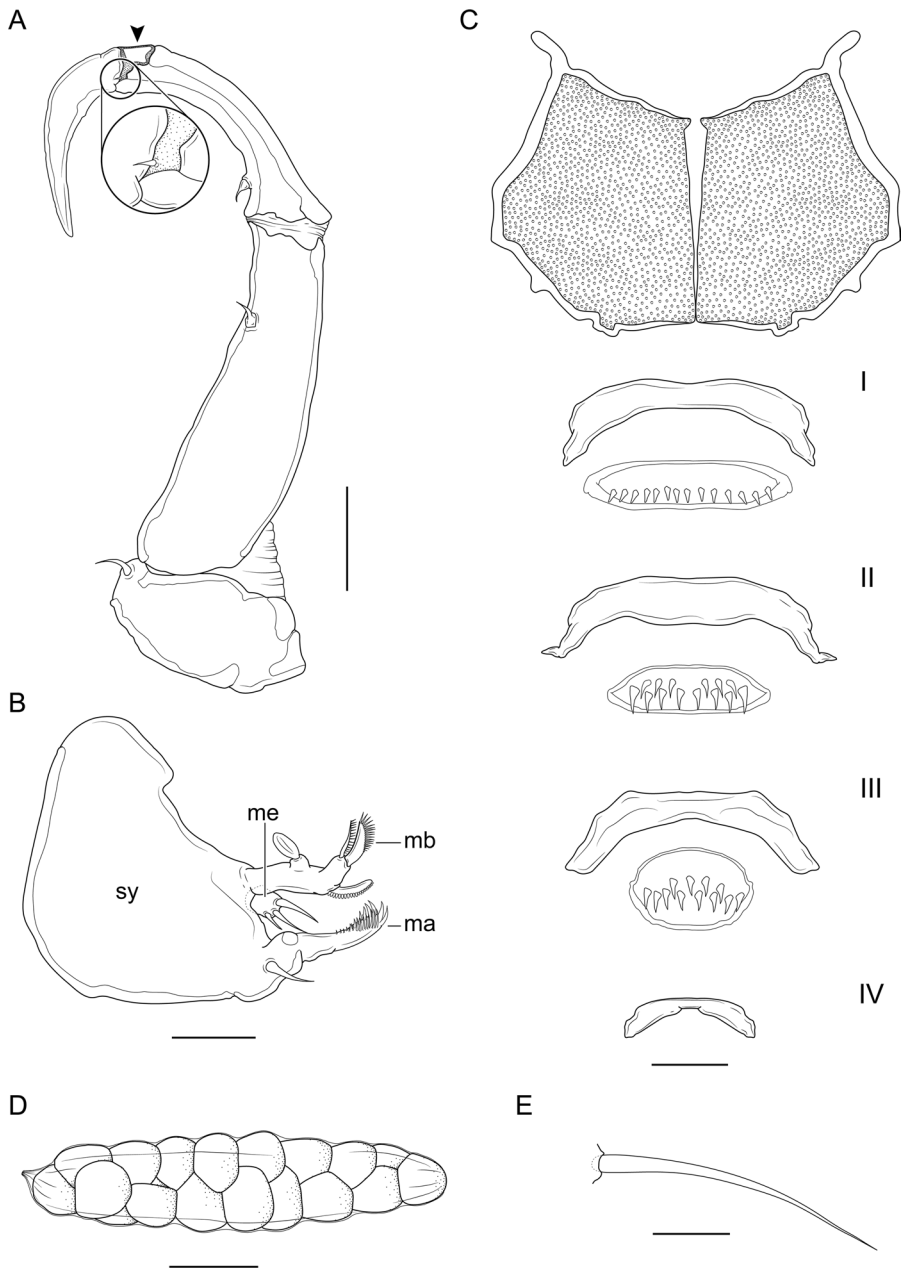

Fig. 2 *Ergasilus lyraephorus* **n. sp.** (adult female). **A** antenna, ventral, with detail of seta on vestigial third segment, arrow pointing vestigial third endopodal segment; **B** mouthparts, ventral, mb= mandible, me= maxillule, sy= syncoxa, ma= maxilla; **C** lyre-shaped ornamentation and interpodal plates of legs 1 to 4, ventral; **D** egg sac, dorsal; **E** leg 5, lateral. Scale bars: **A** = 40 µm; **B** = 15 µm; **C** = 20 µm; **D** = 100 µm; **E** = 10 µm

ornamentation on the ventral surface of the first pedigerous somite, which is an unique feature of the new species.

