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RESEARCH ARTICLE

Two new species of monogenoidean parasites (Platyhelminthes: Neodermata) of ornamental fish of Loricariidae (Siluriformes) from the Xingu River, Brazilian Amazon

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ABSTRACT. Two new monogenoidean species of *Unilatus* Mizelle & Kritsky, 1967 found in the gills of loricariids in the Lower Xingu-Iriri rivers are described: *Unilatus humboldtii* **sp. nov.** from *Baryancistrus niveatus* (Castelnau, 1855), *Panaque armbrusteri* Lujan, Hidalgo & Stewart, 2010, *Pseudacanthicus* sp. (type-host), and *Scobinancistrus aureatus* Burgess, 1994; and *Unilatus luciarappae* **sp. nov.** from *P. armbrusteri*. *Unilatus humboldtii* **sp. nov.** is distinguished from other congeneric species due to its anterior anchor with well-developed superficial root with depressed or truncated distal portion, and inconspicuous or reduced deep root; anterior bar with posteromedial projection; hooks of pair 1 with dilated shaft comprising 2/3 of the hook length; spiraled male copulatory organ with approximately 16–18 counterclockwise loops. *Unilatus luciarappae* **sp. nov.** is characterized by having anterior anchor with well-developed superficial root and reduced deep root, slightly curved shaft, elongated, slightly curved, and tapered point; spiraled MCO with approximately 18–19 counterclockwise loops, with median distal bulbous portion and remaining portion tapered and elongated, comprising 1/4 of the body length; and accessory piece comprising approximately 2/3 of the MCO length. More than fifty years after the description of the type species of *Unilatus* from an artificial environment (U.S. aquaria), this study represents the first formal record and description of *Unilatus* species from hosts collected in natural habitats in the Xingu River. Considering the impact of the Belo Monte dam on the formerly pristine conditions of the study region and the importance of loricariids for the ornamental fish trade, we recommend monitoring monogenoidean diversity, parasite-host interaction, as well as the dispersion patterns and pathogenicity of these parasites.

KEY WORDS. Amazon, Loricariidae, Monogenoidea, parasites, ornamental fish, *Unilatus*.

INTRODUCTION

Brazil is a regional leader in the global exportation of ornamental fish from inland waters, representing 23% of the South American market (Prang 2007). Much of this trade is comprised of fish species from the Amazon basin, which are favorites among Brazilian and foreign aquarists and represent an important source for international trade (Carvalho Júnior et al. 2009). Total revenues in this market are estimated at USD 68,246,689.00 between 2012 and 2019 (Siscomex 2020), with high profitability driving an active global market (Araújo et al. 2017).

The state of Amazonas, especially the Rio Negro region, is the largest source of ornamental fish in Brazil, representing approximately 60% of the country's total exports, with the state of Pará, accounting for an additional 30% (Lacerda 2005). In Pará, the Xingu region is one of the main centers of ornamental fish extraction, with approximately 422 species with trade interests reported for the region (Carvalho Júnior et al. 2009). Among these species, loricariids (Loricariidae), freshwater rays (Potamotrygonidae), and cichlids (Cichlidae) (Camargo 2011) are noteworthy, in part because several species are endemic to the Xingu region, giving them a high added value (Araújo et al. 2017).

In Brazil, the capture, commercialization, and exportation of fish were regulated by Normative Instruction MPA/MMA 001/2012, which was enforced until 2020. This legislation covered 725 fish species from Brazilian continental waters, of which 125 (~17%) belonged to the Loricariidae. Commercial interest in species of this fish family is considerable in the Xingu River basin since, of the 55 species reported, at least 38 are commercialized as ornamental species (Camargo et al. 2011). Loricariids, widely known as commonly called "plecos" or "L" by aquarists.

Endemic to the Neotropics, the Loricariidae is one of the largest fish families in South America with approximately 916 valid species, encompassing about 1/4 of the diversity of the order Siluriformes (Armbruster 2011, Eschmeyer and Fong 2016, Nelson et al. 2016). Loricariids are highly valued on the international ornamental fish market. For example, species like *Scobinancistrus aureatus* Burgess, 1994, commonly known as "Goldie Pleco", can be sold by 1,500% of the Brazilian initial export cost (Araújo et al. 2017). However, loricariid collectors – known as acarizeiros – earn marginal wages. The relatively reduced income of the acarizeiros results in a greater effort of capture. The high individual value of loricariids of commercial interest stimulates intensified selective fishing and may lead to a depletion of natural stocks (Ramos et al. 2015). This is the case of the "Zebra Pleco", *Hypancistrus zebra* Isbrücker & Nijssen, 1991, a species endemic to the Xingu River basin, whose capture was prohibited in 2004 (Ibama 2004) due to overfishing.

Studies on the pathogens or parasites that affect ornamental fishes exported from Brazil (Fujimoto et al. 2013, Tavares-Dias et al. 2017, Cardoso et al. 2018, Hoshino et al. 2018) and abroad (Mehdizadeh Mood and Rassouli 2016, Mendoza-Franco et al. 2018) are still in their early stages. Recent data on monogenoidean platyhelminths, for example, suggest that only 8% of ornamental fish species regularly sold in Brazil are examined for these parasites (Cohen et al. 2013). For monogenoidean parasites, it is currently estimated that only approximately 4% of this diversity has been revealed (Cohen et al. 2013, Branches and Domingues 2014, Acosta et al. 2017a, 2017b, Franceschini et al. 2018, Vianna and Boeger 2019, Kritsky et al. 2020). Currently, 40 species of monogenoids are known from species of Loricariidae, of which 27 species were reported to parasitize the gills and 13 the body surface (Table 1). However, there are no records of monogenoidean parasites from species of Loricariidae in the Xingu basin, despite their importance of the Loricariidae in the regional ichthyofauna (Winemiller et al. 2016).

While investigating the monogenoidean parasite diversity from the gills of *Baryancistrus niveatus* (Castelnau, 1855), *Panaque armbrusteri* Lujan, Hidalgo & Stewart, 2010, *Pseudacanthicus* sp., and *S. aureatus* of Volta Grande, Xingu River, Pará, two new species of *Unilatus* Mizelle & Kritsky, 1967 were found. These two new species are described here, representing the first species of the genus formally described from loricariids in the Xingu River basin.

