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A new species of *Colobomatus* Hesse, 1873 (Copepoda: Philichthyidae) parasitic in the interorbital canals of the Caitipa mojarra *Diapterus rhombeus* (Cuvier, 1829) (Actinopterygii: Gerreidae) from Sepetiba Bay, southeastern Brazil

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Abstract A new species of parasitic copepod, *Colobomatus deborae* **n. sp.**, belonging to the cyclopoid family Philichthyidae Vogt, 1877, is proposed based on adult female specimens collected from the interorbital canals of the Caitipa mojarra *Diapterus rhombeus* (Cuvier) (Gerreidae) from Sepetiba Bay, off the State of Rio de Janeiro, southeastern Brazil. The new species closely resembles six species of *Colobomatus* Hesse, 1873, but differs from these close congeners based on the combination of the following characters: lateral cephalic processes forked basally with sharp tips, midventral cephalic process representing about one third of the length of the laterals, thoracic processes forked and caudal rami with a pair of unequal processes. Together with the new species described in the present study, the philichthyid fauna of Brazil rises to 10 species reported from 14 Brazilian marine fish species. This is also the third report of *Colobomatus* in a gerreid fish, but the first species found parasitizing the genus *Diapterus*.

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Introduction

Members of the family Philichthyidae Vogt, 1877 are subcutaneous dwelling parasitic copepods in marine fish, represented by 94 species of the following genera: *Colobomatoides* Essafi & Raibaut, 1980; *Colobomatus* Hesse, 1873; *Ichthyotaces* Shiino, 1932; *Leposphilus* Hesse, 1866; *Lernaeascus* Claus, 1886; *Philichthys* Steenstrup, 1862; *Procolobomatus* Castro Romero, 1994; *Sarcotaces* Olsson, 1872; and *Sphaerifer* Richardi, 1876 (Boxshall & Halsey, 2004; Walter & Boxshall, 2022). The genus *Colobomatus* is the most speciose within the Philichthyidae, in which its members are characterized by the highly modified morphology of the females, whereas the males retain a more primitive body plan similar to that of free-living forms (Kabata, 1979; Madinabeitia et al., 2013). Species of this genus parasitize wide range of actinopterygian hosts worldwide, especially members of the orders (*sensu* Betancur-R et al., 2017) Eupercaria, Lutjaniformes, Perciformes and Spariformes; however, some species are also associated with Anguilliformes, Beloniformes, Carangiformes,

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Holocentriformes, Myctophiformes, Mugiliformes and Syngnathiformes (Boxshall & Halsey, 2004; Paschoal et al., 2016a; Couto & Paschoal, 2021). As an exception, only *C. lamnae* Hesse, 1873 has been found in an elasmobranch from the order Lamniformes (Delamare Deboutteville, 1962; Paschoal et al., 2016a).

Representatives of the family Gerreidae are abundant and commercially important in tropical and subtropical coastal lagoons worldwide (Nelson et al., 2016; Froese & Pauly, 2022). Sepetiba Bay is a large coastal lagoon of about 519 km^2, representing an important marine ecosystem in the State of Rio de Janeiro, Brazil. Currently, 97 fish species have been reported in this estuary, of which six gerreid species are among the most abundant accounting for more than 30% of the fish catches by beach seine (Araújo et al., 1998, 2018; Araújo & Alcantara Santos, 1999). Despite the high fish biodiversity and the importance for fishery supported by Sepetiba Bay, it has suffered intense degradation of sand banks and vegetation, causing a decrease of some fish populations, including gerreids (Araújo et al., 2018).

During a parasitological survey of specimens of *Diapterus rhombeus* (Cuvier) (Eupercaria, Gerreidae) in Sepetiba Bay, some specimens of parasitic copepods were discovered. A detailed morphological study of these individuals revealed that they represented an unknown species of *Colobomatus*, which is described herein.