Description

Adult female [based on 10 specimens; Figs. 1–4]. Body length from anterior margin of prosome to posterior margin of caudal rami 662–836 (757 ± 48).

Body comprising prosome and urosome (Fig. 1A, B). Surface of body and of all small appendages rough (Figs. 4A–C). Prosome consisting of cephalosome, with antennule visible in dorsal view, and 4 pedigerous somites. Cephalosome and first pedigerous somite not fused (Fig. 1A, B). Cephalosome (Fig. 1A) longer than wide, 180–228 (201 ± 13.2) × 174–215 (197 ± 14), not inflated and slightly constricted, representing less than 1/3 of body length; dorsal surface of cephalosome with small longitudinal mark and 2 sensilla on each posterolateral edge. Depression between cephalosome and first pedigerous somite, with posterior margin of cephalosome distinct in both lateral and dorsal views (Figs. 1A, B). Second pedigerous somite bearing pair of rounded intergumental windows, laterally (Fig. 1A). Urosome consisting of fifth pedigerous somite, genital double-somite, and 3 free abdominal somites; third abdominal somite

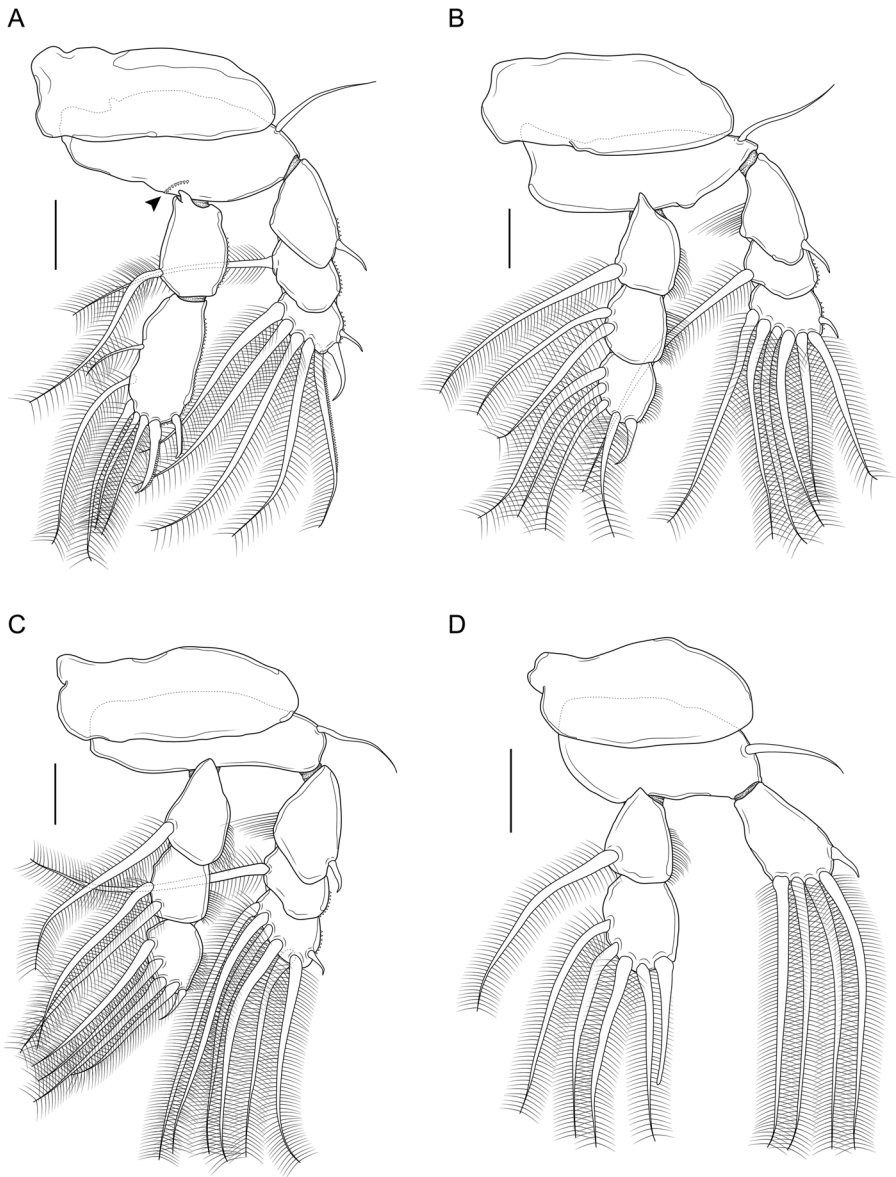

Fig. 3 *Ergasilus lyraephorus* **n. sp.** (adult female). **A** leg 1, ventral, arrow pointing row of spinules; **B** leg 2, ventral; **C** leg 3, ventral; **D** leg 4, ventral. Scale bars: **A**–**D**= 15 µm

(= anal somite) bipartite. Fifth pedigerous somite (Fig. 1C) short. Genital double-somite (Fig. 1C) slightly wider than long, 47–60 (53.5 ± 4.9) × 37–63 (55 ± 7.4), with row of spinules along posteroventral margin. Free abdominal somites (Fig. 1C) wider than long; first somite longer than second; anal somite longer than previous two. Posteroventral margins of abdominal somites ornamented by row of spinules each. Caudal rami (Fig. 1C) longer than anal somite, with 2 rows of spinules, 1 on posterolateral margin near insertion of minor seta, 1 apical near largest seta and 2 protrusions above each row of spinules; each ramus armed with large apical seta, medial subapical seta and 1 minor lateral seta. Two egg-sacs (Fig. 2D) longer than wide, each composed by 1–2 rows of eggs.

