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ORIGINAL ARTICLE

Three previous recorded species of *Dactylogyrus* Diesing, 1850 (Monogenea: Dactylogyridae) infecting cultured *Carassius auratus* in southern Brazil

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Abstract The present study aimed to contribute to the monogenean dactylogyrids that occur in *C. auratus* from an ornamental fish farm in southern Brazil. Samples of goldfish were obtained from a fish farm and the gills were removed and analysed to identify the species of *Dactylogyrus* to determine the levels of infestation. Three species of *Dactylogyrus* were found in the gills: *Dactylogyrus anchoratus*, *Dactylogyrus baueri* and *Dactylogyrus formosus*. The most prevalent species was *D. baueri* [prevalence (*P*) = 70%, mean intensity (MI) = 2.14 ± 1.21, mean abundance (MA) = 1.5 ± 1.43], followed by *D. anchoratus* (*P* = 60%, MI = 1.67 ± 0.81, MA = 1.00 ± 1.05) and *D. formosus* (*P* = 30%, MI = 1.66 ± 1.15, MA = 0.5 ± 1.64). *Dactylogyrus anchoratus* shares morphological characteristics with *D. arcuatus* by the similarity in shape of the haptor parts. *Dactylogyrus baueri* shows similarity to *D. dulkeiti* in relation to the pair of anchors and accessory piece of the male copulatory complex. *Dactylogyrus formosus* presents an accessory piece with branch and total length of the anchors smaller than *D. anchoratus*. This study reports the occurrence of *D. anchoratus*, *D. baueri* and *D. formosus* in goldfish cultured in southern Brazil. These monogenean species have been described in cyprinid fishes that have a wide geographic distribution with the result of the dissemination of the host in the world.

Keywords Goldfish · Ornamental aquaculture · Freshwater · *Dactylogyrus* · Brazil

Introduction

The genus *Dactylogyrus* Diesing 1850 (Monogenea) is the largest group of helminths found mainly in the gills of cyprinid fish (Šimková et al. 2007). Goldfish (*Carassius auratus*), both wild and cultured, may present infestation by several species of *Dactylogyrus* (Borisov 2013; Ling et al. 2016; Roohi et al. 2016; Trujillo-González et al. 2018). Some studies have reported the occurrence of: *D. formosus* in China (Tu et al. 2015); *D. vastator*, *D. baueri* and *D. intermedius* in Singapore (Borisov 2013); *D. dulkeiti*, *D. formosus*, *D. anchoratus*, *D. baueri* and *D. intermedius* collected in Japan (Ogawa and Egusa 1979); *D. vastator*, *D. extensus* and *D. baueri* registered in Iran (Mousavi 2003); *D. vastator* and *D. anchoratus* (Chaudhary et al. 2017) in India; Li et al. (2018) found that *D. vastator*, *D. intermedius*, *D. arcuatus*, *D. baueri*, *D. formosus*, *D. inexpectatus*, and *D. anchoratus* were recorded in a flooded area in China and Mexico. *D. vastator*, *D. baueri* and *D. formosus* in Mexico (Mendoza-Franco et al. 2018).

In Iran, eighteen *Dactylogyrus* spp. were found infecting introduced fishes collected from fisheries ponds, farms and natural waters in three different regions and some of *Dactylogyrus* spp. showed a narrow geographical distribution (Shamsi et al. 2009). Common carp occurs naturally in the Caspian Sea basin and the Tedzhen River and both pond culture and natural lakes, where five *Dactylogyrus* spp. (*D. extensus*, *D. anchoratus*, *D. vastator*, *D. achmerovi* and *D. sahuensis*) can infect the fish (Jalali and Barzegar 2005). In Nwanedi–Luphephe dams of the Limpopo River, South Africa, three *Dactylogyrus* spp. were

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found infecting cyprinids that are valuable ecological indicators of the aquatic ecosystems health (Mbokane et al. 2015).

Dactylogyrus spp. are well-known parasites of cyprinids in Africa, Asia, North America and Europe (Šimková and Morand 2008). However, little is known on the distribution of *Dactylogyrus* species in South America as, for example, common carp, koi carp and goldfish are cultured species in Southern Brazil (Boll and Garádi 1995; Pádua et al. 2013; Moyses et al. 2015), but only four *Dactylogyrus* species have been identified infecting goldfish (*D. intermedius*, *D. baueri*, *D. formosus* and *D. anchoratus*, in Florindo et al. 2017), and two infecting koi carp (*D. extensus* and *D. minutus*, in Santos et al. 2017; Tancredo et al. 2018).