Materials and methods

Eighteen specimens of *D. rhombeus* (body length 15.4–37.3 cm; mean ± standard deviation 26.4 ± 7.3 cm) were caught by artisanal fishermen, between February to April 2022 in Sepetiba Bay (22°57′18″S, 43°54′44″W), near Itacuruçá Island, off the State of Rio de Janeiro, southeastern Brazil (Fig. 1). Fish were kept in thermal boxes filled with ice and transported to the laboratory for analysis. The copepods were collected using the procedures described by Madinabeitia & Nagasawa (2012), fixed and preserved in 70% ethanol. For microscopical observation, specimens were cleared in 85% lactic acid and the appendages were dissected and examined using the wooden slide procedure of Humes & Gooding (1964). Drawings were made with the aid of a Zeiss Standard 20 microscope (Carl Zeiss Foundation, Germany) equipped with a drawing tube. Measurements were based on seven adult females, given as mean followed by the range in parentheses, all in micrometers unless otherwise stated. The morphological terminology and classification follow Boxshall & Halsey (2004). Ecological terminology adopted for parasites is according to Bush et al. (1997). Host identification was based on Menezes & Figueiredo (1980), and the nomenclature and classification were updated according to FishBase (Froese & Pauly, 2022). Type specimens were deposited in the collection of the Museu de Zoologia da Universidade de São Paulo (acronym MZUSP), Brazil.

Systematics

Order Cyclopoida Burmeister, 1834

Family Philichthyidae Vogt, 1877

Genus *Colobomatus* Hesse, 1873

Type-species: *Colobomatus lamnae* Hesse, 1873 by original designation.

Colobomatus deborae n. sp.

Type-host: The Caitipa mojarra *Diapterus rhombeus* (Cuvier) (Eupercaria: Gerreidae).

Type-locality: Sepetiba Bay (22°57′18″S, 43°54′44″W), State of Rio de Janeiro, Brazil.

Site in host: Interorbital canals.

Prevalence and mean intensity: 16.6% (three fish infected out of eighteen examined); mean of 2.3 specimens per infected fish [range 1–4].

Type-material: Holotype female (MZUSP- 43282); paratypes: four females (MZUSP- 43283). Two specimens were dissected and kept in the personal collection of the first author.

ZooBank registration: urn:lsid:zoobank.org:act:D2DA97A2-6428-49D1-AD5A-D603087E8034

Etymology: The species is dedicated to the first author's mother Debora Viana Paschoal, for providing considerable support and encouragement for his studies.

Description (Figs. 2, 3)

Adult female

Body elongate and transformed (Fig. 2A, B), 3.07 mm (2.78–3.52 mm) long; all body processes slender and densely covered by blunt conspicuous spines (Fig. 2A–G). Pre-oral area of cephalosome with three anterior cephalic processes (Fig. 2C); paired lateral