Antennule 6-segmented (Fig. 1D), tapering distally, aesthetascs present on fourth, fifth and sixth segments; setal formula as follows: 1: 10: 5: 2 + ae: 3 + ae: 6 + ae: all setae naked. Antenna (Fig. 2A) comprising coxobasis and 3-segmented endopod with curved terminal claw. Coxobasis short, proximally longer, armed with distally naked seta; membrane between coxobasis and first endopodal segment not inflated. First endopodal segment longest, nearly 1.8× longer than coxobasis, armed with spiniform element inserted on cuticular elevation on inner margin; second endopodal segment longer than wide, about 1.3× longer than coxobasis, with spiniform element, robust proximally, inserted on cuticular elevation on proximal inner margin; third endopodal segment vestigial, with small inner seta, bearing long curved claw slightly shorter than second endopodal segment.

Mouthparts (Fig. 2B) include mandible, maxillule and maxilla; maxilliped absent. Mandible unsegmented bearing palp, anterior, mid and posterior blades; palp small and naked; anterior blade with small spinules on outer margin; mid blade with spines on anterior half of outer margin; posterior blade with smooth teeth along posterior margin. Maxillule small, bearing 3 unequal setae. Maxilla comprising large syncoxa, and naked seta near teeth; second segment (basis) bearing long and sharp anterior teeth with long spinules along anterior and apical margins.

Swimming legs 1–4 biramous (Fig. 3A–D), each with 2-segmented protopod comprising coxa and basis; area anterior to first pair of interpodal plates with lyre-shaped ornamentation (Figs. 2C; 4D), with elevated edges and thick roughness interiorly; interpodal plates (Figs. 2C; 4E, F) with patch of robust spinules (legs 1, 2 and 3) or smooth (leg 4). Armature of legs (spines, Roman numerals; setae, Arabic numerals) as follows:

	Coxa	Basis	Exopod	Endopod
Leg 1	0–0	0–1	I–0; 0-1; II, I, 4	0–1; II,5
Leg 2	0–0	0–1	I–0; 0-1; I, 6	0–1; 0–2; I, 4
Leg 3	0–0	0–1	I–0; 0-1; I, 6	0–1; 0–2; I,4
Leg 4	0–0	0–1	I, 4	0–1; I, 4