MATERIAL AND METHODS

Host sampling

Specimens of *B. niveatus* (n = 2), *P. armbrusteri* (n = 3), *Pseudacanthicus* sp. (n = 3), and *S. aureatus* (n = 4) were collected using a trammel net at Volta Grande, Xingu River (Amazon Basin, Amazonas, Xingu, Iriri, Paru Sub-basin), municipality of Altamira, state of Pará, Brazil (03°21'15,7"S; 52°11'47,5"W) on June 13, 2015. The river basin nomenclature follows the Brazilian Water Agency, Ministry of the Environment (http://hidroweb.ana.gov.br/).

Parasitological procedures

The gill arches of the hosts were removed and packed in labeled vials containing water heated to ~65 °C. Each vial was vigorously shaken, and formalin was added until a final concentration of 5% was reached. In the laboratory, the gill arches and washing sediment were analyzed using a Leica S6E stereoscope, and helminths were removed, counted, and identified. For morphological analysis, some specimens were stained with Gomori's trichrome (Humason 1979, Boeger and Vianna 2006) and mounted on Dammar gum to examine their internal morphology, while others were mounted in Hoyer's or Gray & Wess mounting media (Humason 1979, Boeger and Vianna 2006) to study their sclerotized structures. Illustrations were prepared using a camera lucida attached to a Leica DM 2500 optical microscope. Prevalence and mean intensity followed Bush et al. (1997). Measurements, all in micrometers, were obtained according to Mizelle and Klucka (1953) and represent the mean, followed by the range and the number of specimens (n) in parenthesis. The size of internal organs and other structures represents the largest distance in the dorso-ventral view; they were measured using a micrometer eyepiece. The classification of hooks followed Mizelle and Price (1963). Measurements are shown in mean values, followed by the maximum and minimum values and the number of specimens measured (n) in parenthesis. Type specimens of each species were deposited in the Invertebrate Collection, Museu Paraense Emilio Goeldi (MPEG), Belém, Pará, Brazil.

TAXONOMY

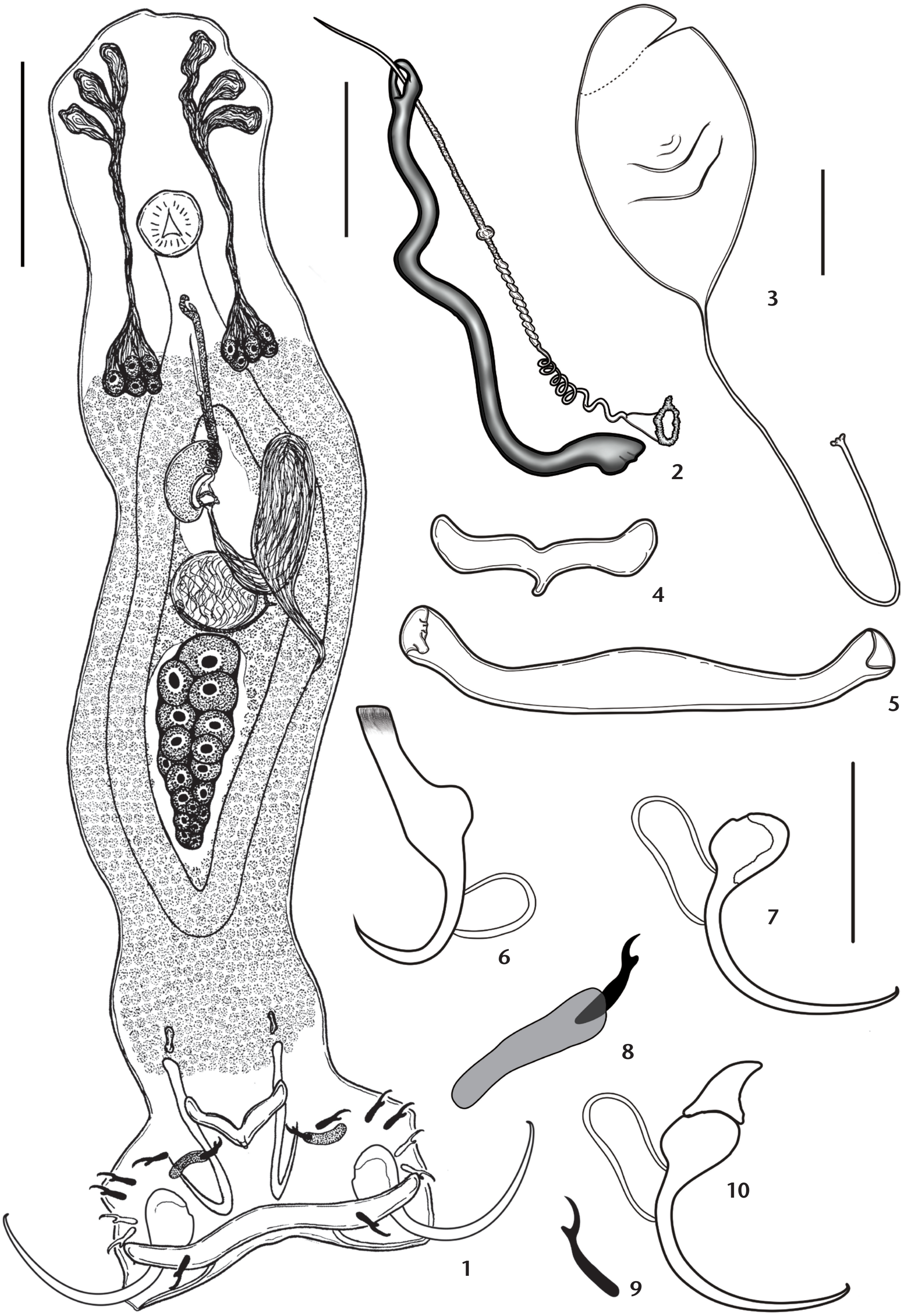
Class Monogenoidea Bychowsky, 1937
Subclass Polyonchoinea Bychowsky, 1937
Order Dactylogyridea Bychowsky, 1937
Dactylogyridae Bychowsky, 1933
Unilatus Mizelle & Kritsky, 1967
Unilatus humboldtii sp. nov.

http://zoobank.org/842CC7F1-54EE-48E8-BC11-69029ABDFA87
Figs 1–10

Description. Based on 17 specimens mounted in Hoyer's. Body fusiform, 459 (200–550; n = 5) long, excluding haptor, 140

Table 1. Checklist of monogenoidean species parasites of fish species of the Loricariidae.