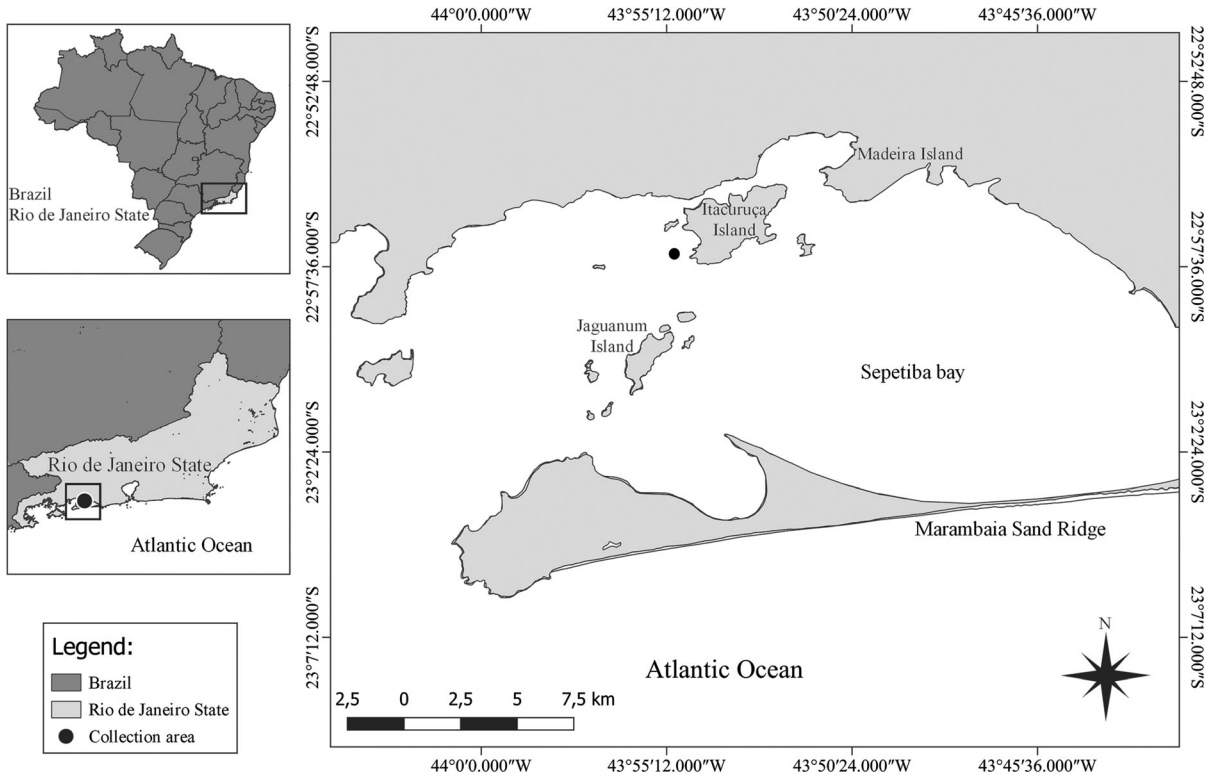

Fig. 1 Sampling area of the present study in Sepetiba Bay, off the State of Rio de Janeiro, Brazil

processes forked basally with sharp tips, length 425 (372–489); midventral process simple, spinulose, with sharp tip, length 135 (121–173), representing 32% (26.5–35.3%) length of lateral ones. Cephalosome ovoid (Fig. 2A, B), slightly longer than wide, 356 (317–422) × 303 (273–328). First to fourth pedigerous somites fused, forming octagonal to ovoid thoracic region, 961 (875–1165) long, representing about 31.2% (29.1%–33.2%) of total body length, 624 (588–694) wide, excluding thoracic processes. Thoracic region with two pairs of forked processes arising from dorsolateral surfaces (Fig. 2A, B); anterior pair of processes slightly shorter than posterior (Fig. 2D), 347 (293–408) long; posterior pair of processes elongated (Fig. 2E), 446 (388–527) long. First to fourth pairs of legs located on ventral surface of fused somites. Fifth pedigerous somite square and separated from preceding fused somites by slight constriction, 261 (217–312) × 276 (258–322). Genital somite wider than long, 164 (117–189) × 237 (213–259), with pair of lateral processes with rounded tips (Fig. 2A, B), 316 (232–362) long. Abdomen four-segmented, first three abdominal somites slightly longer than wide, measuring 212 (153–257) × 203 (168–226), 191 (178–207) × 184 (169–215), 180 (161–202) × 176 (163–188), respectively. Last abdominal somite shorter, 106 (96–115) long. Caudal rami partially fused to last abdominal somite, each ramus armed with pair of processes (Fig. 2F), one ventrolateral on inner margin and one terminal; terminal process armed with one seta on inner margin and about 1.5 times longer than ventrolateral process.

Antennule (Fig. 3A) conical, indistinctly 3-segmented, with armature formula 4, 5 + aesthetasc, 9 + 2 aesthetascs; all setae naked. Antenna modified, forming buccal capsule with mouth parts, posteriorly bordered by simple and undivided labium (Fig. 3B). Labrum not observed. Maxillule (Fig. 3B, C) minute and located at the anterior part of buccal capsule, 1-segmented, located midlaterally in buccal area and bearing two apical setae. Maxilla (Fig. 3B, D) robust and located at the middle part of buccal capsule, apparently 2-segmented, basal segment with one midlaterally spine; distal segment with one thick distal element ornamented with row of spinules. Maxilliped (Fig. 3B, E) robust and located at the

