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The first record of the calanoid family Pseudocyclopidae Giesbrecht, 1893 in the South Atlantic Ocean

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Abstract

Nine hundred and ninety-two (992) specimens of *Pseudocyclops lerneri* Fosshagen, 1968 (Copepoda: Pseudocyclopidae) were collected from the largest South Atlantic coral reef, Abrolhos bank (17°20′–18°10′S; 38°35′–39°20′W). Specimens were distinguished from other *Pseudocyclops* spp. by a close examination of the female and male fifth leg. This is the first record of the family Pseudocyclopidae in the South Atlantic. We further indicate that the low number of studies on this species, and as a consequence, the poorly understood ecology of Pseudocyclopidae may be caused by the use of inadequate sampling methods, indicating the use of demersal-focused samplers, such as emergence traps as an alternative to the sampling of these bottom-dwelling copepods.

Introduction

Calanoida copepods is one of the most abundant and diverse crustacean groups in coastal waters, having a pivotal role in pelagic and benthic food webs (Boxshall and Halsey, 2004; Kunzmann *et al*., 2019; Kiljunen *et al*., 2020). The Pseudocyclopidae Giesbrecht, 1893 represents one of the most plesiomorphic Copepoda families (Bradford-Grieve *et al*., 2014). Pseudocyclopidae typically have small teeth on their mandibles, except for *Exumellina* Fosshagen, 1998 and *Stargatia* Fosshagen & Iliffe, 2003 which have two longer teeth on the lower part. While limited information is available regarding the trophic ecology of this family, it has been deduced, based on the mouthpart structure, that many of their species are fine-particle feeders. (Bradford-Grieve *et al*., 2014). The mandibles also have a well-developed endopod, with four setae on segment 1 and more than nine setae on segment 2. The maxilla has a basis with a longer endite and standard setae on the endopod. The maxilliped usually has an elongated endopod with regular setae (Bradford-Grieve *et al*., 2014). This taxon was initially described by Giesbrecht (1892), with only one genus, *Pseudocyclops*, until recently revised by Bradford-Grieve *et al*. (2014) and fused with the families Ridgewayiidae Wilson, 1958 and Boholinidae Fosshagen and Iliffe, 1989. Pseudocyclopidae contains 85 species and 14 genera of benthic, demersal, and stygobiotic Copepoda. Of these, the genera *Pseudocyclops* and *Ridgewayia* are the most diverse and widely distributed, occurring in temperate, subtropical and tropical shallow waters (Razouls *et al*., 2022), and encompassing 43 of the known Pseudocyclopidae species.

The genus *Pseudocyclops* Brady, 1872 resembles a Cyclopoida copepod, characterized by its small plump body rarely exceeding 1 mm in length, short first antennules and the presence of strong spines on the outer margin of the exopodes of the swimming legs. This general body morphology is usually common in benthopelagic calanoids, which spend a good part of the diel cycle on or near the substrate (Chullasorn *et al*., 2010). *Pseudocyclops* was first described as one of the few Calanoida that displayed bottom-living behaviour (Fosshagen, 1968). However, it was later described as demersal, grazing on both pelagic and benthic microalgae (Ohtsuka *et al*., 1999). Furthermore, although diverse and widely distributed, due to its demersal behaviour and the use of inadequate methodological approaches, *Pseudocyclops* species are poorly known, with 29 of the 39 described species only mentioned once in the literature (Table 1) (Fosshagen, 1968). In the present study, we describe specimens assigned to *Pseudocyclops lerneri* Fosshagen, 1968 sampled in Northeast Brazil, representing the first record of the Pseudocyclopidae family in the South Atlantic. We further discuss their distribution and current knowledge of the ecology of this demersal copepod.