Leg 1 (Fig. 3A) coxa unarmed. Basis with outer naked seta and row of spinules on posterior margin, near endopod insertion. Exopod 3-segmented, with rows of spinules on outer margin of all segments; first segment with small outer spine; second segment with inner plumose seta; third segment with 2 unequal subapical spines, long apical semi-pinnate seta and 4 plumose setae. Endopod 2-segmented, both segments with rows of spinules on outer margin; first segment with plumose inner seta; compound second segment with 5 plumose setae and 2 unequal pectinate spines.

Leg 2 (Fig. 3B) coxa unarmed. Basis with outer naked seta. Exopod 3-segmented, first segment plumose on inner margin, and with row of spinules on outer margins on second and third segments; first segment longest, with small outer spine; second segment with inner plumose seta; third segment, with 6 apical plumose setae and small outer spine. Endopod 3-segmented, all plumose on outer margins; first segment with plumose inner seta; second segment with 2 plumose inner setae; third segment with apical spine, and 4 plumose setae.

Leg 3 (Fig. 3C) similar to Leg 2.

Leg 4 (Fig. 3D) coxa unarmed. Basis with outer naked seta. Exopod 1-segmented, smooth, with small subapical spine and 4 plumose setae. Endopod 2-segmented, first segment plumose on outer margin; first segment with inner plumose seta; second segment with long subapical spine and 4 plumose setae.

Leg 5 (Fig. 2E) represented by naked seta carried on rounded papilla.

Remarks

The adult female specimens examined in the present study, were assigned to *Ergasilus* based on the following features: (1) 6-segmented antennule, (2) antenna with one apical curved claw, shorter or as long as the second endopodal segment, (3) reduced