Host species	Parasite species	Infection site	Reference
Acanthicus hystrix	*Trinigyrus acuminatus*	Gills	Kritsky et al. (1986)
Ancistrus multispinis	*Onychogyrodactylus hydaticus*	Body surface	Kritsky et al. (2007)
	Onychogyrodactylus sudis	Body surface	Kritsky et al. (2007)
Ancistrus sp.	*Nothogyrodactylus amazonicus*	Body surface	Kritsky and Boeger (1991)
	Nothogyrodactylus clavatus	Body surface	Kritsky and Boeger (1991)
	Nothogyrodactylus plaesiophallus	Body surface	Kritsky and Boeger (1991)
	Atopogyrodactylus praecipuus	Body surface	Kritsky et al. (2020)
Dekeyseria scaphirhyncha	*Unilatus scaphirhynchae*	Gills	Suriano (1985)
Farlowella amazonum	*Oogyrodactylus farlowellae*	Body surface	Harris (1983)
Hemiancistrus sp.	*Unilatus dissimilis*	Gills	Suriano (1985)
Hypoptopoma thoracatum	*Trinigyrus tentaculoides*	Gills	Kritsky et al. (1986)
Hypostomus bolivianus	*Unilatus anoculus*	Gills	Price (1968)
Hypostomus iheringii	*Unilatus unilatus*	Gills	Zica et al. (2012)
Hypostomus punctatus	*Phanerothecium spinatus*	Body surface	Boeger et al. (1994)
Hypostomus regani	*Paranaella luquei*	Gills	Kohn et al. (2000)
	Unilatus unilatus	Gills	Zica et al. (2012)
Hypostomus robinii	*Trinigyrus hypostomatis*	Gills	Hanek et al. (1974)
	Unilatus unilatus	Gills	Molnar et al. (1974)
Hypostomus strigaticeps	*Unilatus unilatus*	Gills	Zica et al. (2012)
Hypostomus sp.	*Heteropriapulus heterotylus*	Gills	Jogunoori et al. (2004), Kritsky (2007)
	Paranaella luquei	Gills	Kohn et al. (2000)
	Phanerothecioides agostinhoi	Body surface	Kritsky et al. (2007)
	Unilatus brittani	Gills	Suriano (1985)
Kronichthys lacerta	*Aglaiogyrodactylus forficulatus*	Body surface	Kritsky et al. (2007)
Leporacanthicus galaxias	*Unilatus irae*	Gills	Branches and Domingues (2014)
Loricaria anus	*Demidospermus anus*	Gills	Suriano (1983)
Loricariichthys platymetopon	*Demidospermus paranaensis*	Gills	Ferrari-Hoeinghaus et al. (2010)
	Demidospermus anus	Gills	Franceschini et al. (2017)
Loricaria prolixa	*Demidospermus spirophallus*	Gills	Franceschini et al. (2017)
	Demidospermus prolixus	Gills	Franceschini et al. (2017)
Pareiorhaphis parmula	*Aglaiogyrodactylus conei*	Body surface	Kritsky et al. (2007)
	Aglaiogyrodactylus ctenistus	Body surface	Kritsky et al. (2007)
	Aglaiogyrodactylus salebrosus	Body surface	Kritsky et al. (2007)
	Gyrodactylus anaspidus	Body surface	Vianna and Boeger (2019)
Plecostomus plecostomus	*Phanerothecium harrisi*	Body surface	Kritsky and Boeger (1991)
Plecostomus sp.	*Unilatus brittani*	Gills	Mizelle et al. (1968)
	Unilatus unilatus	Gills	Mizelle and Kritsky (1967)
Pseudotothyris obtusa	*Aglaiogyrodactylus guttus*	Body surface	Kritsky et al. (2007)
Pterygoplichthys ambrosettii	*Heteropriapulus anchoradiatus*	Gills	Acosta et al. (2017a)
	Heteropriapulus heterotylus	Gills	Acosta et al. (2017a)
	Heteropriapulus simplex	Gills	Acosta et al. (2017a)
	Heteropriapulus sp.	Gills	Acosta et al. (2017a
Pterygoplichthys anisitsi	*Unilatus unilatus*	Gills	Mendoza-Palmero et al. (2012)
	Unilatus brittani	Gills	Mendoza-Palmero et al. (2012)
Pterygoplichthys pardalis	*Heteropriapulus* sp.	Gills	Mendoza-Franco et al. (2012)
Pterigoplichthys multiradiatus	*Unilatus unilatus*	Gills	Suriano (1985)
	Unilatus brittani	Gills	Suriano (1985)
Rhinelepis aspera	*Paranaella luquei*	Gills	Kohn et al. (2000)
	Demidospermus rhinelepisi	Gills	Acosta et al. (2017b)
Rhineloricaria sp.	*Hyperopletes malmbergi*	Body surface	Boeger et al. (1994)
Schizolecis guntheri	*Aglaiogyrodactylus calamus*	Body surface	Kritsky et al. (2007)
	Aglaiogyrodactylus forficuloides	Body surface	Kritsky et al. (2007)
Aphanotorulus emarginata	*Trinigyrus mourei*	Gills	Boeger and Jégu (1994)



Figures 1–10. *Unilatus humboldtii* sp. nov.: (1) body in ventral face (composite); (2) copulatory complex; (3) egg; (4) anterior bar; (5) posterior bar; (6) anterior anchor; (7) posterior anchor; (8) hook pair 1; (9) hook pairs 2–7; (10) posterior anchor. Scale bars: 1 = 50 µm scale, 2–10 = 25 µm.