Materials and methods

The specimens of *Pseudocyclops lerneri* were collected at two locations of the Abrolhos bank (17°57′ S; 38°42′ W), the Abrolhos Archipelago (18°1′0.03″S; 38°39′60.00″W) and the Abrolhos Parcel (17°58′38.38″S; 38°42′34.73″W). The Abrolhos bank coral reefs are located on the Brazilian continental shelf occupying an area of approximately 46,000 km^2, between

Table 1. Reported distribution of the 39 *Pseudocyclops* species and available descriptions according to Razouls et al. (2022)

	Species	Known distribution	Available description
1	*Pseudocyclops arguinensis* Andronov, 1986	Mauritania (Cap Blanc)	F, M
2	*Pseudocyclops australis* Nicholls, 1944	Australia (Sellick Reef); Japan	F, M
3	*Pseudocyclops bahamensis* Fosshagen, 1968	Bahamas (Great Gauanna Cay)	F, M
4	*Pseudocyclops bilobatus* Dawson, 1977	California (Los Angeles Harbor)	F, M
5	*Pseudocyclops cokeri* Bowman and Gonzalez, 1961	Porto Rico (Magueyes Canal); Bahamas	F, M
6	*Pseudocyclops constanzoi* Baviera, Crescenti and Zagami, 2007	Faro Lake (Sicilia)	F
7	*Pseudocyclops crassiremis* Brady, 1872	Norway (Atlantic); Ireland (North Sea)	F, M
8	*Pseudocyclops ensiger* Ohtsuka, Fosshagen and Putchakarn, 1999	Thailand (Phucket)	F, M
9	*Pseudocyclops faroensis* Brugnano, Celona and Zagami, 2010	Faro Lake (Sicilia)	F
10	*Pseudocyclops giussanii* Zagami, Brugnano and Costanzo, 2008	Faro Lake (Sicilia)	F
11	*Pseudocyclops gohari* Noodt, 1958	Red Sea (Ghardaqa)	F, M
12	*Pseudocyclops juanibali* Figueroa, 2011	Galapagos (Santa Cruz Island)	F, M
13	*Pseudocyclops kulai* Othman, Greenwood and Rothlisberg, 1990	Australia (Carpentaria Gulf)	F, M
14	*Pseudocyclops iphoph* Haridas, Madhupratap and Ohtsuka, 1994	Maldives Island	F, M
15	*Pseudocyclops latens* Gurney, 1927	Suez Canal	F
16	*Pseudocyclops latisetosus* Sewell, 1932	Indian Ocean	M
17	*Pseudocyclops lepidotus* Barr and Ohtsuka, 1989	Japan (Kyushu)	F, M
18	*Pseudocyclops lerneri* Fosshagen, 1968	Bahamas (Little San Salvador); Brazil (Present study)	F, M
19	*Pseudocyclops magnus* Esterly, 1911	Bermudas; Barbados	F, M
20	*Pseudocyclops mathewsoni* Fosshagen, 1968	Bahamas (Great Guana Cay)	F, M
21	*Pseudocyclops minutus* Ohtsuka, Fosshagen and Putchakarn, 1999	Thailand (Phucket)	F, M
22	*Pseudocyclops minya* Othman and Greenwood, 1989	Australia (Carpentaria Gulf)	M
23	*Pseudocyclops mirus* Andronov, 1986	Mauritania (Cap Blanc)	F, M
24	*Pseudocyclops obtusatus* Brady, 1873	Hudson river bay; Azores; Ireland; Scottland (Inchkeith); Scottland (Forth river estuary); English Channel; Norway; Barents Sea; Sri Lanka; France (Pas de Calais)	F
25	*Pseudocyclops oliveri* Fosshagen, 1968	Bahamas (Little Salvador, Great Guanna Cay)	F
26	*Pseudocyclops ornaticauda* Ohtsuka, Fosshagen and Putchakarn, 1999	Thailand (Phucket)	F, M
27	*Pseudocyclops pacificus* Vervoort, 1964	Caroline Islands	M
28	*Pseudocyclops paulus* Bowman and Gonzalez, 1961	Porto Rico; Barbados	F, M
29	*Pseudocyclops pumilis* Andronov, 1986	Mauritania (Cap Blanc)	F, M
30	*Pseudocyclops reductus* Nicholls, 1944	Red Sea	F
31	*Pseudocyclops rostratus* Bowman and Gonzalez, 1961	Bahamas; Porto Rico; Jamaica; Florida	F, M
32	*Pseudocyclops rubrocinctus* Bowman and Gonzalez, 1961	Bahamas; Porto Rico; Jamaica	F, M
33	*Pseudocyclops saenzi* Figueroa, 2011	Galapagos	F, M
34	*Pseudocyclops schminkei* Chullasorn, Ferrari and Dahms, 2010	Japan (Okinawa)	F, M
35	*Pseudocyclops simplex* Sewell, 1932	Indian Ocean	F, M
36	*Pseudocyclops spinulosus* Fosshagen, 1968	Bahamas (Great Guana Cay)	F
37	*Pseudocyclops steinitzi* Por, 1968	Red Sea	F, M
38	*Pseudocyclops umbraticus* Giesbrecht, 1892	Sicilia (Napoli); Egypt (Port said); Egypt (Ismailia); Canal de Suez; Mauritania (Cap Blanc)	F, M
39	*Pseudocyclops 1 iphophorus* Wells, 1967	Moçambique; Sicilia; Hong Kong;	F, M