Once the monogenean parasites are established within cultured fish, they can become pathogenic and sometimes cause serious epizootic outbreaks (Ozer and Erdem 1999). In carp fry (7 days post-hatching), infection of *D. minutus* reached 55% of prevalence and an extensive hyperplasia of host gills was noted from the second week (Buchmann et al. 1993). Parasitism by gill parasites can lead to severe lesions in the epithelial filament, such as lamellar hyperplasia of secondary lamellae, partial melting of secondary lamellae, telangiectasia, justalamellar oedema and eosinophilic inflammatory infiltrate (Santos et al. 2017). It also impairs respiratory function, negatively affect fish growth causing high mortalities by secondary infections (Dove and Ernst 1998) and increases the reactive oxygen species production in the gill tissue (Mozhdeganloo and Heidarpour 2014).

Considering the negative impact that *Dactylogyrus* spp. have on their hosts, both wild and cultured and their wide distribution, the present study reports monogenean dactylogyrids that infect *C. auratus* from an ornamental fish farm in southern Brazil.

Materials and methods

Goldfish with a mean weight of 19.68 ± 4.40 g and average total length of 11.36 ± 1.80 cm were obtained in September 2016 from an ornamental fish farming located in the municipality of Biguaçu, Santa Catarina (27°27′ 0″S 48°41′32″W) and transported alive to the Aquatic Organisms Health Laboratory (AQUOS), from Federal University of Santa Catarina (UFSC). The fish were distributed in 100 L aquaria and maintained for 2 days under experimental conditions (dissolved oxygen 6.95 ± 0.63 mg L^{-1}, temperature 27.82 ± 0.14 °C, pH 6.1 ± 0.67, conductivity 213.00 ± 46.66 µS cm^{-1}, total suspended solids 106.00 ± 23.33 mg L^{-1} and total ammonia 0.60 ± 0.63 mg L^{-1}), measured with Hanna® HI9829 multiparameter (Hanna Instruments Brazil, Barueri, SP) and ammonia with colorimetric kit (Alfakit, Florianópolis, SC). Fish were fed twice daily until apparent satiety with commercial feed (28% crude protein). All animals' procedure was approved by the Ethics Committee on Animal Use of Federal University of Santa Catarina (CEUA/UFSC/PP00928).

After acclimation period, ten goldfish were anesthetized with clove oil (75 mg L^{-1}) and euthanized by spinal cord section. The gills were removed individually and analysed with stereomicroscope (ZEISS Stemi DV4) for the determination of infestation levels (Jerônimo et al. 2011). Parasitological descriptors (prevalence (*P*), mean infection (MI) and mean abundance (MA) followed Bush et al. (1997).

After collection, the sclerotized structures were studied using dactylogyrids mounted in Hoyer's following the procedures described by Kritsky et al. (1995). Some specimens were stained with Gomori's trichrome (Humason 1979) to study the internal morphology and the criteria used followed the morphology of Kulwiec (1927), Mizelle and McDougal (1970) and Tu et al. (2015).

Results

Three species of *Dactylogyrus* were found in the gills of *C. auratus*: *Dactylogyrus anchoratus* (Dujardin, 1845) Wagener, 1857, *D. baueri* Gussev 1985 and *D. formosus* Kulwièc, 1927 (Fig. 1). The species with the highest prevalence rate (*P*) was *D. baueri* (*P* = 70%) with mean intensity of infection (MI) = 2.14 ± 1.21 and mean abundance (MA) = 1.5 ± 1.43, followed by *D. anchoratus* (*P* = 60%, MI = 1.67 ± 0.81, MA = 1.00 ± 1.05) and *D. formosus* (*P* = 30%, MI = 1.66 ± 1.15, MA = 0.5 ± 1.64).

The morphology of the specimens herein studied (*D. anchoratus*) did not differ from the previous specimens found by Ogawa and Egusa (1979) and Chaudhary et al. (2017) collected in Japan and India, respectively. *Dactylogyrus anchoratus* shares morphological characteristics with *D. arcuatus* by the similarity in shape of the haptor scleritis, which in *D. anchoratus* the anchors are noticeably larger and *D. formosus* for the morphology of the male copulatory organ (Dove and Ernst 1998; Chaudhary et al. 2017). The anchors of *D. anchoratus* from the present study were slightly larger than those found in the specimens collected by Ogawa and Egusa (1979).