(70–175; n = 10) wide at level of germarium; tegument smooth (Fig. 1). Cephalic area with terminal lobes, poorly developed or absent, bilateral head organs present, three to four pairs, with rod-shaped secretion; cephalic glands unicellular, posterolateral to pharynx. Eyespot, accessory chromatic granules absent. Mouth, subterminal, midventral; pharynx muscular, glandular, spherical, 25 (16–32; n = 6) long, 24 (15–31; n = 6) wide; esophagus elongate; two intestinal ceca, confluent posteriorly to gonads, lacking diverticula. Genital pore opening dextroventral, near median line of body at level of cecal bifurcation; genital atrium muscular. Intercecal gonads apparently overlapping, testis not observed. Vas deferens looping left intestinal cecum; seminal vesicle representing a dilation of vas deferens, distal portion looping posteriorly before entering base of male copulatory organ (MCO). Copulatory complex comprising MCO sclerotized, accessory piece. MCO spiral, 88 (71–103; n = 7) long, with approximately 16–18 coils, non-articulated to accessory piece, base with sclerotized edge, median distal portion bulbous (Fig. 2). Accessory piece comprising sinuous rod, distal portion with subterminal flap with hook, thumb, guiding distal portion of MCO, 86 (82–90; n = 3) long. Single prostatic reservoir saccate, anterior to the base of MCO, 20 (n = 1) largest diameter, 17 (n = 1) smallest diameter. Germarium elongate, 53 (n = 1) long, 25 (n = 1) wide. Mehlis' glands, ootype not observed. Vagina single, opening ventrally (dextral) at level of proximal portion of germarium; vaginal vestibule muscular; vaginal canal sclerotized, funnel-shaped, elongate. Seminal receptacle subspherical, at level of anterior margin of germarium, ventral. Vitellaria dense, coextensive with intestinal ceca. Egg ovate, elongate, 62 (54–69; n = 3) long excluding filament, 34 (31–41; n = 3) wide (Fig. 3); proximal filament comprising twice size of the egg. Haptor subtrapezoidal, 126 (60–140; n = 8) long, 92 (55–120; n = 7) wide. Anchors dissimilar, in tandem, (both) on dorsal side of haptor. Anterior anchor, 69 (65–75; n = 9) long, anchor base, 40 (38–45; n = 9) long, with superficial root straight and elongated, distal portion depressed; inconspicuous or reduced deep root; shaft elongate, uniformly curved; point short, slightly curved surpassing level of tip of superficial root (Fig. 6). Accessory structures (one pair) associated with anterior anchor (Fig. 1). Posterior anchor, 55 (46–60; n = 11) long, anchor base, 20 (19–23; n = 11) long (excluding sclerotized cap of base), with superficial, deep roots not differentiated; anchor base covered with sclerotized cap with a small protuberance for articulation of posterior bar; shaft uniformly curved; point short, slightly curved, surpassing level of superficial root (Figs 7, 10). Filament of anterior anchor extends from anterior portion of shaft to its median portion; filament of posterior anchor extends from base of sclerotized cap to anterior portion of shaft. Anterior bar curly bracket-shaped with posterior median projection, 48 (36–55; n = 11) long, 15 (14–19; n = 9) wide, with rounded ends (Fig. 4); posterior bar open-V shaped, with small median anterior expansion, anteriorly curved ends, 121 (106–138; n = 7) long, 16 (11–22; n = 10) wide (Fig. 5). Hooks similar in shape, with erect, thumb; shaft fusiform, short, slightly curved, 15 (12–17; n = 10) long; hook pair 1 39 (32–44; n = 9) long (Fig. 8) with posterior portion of shank inflated, comprising 2/3 of hook length; remaining hooks with non-inflated shanks (Fig. 9).

Type host. *Pseudacanthicus* sp. (Loricariidae: Hypostominae).

Site of infection. Gill filaments.

Type locality. Volta Grande, Xingu River (Amazon Basin; Amazonas, Xingu, Iriri, Paru Sub-basin), municipality of Altamira, Pará, Brazil (03°21'15.7"S; 52°11'47.5"W).

Prevalence. 67% of three hosts specimen examined.

Mean intensity. 10 parasites per infected host specimen.

Other records. *Baryancistrus niveatus* (prevalence: 50% in two hosts; mean intensity: 1); *P. armbrusteri* (prevalence: 33% in three hosts; mean intensity: 3); *S. aureatus* (prevalence: 25% in four hosts; mean intensity: 10), Volta Grande, Xingu River (Amazon Basin; Amazonas, Xingu, Iriri, Paru Sub-basin), municipality of Altamira, Pará, Brazil (03°21'15.7"S; 52°11'47.5"W).

Specimens deposited. Holotype, MPEG 00300; 6 Paratypes, MPEG 00301–00306; 15, vouchers, MPEG 00307–00321.

Etymology. The species is named after Alexander von Humboldt in celebration of his 250th birthday anniversary in 2019.

Remarks. *Unilatus humboldtii* sp. nov. resembles *U. brittani* Mizelle, Kritsky & Crane, 1968 due to the morphological similarities of the anterior bar. However, the new species is distinguished from *U. brittani* morphologically and morphometrically since it has an anterior anchor with well-developed superficial root with depressed or truncated distal portion, inconspicuous or reduced deep root, anterior bar with posteromedial projection; hooks of pair 1 with dilated shaft comprising 2/3 of the hook length, and MCO spiral with approximately 16–18 coils.

Unilatus luciarappae sp. nov.

http://zoobank.org/53487FBA-2F56-4430-A36F-5CEC198A16CC

Figs 11–19

Description. Based on 13 specimens, 11 mounted in Hoyer's medium, two mounted in Gomori´s trichrome. Body fusiform, 279 (175–385; n = 6) long, excluding haptor, 76 (50–100; n = 7) wide at level of germarium; tegument smooth (Fig. 11). Cephalic area with terminal lobes, poorly developed or absent; bilateral head organs present, three pairs, with rod-shaped secretion; cephalic glands not observed in studied specimens. Eyespots, accessory chromatic granules absent. Mouth subterminal, midventral; pharynx muscular, spherical, 19 (17–22; n = 9) in diameter; esophagus elongated; two intestinal ceca, confluent posteriorly to gonads, lacking diverticula. Genital pore, opening dextroventral, near median line of body at level of cecal bifurcation; genital atrium muscular. Intercecal gonads apparently overlapping, testis not observed. Vas deferens looping left intestinal cecum; seminal vesicle representing a dilation of vas deferens, distal portion looping posteriorly before entering base of MCO. Copulatory complex comprising sclerotized MCO, accessory piece. MCO spiral, 103 (89–120; n = 11) long, counterclockwise, with approximately 18–19 coils, non-articulated to accessory piece, base with sclerotized edge, median distal portion bulbous, final distal portion tapered (Fig. 12). Accessory piece 72 (43–100; n = 6) long, straight or slightly sinuous rod, comprising approximately 2/3 of MCO length; distal portion of accessory piece with subterminal two small flaps, guiding distal portion of MCO. Single prostatic reservoir, saccate, anterior to base of MCO, 22 (n = 1) largest diameter, 13 (n = 1) smallest diameter. Germarium fusiform, 37 (n = 1) long, 15 (n = 1) wide. Mehlis' glands, ootype not observed. Vagina single, opening ventrally (dextral) at level of vitelline commissure; vaginal vestibule muscular; vaginal canal heavily sclerotized, sigmoid, with a loop in distal portion. Seminal receptacle subspherical, at level of anterior margin of germarium, ventral. Vitelline follicles dense. Egg ovate elongate, 62 (55–68; n = 4) long excluding filament, 29 (25–33; n = 4) wide (Fig. 13). Egg filament comprising twice the size of the egg. Haptor trapezoidal, 77 (55–105; n = 4) long, 49 (25–75; n = 5) wide. Anchors dissimilar, in tandem, (both) on dorsal side of haptor. Anterior anchor, 30 (30–32; n = 11) long, anchor base, 19 (16–20; n = 11) long (Fig. 16), with superficial root straight, elongate, distal portion round; inconspicuous or reduced deep root; slightly curved shaft; point elongate, extending to level of superficial root, tapered; filament of anterior anchor extends from deep root to median portion of shaft. Accessory structures (one pair) associated with anterior anchor (Fig. 11). Posterior anchor 37 (35–40; n = 9) long, anchor base 13 (12–14; n = 9) long (Figs 18–19) with superficial, deep roots not differentiated; anchor base covered with sclerotized layer with a small protuberance for articulation of posterior bar; shaft, point uniformly curved, point extending beyond level of tip of superficial root; filament of posterior anchor in anterior portion of shaft. Anterior bar open-V shaped, 33 (27–41; n = 8) long, 4 (3–5; n = 8) wide, with round ends (Fig. 15); posterior bar open-V shaped, 71 (61–81; n = 7) long, 8 (7–10; n = 8) wide, with tapered, rounded ends (Fig. 14). Hooks similar in shape, 11 (10–12; n = 11) long, with erect thumb, short, slightly curved shaft, shank divided into two subunits; hook filament not observed (Fig. 17).