16°40′-19°40′S and 37°20′-39°10′W, and are characterized by unique coralline mushroom-shaped pinnacles, known locally as ‘Chapeirões (Leão, 1999). The major coralline formations include an inner arc and an outer arc. The outer arc is located 60–65 km offshore and is composed of the Abrolhos Archipelago and the Abrolhos Parcel (Leão, 1999; Moura et al., 2013). The Parcel dos Abrolhos is formed by multiple and sparse coralline pinnacles ('Chapeirões') that reach the surface, while the Abrolhos Archipelago is composed of five volcanic islands that present fringing reefs extending up to 50–60 m from the islands.

The sampling was carried out in the summer (February) of 2014. The bottom of the Abrolhos Archipelago site (≈ 6 m depth) consists of a reef formation dominated by turf algae, scleractinian corals, articulated calcareous algae, fleshy algae, and adjacent coarse sandy bottom (Francini-Filho *et al*., 2013). The Parcel dos Abrolhos site comprises a series of unique mushroom-shaped pinnacles (≈ 7 m depth) and has the same coverage as the fringing reefs (Francini-Filho *et al*., 2013).

Two emergence trap designs were employed to cover the variability of the demersal community as well as possible (Youngbluth, 1982), consisting of a conical net attached to a metal frame with a catching chamber at the net end. A large emergence trap consisted of a modification of Melo *et al.* (2010) design, with a 200 µm mesh size, 1 m mouth diameter and 1 m between the substrate and the catch chamber. The second design consisted of a modification of Kramer *et al.* (2013) with 64 µm mesh size, 30 cm mouth and 30 cm between the substrate and the catch chamber. The traps were placed randomly across the reef and sand substrate at the Abrolhos Archipelago (between 5 and 6 m) and Parcel dos Abrolhos (between 6 and 7 m). Traps were placed at dusk and retrieved at sunrise. Surrounding the base of the traps was a 15 cm wide, 64 µm mesh 'skirt' to seal the entrance and prevent escape and contamination by pelagic organisms. Three replicates of each type of trap were deployed simultaneously over each substrate during the full moon, constituting 24 samples. After withdrawals, the samples were transferred to 500 ml sample flasks and fixed with 4% formaldehyde buffered with sodium tetraborate (Harris *et al*., 2000). Ten specimens (five males and five females) were deposited in the Museu de Oceanografia Professor Petrônio Alves Coelho from Universidade Federal de Pernambuco (202205-01).

The number of specimens was tested for normality (Kolmogorov-Smirnov) and homogeneity of variance (Levene). Subsequently, results were tested between substrates, areas and sampling devices using *t*-test. The analyses were done using the software *PAST 3.20*, values of $P < 0.05$ were considered significant.

Results and discussion

A total of 992 specimens (555 females and 437 males) from the Abrolhos Bank were identified as *Pseudocyclops lerneri*. Females (Figure 1A) ranged from 378.97 to 967.39 µm and males (Figure 1B) ranged from 408.26 to 1015.82 µm, with an average size of 603.64 and 751.95 µm, respectively. Most of the specimens were sampled from the Parcel dos Abrolhos (836 specimens) (Table 2), although between areas no statistical difference could be found ($P = 0.06$). Regarding the substrate, a similar number of individuals were found in the sand (458 specimens) and reef (534 specimens) substrates with no significative difference between the substrates ($P = 0.30$). The only significant difference was found between sampling devices, with a better efficiency with the 64 µm mesh trap (742 specimens) ($P = 0.04$). The morphological features of the specimens agreed with Fosshagen (1968) diagnosis, regarding the main characteristics: small body, not exceeding 1 mm (both male and female), prosome almost twice as long as broad and the first, fourth and fifth pedigerous somites not fused (Figure 1A, B). Female fifth leg exopod with one seta distally on the inner margin of the second segment and with 3–4 setae along the inner margin of the third (Figure 1C), three terminal spines (of nearly equal length) on the third exopod segment (Figure 1C). Endopod 3-segmented with outer distal corners of each segment produced into a point (Figure 1C, 2), 3–4 terminal setae present on the third endopod segment and 1 seta on the distal inner margin of each of the other segments, and the coxa and basipod with rows of spinules, particularly along the distal margins (Figure 1C). Male right exopod with a strong outermost spine, two inwardly spines, one shorter than the outermost spine (Figure 1D 3–6). Right endopod rudimentary and club-shaped. Right basipod and coxa armed with rows of spinules (Figure 1D). Left exopod with a short spine present halfway along the inner margin. Right exopod with outer distal corner produced into a point. Left endopod narrow at the base but broadening towards the distal margin which carries 5 plumose jointed setae (Figure 1d).