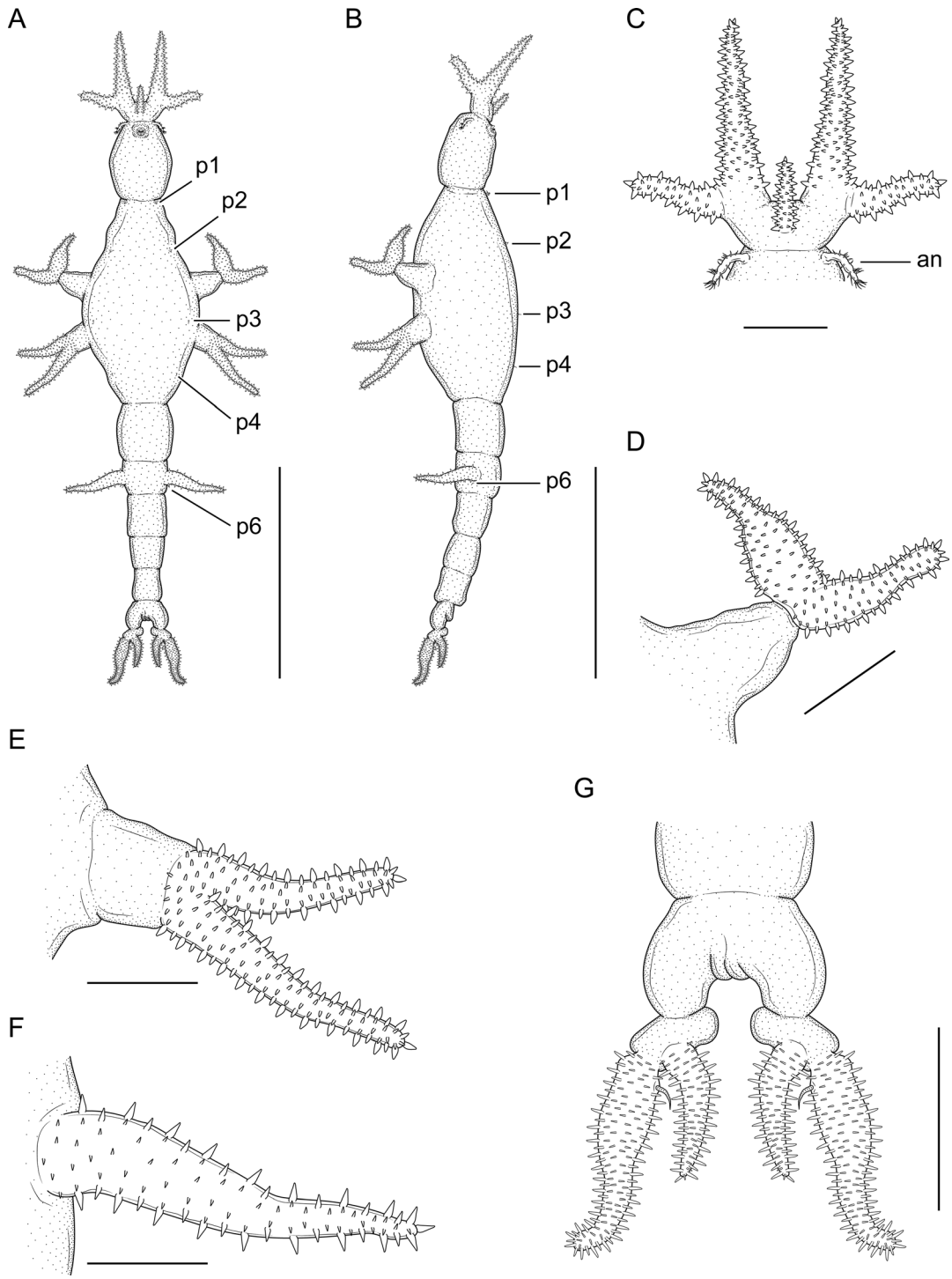

Fig. 2 *Colobomatus deborae* **n. sp.** (adult female). A, habitus, ventral, p1 = leg 1, p2 = leg 2, p3 = leg 3, p4 = leg 4, p6 = leg 6; B, habitus, lateral, p1 = leg 1, p2 = leg 2, p3 = leg 3, p4 = leg 4, p6 = leg 6; C, detail of cephalic process, ventral, an = antennule; D, detail of first thoracic process, ventral; E, detail of second thoracic process, ventral; F, detail of genital process, ventral; G, detail of distal part of the abdomen and caudal rami, ventral. Scale bars: A–B = 1000 μm; C = 200 μm; D–E = 150 μm; F = 100 μm; G = 200 μm