Type host. *Panaque armbrusteri* (Loricariidae: Hypostominae).

Site of infection. Gill filaments.

Type locality. Volta Grande, Xingu River (Amazon Basin; Amazonas, Xingu, Iriri, Paru Sub-basin), municipality of Altamira, Pará, Brazil (03°21'15,7"S; 52°11'47,5"W).

Prevalence. 67% of three hosts examined.

Mean intensity. 20 parasites per infected host.

Specimens deposited. Holotype, MPEG 00322; 12 Paratypes, MPEG 00323–00334.

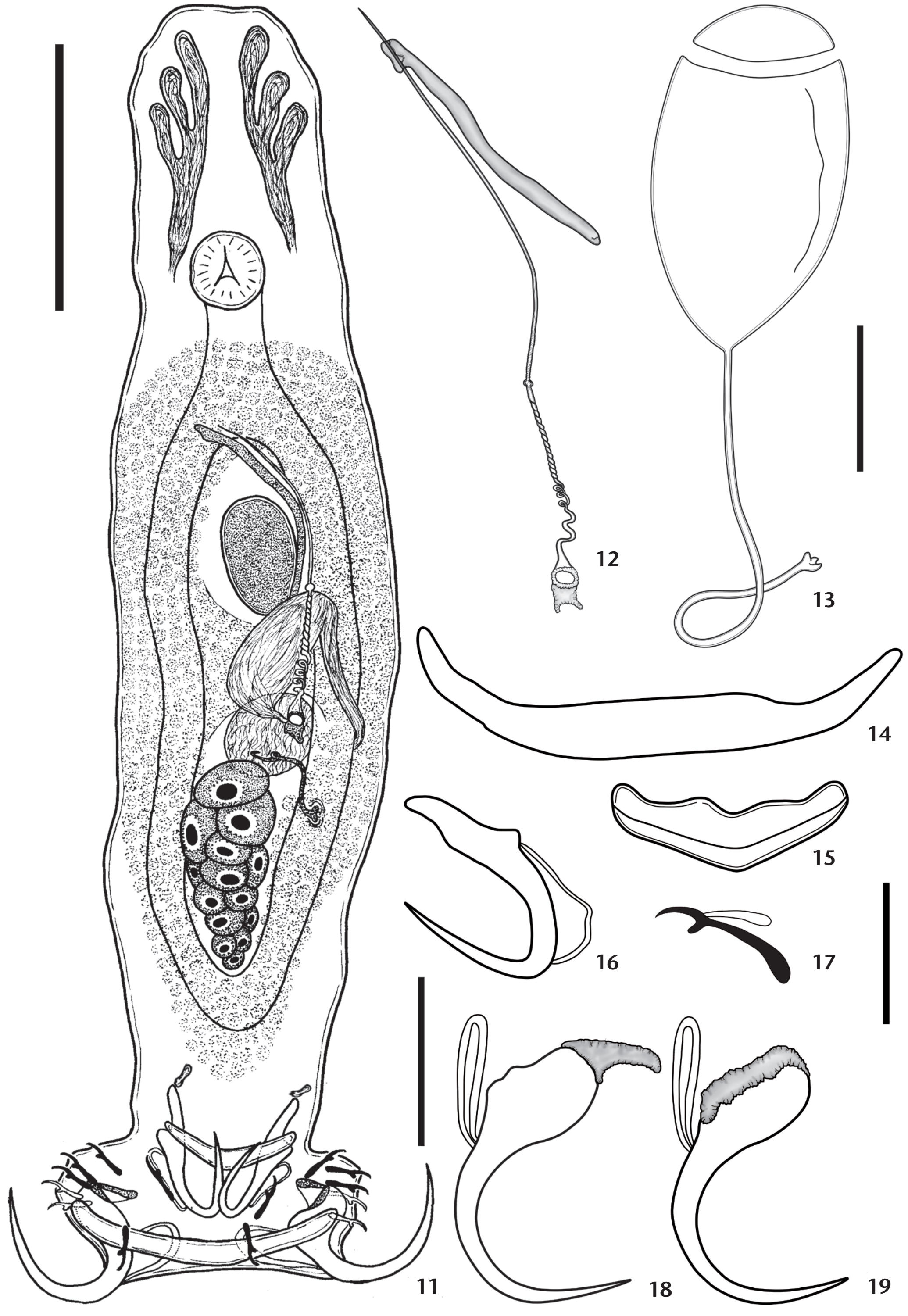
Etymology. The species is named in honor of Dra Lucia Rapp of the Instituto Nacional de Pesquisas da Amazônia (INPA), Brazil, in recognition of her contribution to the knowledge of loricariid diversity.