The genus *Pseudocyclops* is widely distributed in tropical and subtropical waters of the northern hemisphere (Figure 2), especially in Caribbean waters and Southeast Asia (Razouls *et al*., 2022). However, although frequently identified in plankton samples, in particular during nighttime, literature reports usually found *Pseudocyclops* in low abundance, rarely surpassing 30 specimens (Fosshagen, 1968; Zagami *et al*., 2008; Brugnano *et al*., 2010). The limited reports of this taxa in the literature hinders our understanding of their distribution and key ecological aspects, e.g. although recent efforts have increased in three times the known diversity of *Pseudocyclops* in the last half century (Baviera *et al*., 2007), many species are still identified based only on one specimen of a female or male (Table 1). Compared with the planktonic calanoids, this low abundance has been assigned as an ecological characteristic of the *Pseudocyclops* assemblages (Campolmi *et al*., 2001; Zagami *et al*., 2008; Brugnano *et al*., 2010). However, as Fosshagen (1968) suggested, this is more likely associated with inadequate sampling methodologies used. *Pseudocyclops* have been sampled with the usual plankton vertical tows (Esterly, 1911; Gurney, 1927; Sewell, 1932; Bowman and González, 1961; Vervoort, 1964; Yeatman, 1975; Dawson, 1977; Alldredge and King, 1980; Othman and Greenwood, 1989; Haridas *et al*., 1994; Campolmi *et al*., 2001; Zagami *et al*., 2008; Brugnano *et al*., 2010), hand tows (Bowman and González, 1961; Ohtsuka *et al*., 1999) and the scraping of fouling community on moored posts (Zagami *et al*., 2005). However, due to its characteristically vertical migration behaviour, the use of demersal traps is a much more adequate method of sampling not only *Pseudocyclops* but all demersal zooplankton (Youngbluth, 1982; Farias *et al*., 2020). In this study, using emergence traps we found a higher number of specimens than previously recorded in the literature for this family. The demersal zooplankton has complex migration patterns, which are influenced by taxa innate behaviour, seasonal variability, moonlight, and substrate preferences (Porter and Porter, 1977; Alldredge and King, 1980; Pacheco *et al*., 2013). This community migrates in multiple pulses during the night, depending on the community ethological characteristics, i.e. relationship with moonlight intensity and seasonal reproductive periods (Alldredge and King, 1980), therefore sampling methods that do not cover a large time frame, i.e. net tows, are not capable of properly assessing the distribution of these organisms. Furthermore, regarding the trap design, we observed a clear higher abundance in the traps presenting a smaller distance between the sediment and the catching chamber. The height of the demersal zooplankton in the water column can also change depending on the taxa and environmental conditions. Some species emerge only a few centimetres from the substrate, as some copepods, and larger taxa migrate metres in the water column (Alldredge and King, 1985). Some studies indicate the reduction of the emergent fauna near the substrate during the night from a few centimetres to 1.5 m, but without reaching the surface (Holzman and Genin, 2005; Yahel *et al*., 2005). Although the results might be caused by a mesh selection, a second probable hypothesis is that *Pseudocyclops lerneri* is a weak swimmer,