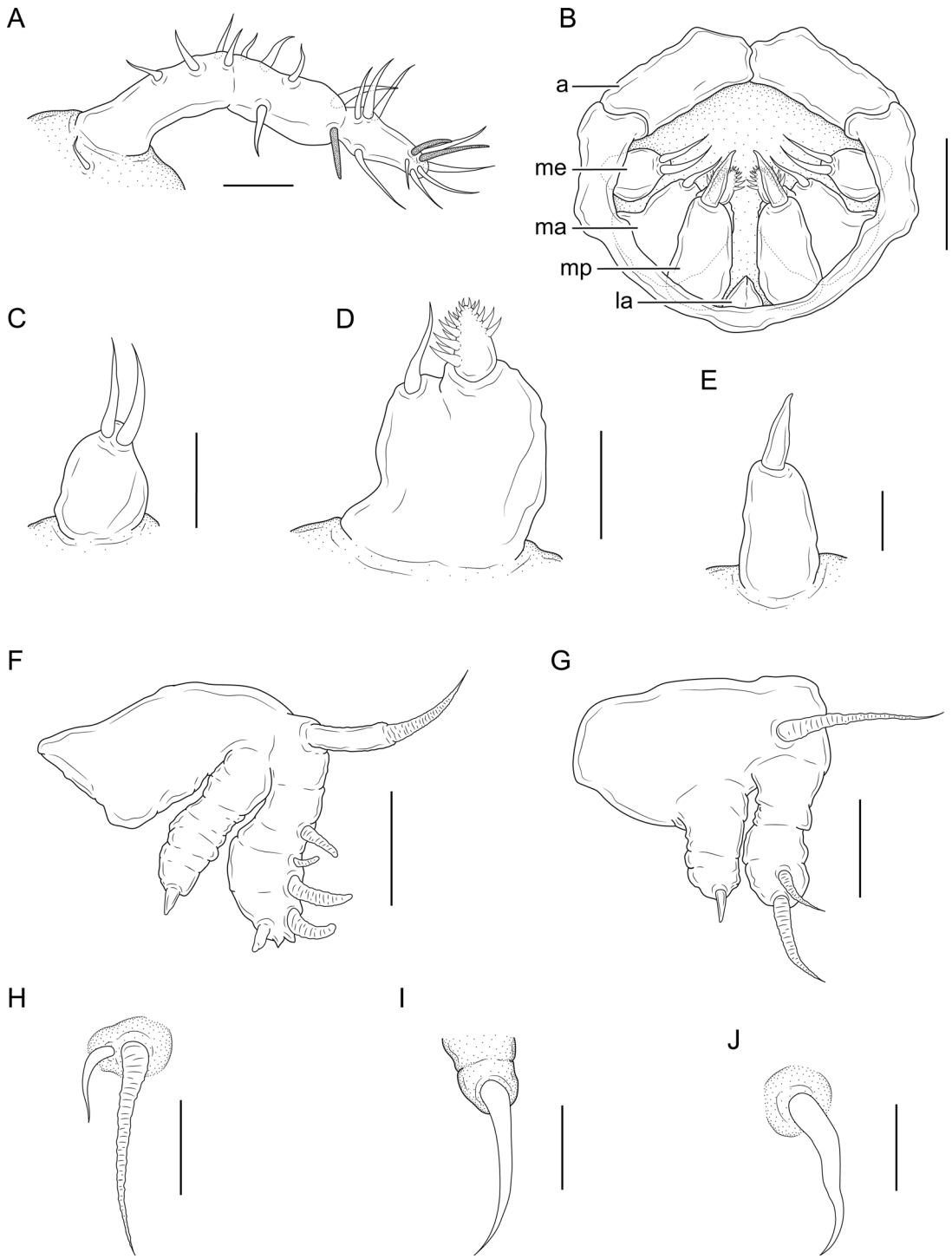

Fig. 3 *Colobomatus deborae* **n. sp.** (adult female). A, antennule, ventral; B, buccal area, showing position of antenna (a), maxillule (me), maxilla (ma), maxilliped (mp) and labium (la), ventral; C, maxillule, ventral; D, maxilla, ventral; E, maxilliped, ventral; F, leg 1, ventral; G, leg 2, ventral; H, leg 3, ventral; I, leg 4, ventral; J, leg 6, ventrolateral. Scale bars: A = 25 μm; B = 20 μm; C–E = 10 μm; F = 15 μm; G–I = 10 μm; J = 5 μm

posterior part of buccal capsule, with basal segment and one distal spine. Maxilliped overlapping the maxilla (Fig 3B). Posterior rim of buccal capsule undivided.