Remarks. *Unilatus luciarappae* sp. nov. resembles *U. brittani* by to the morphology of the anterior anchor/bar complex. However, *U. luciarappae* sp. nov. is distinguished by having a posterior anchor with shaft and uniformly recurved point, and posterior bar with tapered ends, while *U. brittani* has a posterior anchor with a slightly curved shaft and long and straight point, as well as a posterior bar with expanded and rounded ends. These species can also be differentiated by the ratio of the distance from the proximal portion of the MCO to the dilation of the MCO and the distance from the dilation of the MCO to the distal end of the MCO (*Unilatus luciarappae* sp. nov. 1:2; *U. brittani* 1:1).

DISCUSSION

The first known monogenoidean species in fish from Brazilian continental waters were initially described and reported from ornamental fishes in aquaria in the U.S. Mizelle and Price (1965) proposed *Anacanthorus* Mizelle & Price, 1965 and described eight new species from material collected from the gills of *Pygocentrus nattereri* Kner, 1858 (Characiformes: Serrasalmidae) in the Steinhart Aquarium in San Francisco, California. From this same aquarium, Mizelle and Kritsky (1967) described *Unilatus unilatus* Mizelle & Kritsky, 1967 from the gills of *Hypostomus* sp. (Loricariidae); Mizelle et al. (1968) described *Jainus jainus* Mizelle, Kritsky & Crane, 1968 from the gills of *Chalceus macrolepidotus* Cuvier, 1818 (Characiformes: Chalceidae), *Unilatus brittani* from the gills of *Hypostomus* sp., and *Urocleidoides carapus* Mizelle, Kritsky & Crane, 1968, and *U. gymnotus* Mizelle, Kritsky & Crane, 1968 from the gills of *Gymnotus carapo* Linnaeus, 1758 (Gymnotiformes: Gymnotidae).

Subsequently, several monogenoidean species probably originating from the Neotropical region were described and/or reported in freshwater ornamental fish exported from Brazil to aquariums abroad. Jogunoori et al. (2004) reported three species of monogenoids belonging to the genera *Heteropriapulus* Jogunoori Kritsky & Venkatanarasaiah, 2004, *Diaphorocleidus* Jogunoori Kritsky & Venkatanarasaiah, 2004, and *Urocleidoides* Mizelle & Price, 1964, collected from the gills of *Hypostomus* sp., *Gymnocorymbus ternetzi* (Boulenger, 1895) (Characidae), and *Xiphophorus helleri* Heckel, 1848 (Ciprinodontifomes, Poeciliidae), respectively, sold in Indian ornamental fish trade. Mehdizadeh et al. (2016) investigated the occurrence of monogenoids of exotic fish sold in Iranian ornamental fish markets and found *Gonocleithrum cursitans* Kritsky & Thatcher, 1983 and *U. unilatus* parasitizing the gills of the South American fishes *Osteoglossum bicirrhosum* (Cuvier, 1829) (Osteoglossiformes: Osteoglossidae) and *Hypostomus plecostomus* (Linnaeus, 1758), respectively. Mendoza-Franco et al. (2018) evaluated the occurrence of monogenoids in exotic freshwater fish from the production units of Mexican aquaria. These authors evaluated 13 fish species and found 29 species of monogenoids, four of which parasitize fish commonly exported from Brazil. Monogenoids were also recorded in freshwater fish imported from South America that became co-invasive species in rivers in Europe and Asia. Boeger et al. (2002) reported *Mymarothecium viatorum* Boeger, Piasecki & Sobecka, 2002 from the gills



Figures 11–19. *Unilatus luciarappae* sp. nov.: (11) body in ventral face (composite); (12) copulatory complex; (13) egg; (14) posterior bar; (15) anterior bar; (16) anterior anchor; (17) hook pairs 1–7; (18–19) posterior anchor. Scale bars: 11 = 50 µm; 12–16, 18–19 = 25 µm; 17 = 10 µm.

of *Piaractus brachypomus* (Cuvier, 1818) (Serrasalmidae) captured in a channel system of a power plant in Poland. Li et al. (2009) found *Trinigyrus hypostomatis* Hanek, Molnar & Fernando, 1974 and *U. unilatus* in the gills of *H. plecostomus* introduced in the Pearl River, Guangzhou, China. In the same fish species, Li and Huang (2012) found the first record of *Heteropriapulus* in a fish market, also in Guangzhou. Nitta and Nagasawa (2013, 2016) reported *Heteropriapulus heterotylus* Jogunoori Kritsky & Venkatanarasaiah, 2004; *Trinigyrus peregrinus* Nitta & Nagasawa, 2016; *Unilatus unilatus*, and *U. britanni* from the gills of *Pterygoplichthys disjunctivus* (Weber, 1991), which had been introduced into the inland waters of Okinawa Island, Japan.

Unilatus presently comprises eight species, including the two described in this study. Of these, seven have been reported in loricariids sold on the Brazilian ornamental fish market. Species of the genus have only been recorded in fish exported from Brazil in the cases of *U. unilatus* and *U. britanni*. There are no records of these parasites being transferred to other hosts after their introduction, and their pathogenicity is unknown in native and alien environments.

Jogunoori et al. (2004) suggest that possible economic losses and environmental impacts may occur due to the introduction of monogenoidean species into new environments and hosts. However, they note a low potential for monogenoids to transfer between alien and native host species. Jiménez-Garcia et al. (2001) found that monogenoidean species typically found in African cichlids used worldwide in aquaculture systems had parasitized freshwater cichlid species native to Mexico. Also, García-Vásquez et al. (2017) recorded *Gyrodactylus cichlidarum* Paperna, 1968, a monogenoidean parasite typically reported from the African "tilapia", on poeciliids (Cyprinodontiformes) in Mexico. However, even if there is no evidence of problems these parasites can provoke after becoming established, care should be taken to prevent their establishment in new ecosystems. Adopting prophylactic measures and quarantine procedures to mitigate the transfer of parasites among fish sold on the Brazilian ornamental fish market is important. However, studies on the diversity of parasites that occur in these fish are also needed, as they shed light on the potential of dispersion of these parasites as well as their pathogenicity.

More than 50 years after the description of the type species of *Unilatus* from an artificial environment (U.S. aquariums), this study is the first formal record and description of *Unilatus* species from hosts collected in natural habitats in the Xingu River basin. Considering the loss of pristine conditions in the studied region as a result of the construction of the Belo Monte Dam, we recommend monitoring monogenoidean diversity, parasite-host interactions, parasite indices, and parasite dispersion patterns and pathogenicity. Such studies may provide important insights into the impacts of changes to the hydrological regime in the Xingu River caused by the Belo Monte Dam.