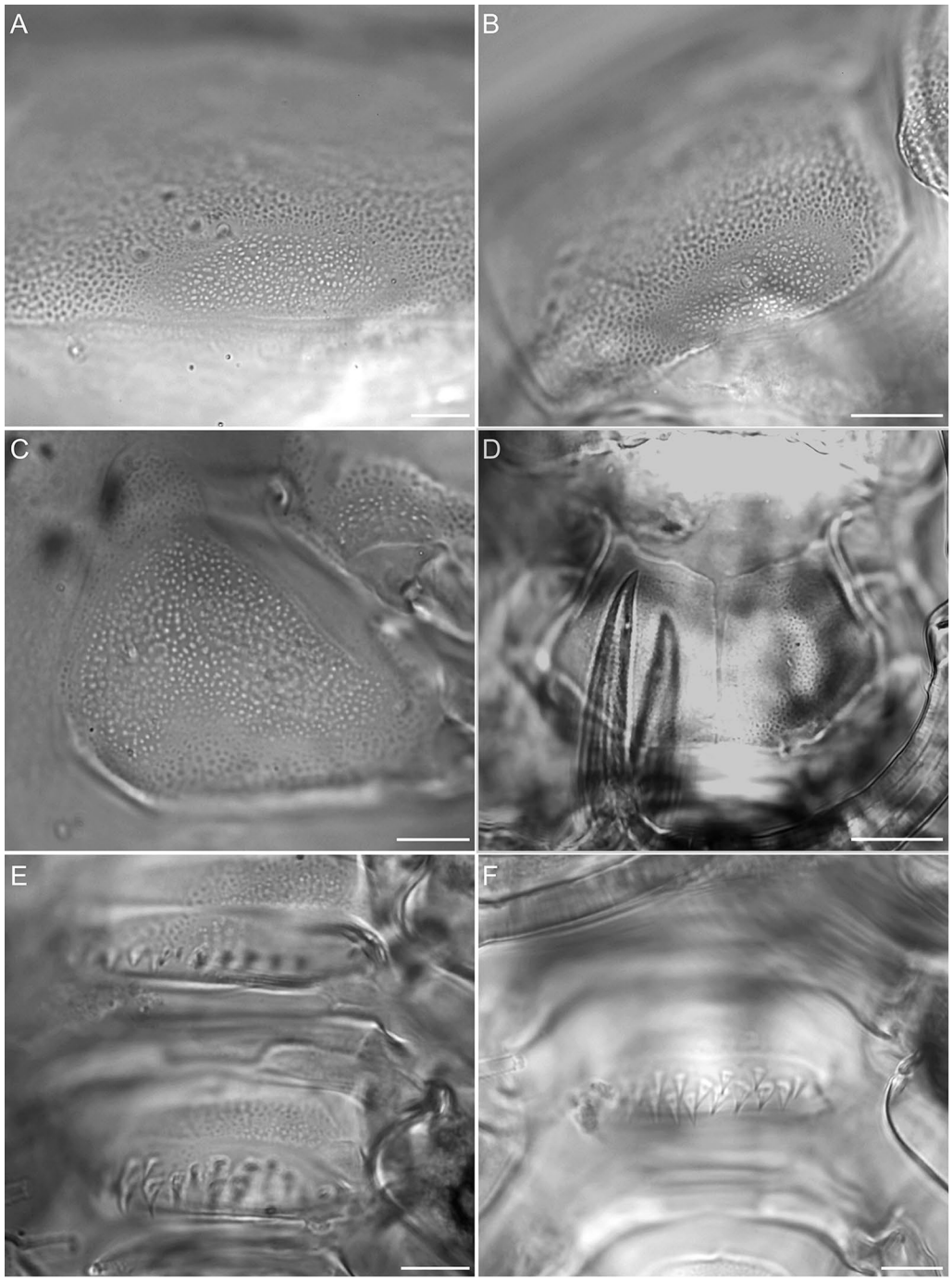

Fig. 4 Light micrographs of *Ergasilus lyraephorus* **n. sp.** (adult female). **A** rough surface of cephalosome, lateral; **B** rough surface of dorsal shield of first pedigerous somite, lateral; **C** rough surface of syncoxa, ventral; **D** lyre-shaped ornamentation, ventral; **E** interpodal plates of legs 1 and 2, ventral; **F** interpodal plate of leg 2, ventral. Scale bars: **A**–**F**= 10 µm

maxilla, (4) legs 1–4 biramous, with exopods with 1–3 segments and endopods with 2–3 segments, and (5) leg 5 uniramous (Boxshall & Halsey 2004; Muriel-Hoyos et al., 2015; Narciso et al., 2022).

Currently, the genus *Ergasilus* comprises more than 150 species described worldwide, but only two have leg 4 with a 1-segmented endopod as in the new species, *i.e.*, *E. coatiarus* Araujo & Varella, 1998 and *E. curticus* Muriel-Hoyos, Santana-Piñeros, Cruz-Quintana & Suaréz-Morales, 2015 (Araújo & Varella, 1998; Marques, 2014; Muriel-Hoyos et al., 2015). However, *E. lyraephorus* **n. sp.** differs from these closely related congeners by having the maxillule with three elements (vs. maxillule unarmed in *E. coatiarus* and *E. curticus*), patches of robust spinules on the interpodal plates of legs 1–3 (vs. interpodal plates smooth in *E. coatiarus* and *E. curticus*) and leg 5 reduced to a single seta of moderate size (vs. two setae in *E. coatiarus* and one minute seta in *E. curticus*) (Araújo & Varella, 1998; Marques, 2014; Muriel-Hoyos et al., 2015). The new species also has a lyre-shaped ornamentation anterior to the first interpodal plate, which has never been reported in other members of Ergasilidae.

Ergasilus coatiarus was originally described by Araújo and Varella (1998), based on females parasitizing the branchial filaments of the Tucunaré, *Cichla monoculus* Agassiz (Cichlidae), from the Solimões river, State of Amazonas, Brazil (Araújo & Varella, 1998). Subsequently, Marques (2014) redescribed this species based on the paratypes because the original description was inaccurate. Therefore, based on Marques (2014), the new species differs from *E. coatiarus* because the first possesses cephalosome comprising about one third of total body length (vs. half of body length in the latter), leg 4 with four setae on the last endopodal segment (vs. five setae in the latter), caudal rami with three setae (vs. five setae in the latter) and egg-sacs with 1–2 rows of eggs (vs. 3–4 rows in the latter) (Araújo & Varella, 1998; Marques, 2014).