Legs 1 and 2 inserted in rugose area. Leg 1 (Fig. 3F) biramous, located immediately posterior to junction of cephalosome and first pedigerous somite; protopod with one irregularly annulated lateral seta; exopod indistinctly 2-segmented, armed with four lateral setae and three apical blunt elements; endopod 1-segmented and armed with one apical spine. Leg 2 (Fig. 3G) biramous, located posterior to leg 1, in second part of fused somites; protopod with one irregularly annulated lateral seta; exopod indistinctly 2-segmented, armed with two distal setae of unequal sizes; endopod 1-segmented and armed with one apical spine. Leg 3 (Fig. 3H), located in third part of fused somites (third pedigerous somite) and reduced to two setae of unequal sizes. Leg 4 (Fig. 3I), located in last part of fused somites (fourth pedigerous somite), and represented by single seta. Leg 5 absent. Leg 6 (Fig. 3J) located near genital apertures, represented by naked seta.

Adult Male
Unknown

Remarks

The new species described in the present work has an elongate body comprising the cephalosome, fused thoracic somites, free fifth pedigerous and genital somites, abdomen and caudal rami, at least two pairs of divergent lateral processes in the thoracic region, resembling a X-shape and leg 4 reduced to a single seta or completely absent. These features are diagnostic for the genus *Colobomatus* (West, 1992; Boxshall & Halsey, 2004).

According to Couto & Paschoal (2021), the genus *Colobomatus* currently comprises 75 species; however, 19 congeners have the cephalosome with three anterior cephalic processes, one simple midventral and two paired laterally, as in *C. deborae* **n. sp.** (see Paschoal et al., 2016a). Of these, only six species are characterized by having the lateral cephalic processes forked as in the new species: *C. baraldii* (Richiardi, 1877) parasite of the Gilthead seabream *Sparus aurata* Linnaeus (Sparidae), *C. denticis* (Richiardi, 1877) of the Common dentex *Dentex dentex* (Linnaeus) (Sparidae), *C. mulli* Essafi, Raibaut & Boudaoud-Krissat, 1983 of the Red mullet *Mullus barbatus* Linnaeus and the Surmullet *M. surmuletus* Linnaeus and *C. steenstrupi* (Richiardi, 1876) of *M. surmuletus* and *M. barbatus*, all from Mediterranean Sea (Delamare Deboutteville, 1962; Essafi et al., 1983, 1984); *C. kimi* Paschoal, Pereira & Luque, 2016 parasite of the Dwarf goatfish *Upeneus parvus* (Poey) (Mullidae) off Brazil (Paschoal et al., 2016a); and *C. pagri* (Richiardi, 1877) parasite of the Red porgy *Pagrus pagrus* (Linnaeus) from Mediterranean Sea and off Argentina and Brazil (Delamare Deboutteville, 1962; Soares et al., 2018). However, *C. deborae* **n. sp.** can be easily differentiated from these closely congeners by having the lateral cephalic processes forked basally (vs. lateral cephalic processes forked apically in the six species above) (Delamare Deboutteville, 1962; Essafi et al., 1983, 1984; Paschoal et al., 2016a).

It should be observed that the forked thoracic processes and the caudal rami present in *C. deborae* **n. sp.** resemble those of *C. denticis, C. kimi* and *C. pagri* (Essafi et al., 1984; Paschoal et al., 2016a). However, the new species differs from *C. denticis* and *C. pagri* by having caudal rami with terminal process longer than the ventrolateral (vs. ventrolateral process longer than terminal in *C. denticis* and equal in length in *C. pagri*) (Essafi et al., 1984). Moreover, *C. deborae* **n. sp.** differs from *C. kimi* because the length of its midventral cephalic process is only about 32% of the length of the laterals (vs. 53% in the latter), the endopods of legs 1 and 2 are armed with a single apical spine (vs. endopods without spines in the latter) and its leg 3 is represented by two setae (vs. represented by a single seta in the latter) (Paschoal et al., 2016a).