Studies of the Belo Monte Dam's impacts on the persistence of the diversity of the loricariid hosts and the associated helminth fauna recently described for the Xingu basin are urgently and continuously required. The changes in ecological dynamics are characterized by the 'lentification' of the aquatic environment once formed by rapids in the region upstream of the dam and by the reduced flow stretch for the 100-km stretch of the 'Big Bend'. These changes have caused high mortality of ichthyofauna in the region while decreasing oxygenation and increasing water temperature due to the Xingu River's rocky bed. Thus, the risks for the conservation of the diversity of the recently described helminth fauna and the parasite-host ecological dynamics are increased. Furthermore, all aquatic biota and the livelihood of human populations in the region have been negatively impacted.

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LITERATURE CITED

Acosta AA, Franceschini L, Zago AC, Scholz T, Da Silva RJ (2017a) Six new species of *Heteropriapulus* (Monogenea: Dactylogyridae) from South American fishes with an amended diagnosis to the genus. Zootaxa 4290: 459–482. https://doi.org/10.11646/zootaxa.4290.3.3

Acosta AA, Scholz T, Blasco-Costa I, Alves PV, Da Silva RJ (2017b) A new genus and two new species of dactylogyrid monogeneans from gills of Neotropical catfishes (Siluriformes: Doradidae and Loricariidae). Parasitology International 67: 4–12. https://doi.org/10.1016/j.parint.2017.09.012

Araújo JG, Santos MAS, Rebello FK, Isaac VJ (2017) Cadeia comercial de peixes ornamentais do rio Xingu, Pará, Brasil. Boletim do Instituto de Pesca 43: 297–307. https://doi.org/10.20950/1678–2305.2017v43n2p297

Armbruster JW (2011) Global Catfish Biodiversity. American Fisheries Society Symposium 77: 15–37.

Boeger WA, Piasecki W, Sobecka E (2002) Neotropical Monogenoidea. 44. *Mymarothecium viatorum* sp. n. (Ancyrocephalinae) from the gills of *Piaractus brachypomus* (Serrasalmidae, Teleostei) captured in a warm-water canal of a power plant in Szczecin, Poland. *Acta Ichthyologica et Piscatoria* 32: 157–161.

Boeger WA, Vianna RT (2006) Monogenoidea. In: Thatcher VE (Ed.). Aquatic Biodiversity in Latin America. Amazon Fish Parasites. Pensoft Publishers, Sofia, 2nd ed., 42–116.

Branches B, Domingues MV (2014) A new species of *Unilatus* (Platyhelminthes: Monogenoidea) from the gills of *Leporacanthicus galaxias* Isbrücker et Nijssen (Siluriformes: Loricariidae) from Brazil. Acta Parasitologica 59: 91–97. https://doi.org/10.2478/s11686-014-0213-7

Bush AO, Lafferty KD, Lotz JM, Shostak AW (1997) Parasitology meets ecology on its own terms: Margolis et al. Revisited. Journal of Parasitology 83: 575–583. https://doi.org/10.2307/3284227

Camargo M, Carvalho-Júnior J, Estupiñan RA (2011) Peixes Comerciais da Ecorregião Aquática Xingu-Tapajós. In: Castilhos ZC, Buckup PA. Ecorregiões Aquáticas Xingu-Tapajós. Centro de Tecnologia Mineral/MCT, Rio de Janeiro, 175–192.

Cardoso PHM, Costa AR, Balian SC (2018) Ectoparasitic fauna in freshwater ornamental fish acquired by a wholesaler in the city of São Paulo. Brazilian Journal of Veterinary Research and Animal Science 55: 1–6. https://doi.org/10.11606/issn.1678-4456.bjvras.2018.144086

Carvalho-Júnior JR, Carvalho NASS, Nunes JLV, Camões A, Bezerra MFC, Santana AR, Nakayama L (2009) Sobre a pesca de peixes ornamentais por comunidades do rio Xingu, Pará – Brasil: relato de caso. Boletim do Instituto de Pesca 35: 521–530.

Cohen SC, Justo MCN, Kohn A (2013) South American Monogenoidea Parasites of Fishes, Amphibians and Reptiles. Oficina de livros, Rio de Janeiro, 663 pp.

Eschmeyer WN, Fong JD (2016) Catalog of Fishes: Species by Family Subfamily. http://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesyFamily.asp [Accessed: 20/07/2020]

Franceschini L, Zago AC, Muller MI, Francisco CJ, Takemoto RM, Da Silva RJ (2018) Morphology and molecular characterization of *Demidospermus spirophallus* n. sp., *D. prolixus* n. sp (Monogenea: Dactylogyridae) and a redescription of *D. anus* in siluriform catfish from Brazil. Journal of Helminthology 92: 228–243. https://doi.org/10.1017/S0022149X17000256

Fujimoto RY, Barros ZMN, Marinho-Filho AN, Diniz DG, Eiras JC (2013) Parasites of four ornamental fish from the Chumucuí River (Bragança, Pará, Brazil). Revista Brasileira de Parasitologia Veterinária 22: 34–38. https://doi.org/10.1590/S1984-29612013005000015

García-Vásquez A, Razo-Mendivil U, Rubio-Godoy M (2017) Triple trouble? Invasive poeciliid fishes carry the introduced tilapia pathogen *Gyrodactylus cichlidarum* in the Mexican highlands. Veterinary Parasitology 235: 37–40. https://doi.org/10.1016/j.vetpar.2017.01.014

Hoshino EM, Hoshino MDFG, Tavares-Dias M (2018) Parasites of ornamental fish commercialized in Macapá, Amapá State (Brazil). Revista Brasileira de Parasitologia Veterinária 27: 74–79. https://doi.org/10.1590/S1984-29612018002

Humason GL (1979) Animal Tissue Techniques. San Francisco, W.H. Freeman, 4th ed., 661 pp.