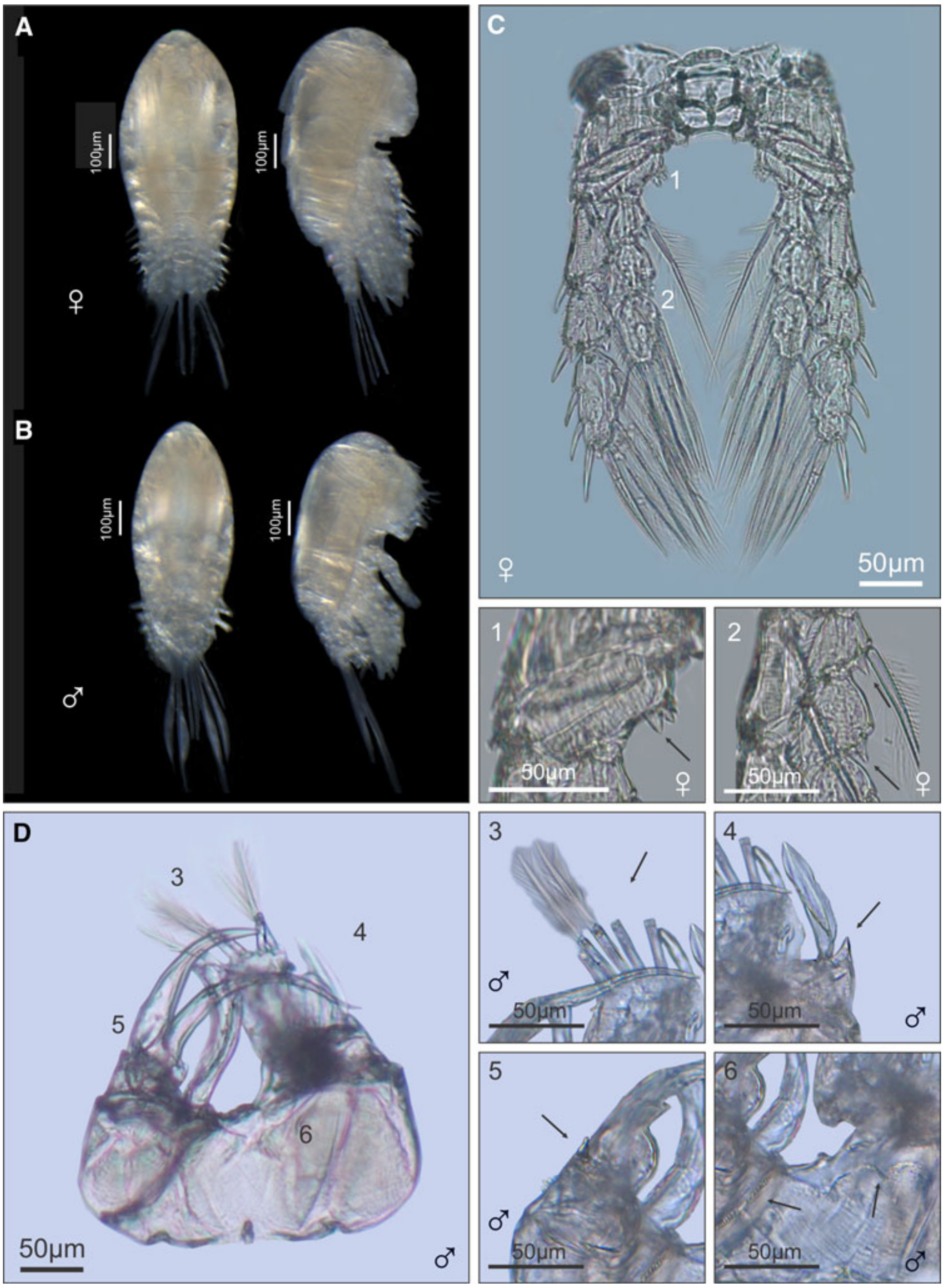

Figure 1. *Pseudocyclops lerneri* Fosshagen, 1968, collected at Abrolhos Bank. (A) Female in dorsal and lateral view; (B) Male in dorsal and lateral view; (C) *Pseudocyclops lerneri* Fosshagen, 1968, female fifth leg, with highlights for the: 1. A row of spinules on the coxa distal margin and; 2. Endopodites segments distal margin produced into a point; (D) Male fifth leg, with highlights for the: 3. 5 plumose jointed setae on the left endopodite; 4. Outer distal corner of right exopod produced into a point; 5. Left exopod with a short spine present halfway along the inner margin; 6. Rows of spines on the coxa.

remaining close to the substrate during the night. It has been suggested that the general morphology of *Pseudocyclops* with plump body and short first antennae may limit their ability to remain in the water column (Chullasorn *et al.*, 2010). This would also explain the contrast in abundance in this study to previous *Pseudocyclops* studies which used subsurface net tows. We emphasize that the use of more adequate sampling methods could greatly enhance the current distribution of *Pseudocyclops*, as well as other Pseudocyclopidae demersal genera, diversity, biogeography, and ecological importance in shallow ecosystems.