In addition, the new species differs from *C. baraldii* and *C. steenstrupi* by having thoracic processes forked (vs. first pair of thoracic processes simple in *C. baraldii* and thoracic processes digitiform in *C. steenstrupi*) (Delamare Deboutteville, 1962; Essafi et al., 1983). Finally, it differs from *C. mulli* by the caudal rami with a pair of processes and densely covered by spines (vs. simple, rounded and lacking spines in the latter) (Essafi et al., 1983).

Discussion

The description of *C. deborae* **n. sp.** represents the 76th valid species of *Colobomatus* and only two have

been reported parasitizing fish of the family Gerreidae, *i.e.*, *C. gietzelae* West, 1992 of the Whipfin silver-biddy *Gerres filamentosus* Cuvier and *C. lesteri* West, 1992 of the Common silver belly *G. subfasciatus* Cuvier, both from Queensland, Australia (see West, 1992). These two species have a cephalosome bearing one pair of processes (West, 1992), which easily differentiates them from the new species. Moreover, *C. gietzelae* has swollen fused thorax, minute posterior thoracic lobes and lacks anterior thoracic lobes (West, 1992), which are exclusive diagnostic features of the species. The thoracic processes of *C. lesteri* are simple and elongated (West, 1992), differing from those of the new species (forked thoracic processes). Therefore, it is clear that *C. deborae* **n. sp.** is different from the other species parasitic in gerreid fish and represents the third *Colobomatus* to be reported parasitizing fish belonging to Gerreidae, and the first congener to be reported in the Atlantic Ocean. The present results also include the genus *Diapterus* as a potential host for these parasitic copepods, representing one more step towards improving knowledge of the diversity of *Colobomatus* in gerreid fish.

The host specificity of *Colobomatus* spp. has been well discussed and two hypotheses have been formulated: (*i*) the species exhibit high host specificity, usually parasitizing a single or rarely two host species (Grabda, 1991); (*ii*) the species may be specific to certain host families or genera (Hayward, 1996). Currently, species of *Colobomatus* associated to gerreid fish show high host specificity, in which these parasites use a single host species, *i.e.*, *C. gietzelae* from *G. filamentosus*, *C. lesteri* from *G. subfasciatus* and now *C. deborae* **n. sp.** from *D. rhombeus*, corroborating thus with the first hypothesis above. However, the current panorama is still too premature for any conclusion about the real specificity of these copepods parasite of Gerreidae; since this family represents one of the most abundant groups of fish in tropical sea waters, currently allocating 53 known species from eight genera (see Froese & Pauly, 2022), and only three species of *Colobomatus* has been reported from three gerreid fish until now.

Since the description of the first *Colobomatus* species in the 19th Century (Walter & Boxshall, 2022), the morphology of females remains the most important diagnostic tool. Their modified body plan with processes on the different tagmata that vary in quantity, size, proportion, and ornamentation, enables researchers to differentiate between the congeners and demonstrate the value of morphological analysis (West, 1992; Kim & Moon, 2013; Paschoal et al., 2016a). In the present study, the diagnosis of the new species was based on the classic comparison of the body plan in females, but the armature of the legs demonstrated be a useful character for supplementing the identification. Nevertheless, several species of *Colobomatus* lack morphological details, especially those described from the Mediterranean Sea during the late 19th century in the pioneering works by Richiardi (1876a, b; 1877a, b; 1880; 1883), as well as from European waters in the second half of the 20th century, in the diligent work by Delamare Deboutteville (1962). In most cases, the leg morphology was overlooked in these early descriptions probably due the taxonomic criteria of the period, since the differentiation between philichthyid species used to be based only on the body plan of females. Thus, the present observations suggest that some species of *Colobomatus* require a critical redescription based on modern standards, including detailed observations of small appendages such as the legs.