Jiménez-García MI, Vidal-Martínez VM, López-Jiménez S (2001) Monogeneans in introduced and native cichlids in México: Evidence for transfer. Journal of Parasitology 87: 907–909. https://doi.org/10.1645/0022-3395(2001)087[0907:MIIANC]2.0.CO;2

Jogunoori W, Kritsky D, Venkatanarasaiah J (2004) Neotropical Monogenoidea 46. Three new species from the gills of introduced aquarium fishes in India, the proposal of *Heterotylus* n. g. and *Diaphorocleidus* n. g., and the reassignment of some previously described species of *Urocleidoides* Mizelle & Price, 1964 (Polyonchoinea: Dactylogyridae). Systematic Parasitology 58: 115–124. https://doi.org/10.1023/B:SYPA.0000029422.16712.9a

Kritsky DC, Boeger WA, Patella L (2020) Neotropical Monogenoidea. 63. *Atopogyrodactylus praecipuus* gen. et sp. n. (Gyrodactylidae), an oviparous gyrodactylid from the external surface of a bristlenose catfish *Ancistrus* sp. (Siluriformes: Loricariidae) from the Rondonian Amazon, Brazil. Zootaxa 4732: 169–176. https://doi.org/10.11646/zootaxa.4732.1.8

Lacerda MT (2005) Aquarienfische aus Brasilien: die Geschichte des fischexports. Amazonas 1(1): 32–37.

Li H-Y, Huang Q-C (2012) One new Chinese record genera (Ancyrocephalidae) and one new species and one new recorded of Monogenea parasiting on gills of *Hypostomus plecostomus*. Journal of Dalian Ocean University 27: 116–119.

Li H-Y, Man G-B, Chen W-T, Wu Y (2009) Pearl River water system alien fish Monogenea research II. Two new Chinese genera parasitizing the gills of *Hypostomus plecostomus*. Sichuan Journal of Zoology 28: 598–600.

Mehdizadeh Mood S, Rassouli M (2016) Monogenean infestations of arowana (*Osteoglossum bicirrhosum*) and catfish (*Hypostomus plecostomus*). Iranian Journal of Fisheries Science 15: 606– 612.

Mendoza-Franco EF, Caspeta-Mandujano JM, Osorio MT (2018) Ecto- and endo-parasitic monogeneans (Platyhelminthes) on cultured freshwater exotic fish species in the state of Morelos, South-Central Mexico. ZooKeys 776: 1–12. https://doi.org/10.3897/zookeys.776.26149

Mizelle JD, Klucka AR (1953) Studies on monogenetic trematodes. XVI. Dactylogyridae from Wisconsin fishes. The American Midland Naturalist 49: 720–733. https://doi.org/10.2307/2485203

Mizelle JD, Kritsky DC (1967) *Unilatus* gen. n. a unique neotropical Genus of Monogenea. Journal of Parasitology 53: 1113–1114.

Mizelle, JD, Kritsky DC, Crane JW (1968) Studies on Monogenetic Trematodes. XXXVIII. Ancyrocephalinae from South America with the proposal of *Jainus* gen. n. The American Midland Naturalist 80: 186–198. https://doi.org/10.2307/2423609

Mizelle JD, Price CE (1963) Additional haptoral hooks in the genus *Dactylogyrus*. Journal of Parasitology 51: 30–36. https://doi.org/10.2307/3275746

Mizelle JD, Price CE (1965) Studies on monogenetic trematodes. XXVIII. Gills parasites of the piranha with the proposal of *Anacanthorus* gen. n. Journal of Parasitology 51:30–36. https://doi.org/10.2307/3275640

Nelson JS, Grande TC, Wilson MVH (2016) Fishes of the World. John Wiley & Sons, New Jersey, 5th ed., 651 pp. https://doi.org/10.1002/9781119174844

Nitta M, Nagasawa K (2013) First Japanese record of *Heteropriapulus heterotylus* (Monogenea: Dactylogyridae), from the alien catfish *Pterygoplichthys disjunctivus* (Siluriformes: Loricariidae) in Okinawa. Species Diversity 18: 281–284. https://doi.org/10.12782/sd.18.2.281

Nitta M, Nagasawa K (2016) Four Alien Monogeneans, Including *Trinigyrus peregrinus* n. sp., Parasitic on the Invasive Armored Catfish *Pterygoplichthys disjunctivus* (Siluriformes: Loricariidae) from Okinawa-jima Island, Okinawa Prefecture, Japan. Species Diversity 21: 95–104. https://doi.org/10.12782/sd.21.2.095

Prang G (2007) An industry analysis of the freshwater ornamental Fishery with particular reference to the supply of Brazilian freshwater ornamentals to the UK market. Uakari 3: 7–51. https://doi.org/10.31420/uakari.v3i1.18

Ramos FM, Araújo MLG, Prang G, Fujimoto RY (2015) Ornamental fish of economic and biological importance to the Xingu River. Brazilian Journal of Biology 75: 95–98. https://doi.org/10.1590/1519-6984.02614BM

Siscomex (2020) Sistema Integrado de Comércio Exterior. Comex Stat http://comexstat.mdic.gov.br/pt/geral/16168 [Accessed: 20/07/2020]

Tavares-Dias M, Gonçalves RA, Oliveira MSB, Neves LR (2017) Ecological aspects of the parasites in *Cichlasoma bimaculatum* (Cichlidae), ornamental fish from the Brazilian Amazon. Acta Biológica Colombiana 22: 175–180. https://doi.org/10.15446/abc.v22n2.60015

Vianna RT, Boeger WA (2019) Neotropical Monogenoidea. 60. Two new species of *Gyrodactylus* (Monogenoidea: Gyrodactylidae) from the armored-catfish, *Pareiorhaphis parmula* Pereira (Loricariidae) and from the cascarudo, *Callichthys callichthys* (Linnaeus) (Callichthyidae) from Brazil. Zootaxa 4551: 87–93. https://doi.org/10.11646/zootaxa.4551.1.6

Winemiller KO, McIntyre PB, Castello L, Fluet-Chouinard E, Giarrizzo T, Baird IG, Darwall W, Lujan NK, Harrison I, Stiassny MLJ, Silvano RAM, Fitzgerald DB, Pelicice FM, Agostinho AA, Gomes LC, Albert JS, Baran E, Petrere Jr M, ZarflC, Mulligan M, Sullivan JP, Arantes CC, Sousa LM, Koning AA, Hoeinghaus DJ, Sabaj M, Lundberg JG, Armbruster J, Thieme ML, Petry P, Zuanon J, Torrente Vilara G, Snoeks J, Ou C, Rainboth W, Pavanelli CS, Akama A, van Soesbergen A, Sáenz L (2016) Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Science 351(6269): 128–129. https://doi.org/10.1126/science.aac7082.

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