Table 2. Number of specimens of *Pseudocyclops lerneri* caught from the two sites of the Abrolhos bank in 2014

	Abrolhos Archipelago				Parcel dos Abrolhos			
Abundance	Reef		Sand		Reef		Sand	
Mesh size	64 µm	200 µm	64 µm	200 µm	64 µm	200 µm	64 µm	200 µm
Pseudocyclos lerneri	71	61	28	–	328	76	414	15

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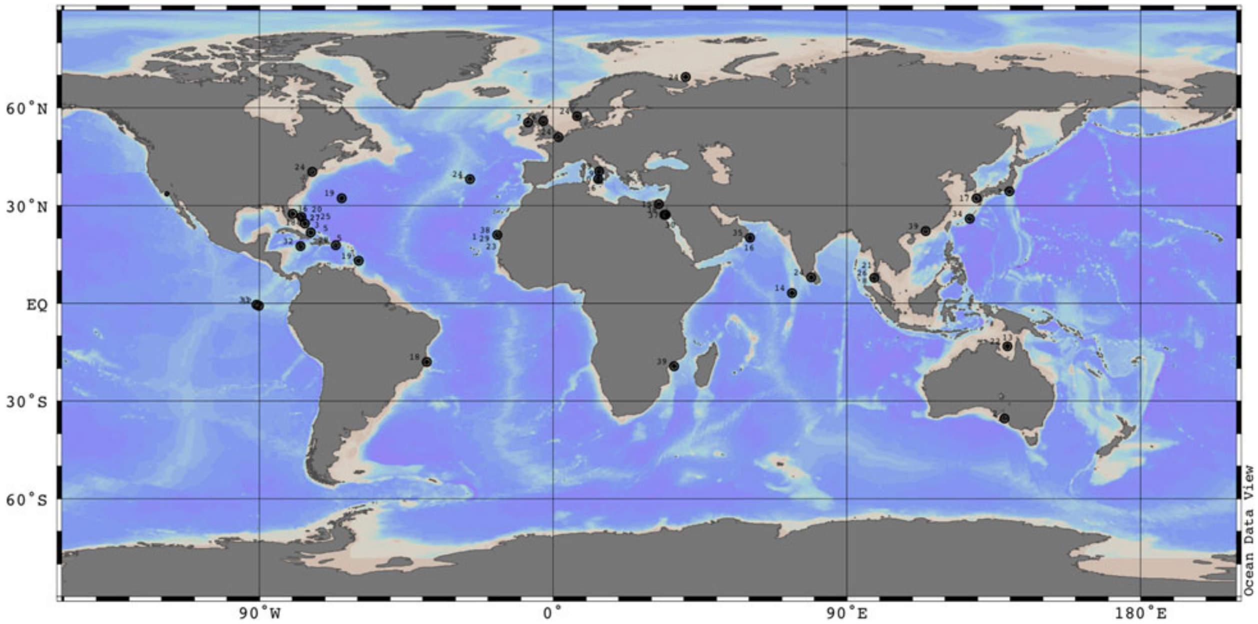

Figure 2. Global distribution of *Pseudocyclops* based on this study and literature records (black dots). Numbers correspond to numbers of Table 1.

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Authors' contributions. G.B.F.: Conceptualization, Methodology, Validation, Formal Analysis, Writing – original draft, Writing-Reviewing and Editing. K.H.F.: Conceptualization, Methodology, Validation, Formal Analysis, Writing-Reviewing and Editing. L.G.P.F.: Investigation and Methodology. P.A.M.C.M.: Writing-Reviewing and Editing. S.N.L.: Writing-Reviewing and Editing.

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Competing interest. None.

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

Data availability. Data will be available on request.

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