Additionally, *E. curticus,* a parasite of *Bryconops giacopinii* (Fernández-Yépez) (Characidae) in the Vichada River Basin, Colombia, also differs from the new species by the first pedigerous somite having a trapezoidal shape, as wide as cephalosome (vs. somite bilobular, larger than cephalosome in *E. curticus*), legs 2 and 3 with two inner setae on the second endopodal segment and four setae on the last endopodal segment (vs. one and four setae, respectively, in *E. curticus*) (Muriel-Hoyos et al., 2015).

Discussion

Copepods of the family Ergasilidae are usually differentiated by the morphology of the modified antennae, number of blades in mandible and the number of segments in the exopod of leg 4 (Boxshall & Halsey, 2004). However, delimiting the boundaries between some genera within the family can be problematic, mainly because molecular data are scarce and some of these genera seem to be artificial. In this sense, the present specimens share the following features with *Tiddergasilus* Marques & Boeger, 2018, which also occurs in the Neotropical Region: (1) antennule with six segments; (2) endopod of leg 1 with two segments; (3) non-falciform semi-pinnate seta on the terminal exopodal segment of leg 1; and (4) leg 5 reduced to a single seta. Moreover, the recently described species, *T. bipartitus* Narciso, Vieira & Silva, 2022, has the endopod reduced to a single segment on leg 4, as in the new species. However, *E. lyraephorus* **n. sp.** was not allocated in *Tiddergasilus*, since its second endopodal segment of the antenna is long, slender and curved (vs. segment short and robust in the latter genus) and its claw is smooth, long and curved (vs. claw short with indentation in the latter genus) (Marques & Boeger, 2018; Narciso et al., 2022).

In Brazil, *Ergasilus* is the most commonly reported genus of ergasilid copepods infesting fish, most frequently in the Amazon basin. According to Engers et al. (2000), some species belong to a unique lineage showing the first leg with a semi-pinnate, falciform seta on the terminal exopodal segment, and the endopods of the first and fourth legs with two segments; these species are: *E. bryconis* Thatcher, 1981, *E. jaraquensis* Thatcher & Robertson, 1982, *E. hydrolycus* Thatcher, Boeger & Robertson, 1984, *E. callophysus*, Thatcher & Boeger, 1984, *E. holobryconis* Malta & Varella, 1986, *E. hipophthalmi* Boeger, Martins & Thatcher, 1993, *E. urupaensis* Malta, 1995, *E. triangularis* Malta, 1994, *E. yumaricus* Malta & Varella, 1995, and *E. turucuyus* Malta & Varella, 1995. More recently, Muriel-Hoyos et al. (2015) described *E. curticus* from the Orinoco River, Colombia, a species that possesses the previous features in addition to

the exopod reduced to one segment in leg 4, and leg 5 reduced to a small seta. Therefore, *E. curticus* may belong to such distinct lineage of eargasilids, being dispersed to the Orinoco River through past connections with the Amazon basin, since this species and those from the Amazon share the previously mentioned morphological features (Muriel-Hoyos et al., 2015). These morphological features are also present in *E. lyraephorus* **n. sp.**, except by a non-falciform semi-pinnate seta present on the exopod of the first leg. In this sense, it is possible that the new species also has a common origin with the Amazonian lineage and, as observed in *E. curticus*, the reductions in legs 4 and 5 may have arisen after geographical dispersion, followed by isolation. However, additional genetic data and phylogenetic approaches including all the previously mentioned species are needed in order to confirm such assertions.