Species of philichthyids can be found in different host taxa worldwide but are mainly reported in the Mediterranean Sea and Asian marine waters (Delamare Deboutteville, 1962; Raibaut et al. 1998; Madinabeitia et al., 2013; Madinabeitia & Iwasaki, 2013; Uyeno & Nagasawa, 2021). According to some authors the real diversity of Philichthyidae is underestimated and most likely higher than the currently known, mainly because these parasites inhabit subcutaneous spaces of the fish that are easily neglected during parasitological surveys (West, 1992; Paschoal et al., 2016b; Couto & Paschoal, 2021). According to Boxshall & Halsey (2004), the uneven biogeographical distribution of species richness of Philichthyidae is likely to be related to uneven sampling effort. In Brazilian waters 10 species of philichthyid are known, nine of which belonging to *Colobomatus* and one to *Lepsophilus* being seven of them described in the last 10 years (Table 1). It should be mentioned that Brazil possesses the longest coastline in South America, extending for more than 7,000km, supporting 1,238 fish species (Froese & Pauly, 2022) and the records of philichthyids are concentrated off the State of Rio de Janeiro where nine species have been recorded. It contrasts with the coastal zones of the State of Rio Grande do Sul where only two species have been

Table 1 Species of Philichthyidae associated with hosts and their distribution off Brazil (listed in chronological order).

Copepod species	Host species (Family)	Distribution	Reference
Colobomatus belizensis Cressey & Schotte, 1983	*Haemulon atlanticus* Carvalho, Marceniuk, Oliveira and Wosiacki; *Orthopristis rubra* (Cuvier) (Haemulidae)	Coastal zone of the State of Rio de Janeiro	Cressey & Schotte (1983); Luque & Takemoto (1996); Luque & Tavares (2007); Paschoal et al. (2015, 2016a)
	H. aurolineatum Cuvier (Haemulidae)	Coast off Rio Grande do Norte	Cressey & Schotte (1983); Paschoal et al. (2015, 2016a)
Leposphilus vogti Paschoal, Nagasawa & Luque, 2016*	*Micropogonias furnieri* (Desmarest) (Sciaenidae)	Sepetiba Bay, State of Rio de Janeiro	Alves & Luque (2001); Paschoal et al. (2016b)
Colobomatus sudatlanticus Pereira, Timi, Lanfranchi & Luque, 2012	*Mullus argentinae* Hubbs and Marini (Mullidae)	Coast off Florianopolis, State of Santa Catarina, Rio de Janeiro and coastal Waters off Rio Grande, State of Rio Grande do Sul	Pereira et al. (2012); Luque et al. (2013); Paschoal et al. (2016a)
Colobomatus stelliferi Pombo, Turra, Paschoal & Luque, 2015	*Stellifer brasiliensis* (Schultz); *S. rastrifer* (Jordan); *S. stelliferi* (Bloch) (Sciaenidae)	Caraguatatuba Bay, State of São Paulo	Pombo et al. (2015); Paschoal et al. (2016a)
Colobomatus kimi Paschoal, Pereira & Luque, 2016a	*Upeneus parvus* Poey (Mullidae)	Coast off Espírito Santo and Rio de Janeiro	Paschoal et al. (2016a)
Colobomatus pagri (Richiardi, 1877)	*Pagrus pagrus* (Linnaeus) (Sparidae)	Coast off Rio de Janeiro and Rio Grande do Sul	Soares et al. (2018)
Colobomatus sp.	*Umbrina canosai* Berg (Sciaenidae)	Coast off Rio de Janeiro	Canel et al. (2019)
Colobomatus freirei Couto & Paschoal, 2021	*Holocentrus rufus* (Walbaum) (Holocentridae)	Coastal zone of the State of Rio de Janeiro	Couto & Paschoal (2021)
Colobomatus luquei Couto & Paschoal, 2021	*Holocentrus adscensionis* (Osbeck) (Holocentridae)	Coastal zone of the State of Rio de Janeiro	Couto & Paschoal (2021)
Colobomatus deborae **n. sp.**	*Diapterus rhombeus* (Cuvier) (Gerreidae)	Sepetiba Bay, State of Rio de Janeiro	This study

*First recorded as *Colobomatus* sp. by Alves and Luque (2001) (see Paschoal et al., 2016b).

recorded and Espirito Santo, São Paulo, Santa Catarina and Rio Grande do Norte where only one species has been recorded in each State (see Table 1 for details). Based on these data, it is clear that the real number of philichthyid species in Brazil is still uncertain and the present results highlight that these parasitic copepods represent good models for future studies using similar approaches.

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Author contributions FP and JLL performed field collections; FP and JVC analyzed the copepods and prepared the illustrations; FP and FBP prepared the main manuscript document; all authors reviewed the manuscript & approved the final version.

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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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