The family Sternopygidae includes freshwater electric fish, distributed throughout South America, containing 60 nominal species in seven genera. The taxon has great taxonomic and ecological importance in the Amazon basin, in which *Sternopygus* (Bloch & Schneider) is the most widespread genus (Reis, 2003; Fricke et al., 2023). However, the parasitic fauna of fish of this family is still poorly known, and can be summarized as: myxozoans *Myxobolus inaequus* Kent & Hoffman, 1984 (Bivalvulida: Myxobolidae) and *Henneguya theca* Kent & Hoffman, 1984 (Bivalvulida: Myxobolidae) parasitizing *Eigemannia virescens* (Valenciennes); an unidentified species of Cestoda infecting *S. macrurus* in Brazil; an unidentified species of Digenea in *S. macrurus*; the monogeneans *Urocleidoides virescens* Mizelle, Kritsky & Crane, 1968 (Polyonchoinea; Dactylogyridae) infesting *E. virescens* and *E. trilineata* López & Castello, and a Dactylogyridae gen. sp. from *E. trilineata*; the isopod *Riggia nana* Szidat & Schubart, 1960 (Isopoda: Cymonthoidae) infesting *E. virescens* and *E. macrops* (Boulenger), all reports from Brazil (see Kent & Hoffman, 1984; Araújo, 2002; Kohn et al., 2011; Yamada, 2020). Thus, *E. lyraephorus* **n. sp.** infesting *S. macrurus*, represents the first report of a parasitic copepod infesting a fish of the family Sternopygidae.

The Viana Lake System comprises four independent lakes within the Baixada Maranhense namely, Maracú Lake, Viana Lake, Aquiri Lake and Maracassumé Lake, which become interconnected during annual flood cycles. This system supports a diverse ichthyofauna represented by 101 fish species, highlighting its crucial role in the sustainability of nearby communities and local markets (Silva, 2016; Guimarães et al., 2020). Despite its high biodiversity, research focused on parasitic copepods in this region remains limited. Such situation extends to the border of the State of Maranhão, where only two species of parasitic copepods have been reported: *Ergasilus atafonensis* Amado & Rocha, 1996, and *E. caraguatatubensis* Amado & Rocha, 1996, both on *Mugil curema* Valenciennes (Mugilidae) in the Cururuca River, municipally of São Luís (Amado & Rocha, 1996). In this sense, the present study represents the first report of a parasitic copepod in the Viana Lake System, emphasizing the still poorly known diversity of copepods in the region, which is underestimated as a result of limited research efforts.

Parasitic copepods represent one of the most frequent groups of parasites infesting fish in Brazil. However, parasitological studies have been historically focused on commercially important hosts, which may underestimate the real diversity of these parasites in the country (Eiras, 1994; Luque & Poulin, 2007; Paschoal et al., 2022a; Couto et al., 2023). It should be mentioned that a number of studies have proposed new species of parasitic copepods from hosts with little or no commercial importance, for example, *Duoergasilus basilongus* Narciso, Brandão, Perbiche-Neves & Silva, 2019 and *Rhinergasilus digitus* Narciso, Brandão, Perbiche-Neves & Silva, 2020 from *Psalidodon fasciatus* (Cuvier) (= *Astyanax fasciatus*) (Characidae) in the Paranapenema River, State of São Paulo; *Colobomatus freirei* Couto & Paschoal, 2021 (Philichthyidae) and *C. luquei* Couto & Paschoal, 2021 from *Holocentrus* spp. (Holocentridae); *C. deborae* Paschoal, Couto, Pereira & Luque, 2022a, 2022b, from *Diapterus rhombeus* (Cuvier) (Gerreidae); *Hatschekia nagasawai* Paschoal, Couto, Pereira & Luque, 2022a, 2022b from *Anisotremus virginicus* (Linnaeus) (Haemulidae), all off the State of Rio de Janeiro; and the present new species, a parasite of *S. macrurus* in the Viana Lake System, State of Maranhão (Narciso et al., 2019; Narciso et al., 2020; Couto & Paschoal, 2021; Paschoal et al., 2022a, b; Froese & Pauly, 2023). These findings indicate a high biodiversity potential of parasitic copepods associated with fish of little economic importance and highlight the need for further taxonomic studies on these organisms.

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Author contributions JLSN, GR and FP performed field collections and the parasitological survey. JVC, FP and FBP analyzed the copepods, prepared the illustrations and wrote the first draft of the manuscript. All reviewed the manuscript and approved the final version. FP and FBP supervised the study.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable institutional, national and international guidelines for the care and use of animals were followed.

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