Dactylogyrus baueri shows similarity to *D. dulkeiti* in relation to the pair of anchors and accessory piece of male copulatory organ, described by Ogawa and Egusa (1979), but they are easily distinguishable, since *D. baueri* has an almost linear accessory piece with a branch and the total length of the anchor is smaller. Compared to Borisov

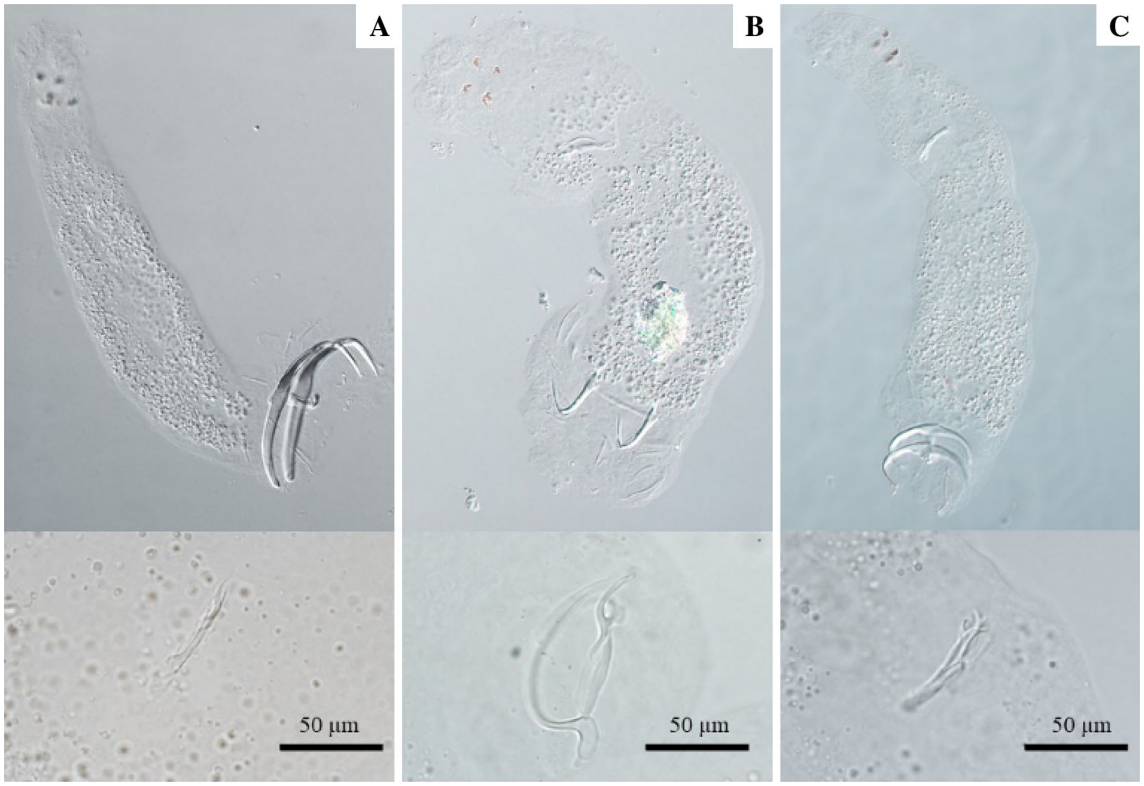

Fig. 1 Photomicrographs of *Dactylogyrus* spp. from *Carassius auratus* cultivated in southern Brazil. **a** *Dactylogyrus anchoratus* (Dujardin, 1845) Wagener, 1857; **b** *Dactylogyrus baueri* Gussev 1985; **c** *Dactylogyrus formosus* Kulwièc, 1927

(2013) and Ogawa and Egusa (1979), the mean length of the anchor of the present study is slightly larger.

Dactylogyrus formosus presents an accessory piece with branch and total length of the anchors smaller than *D. anchoratus*, but at the same time of similar morphology, which usually could be confused during the identification (Ogawa and Egusa 1979; Tu et al. 2015). *Dactylogyrus formosus* shows similarity to *D. arcuatus*, both in body size and male copulatory organ morphology (Tu et al. 2015). Quantitative differences between the present study and previous observations on *C. auratus* of *Dactylogyrus* spp. are presented in Table 1.

Discussion

The genus *Dactylogyrus* is composed of numerous species, and *C. auratus* is one of the most important host species, which can be parasitized by up to seven *Dactylogyrus* spp. (Ling et al. 2016). In this study, we recorded three species (*D. anchoratus*, *D. baueri* and *D. formosus*) which have been previously recorded from goldfish.

Differences in the diversity of monogenean communities between wild and farmed fish are possibly due to differences in environmental parameters (Li et al. 2018), that may affect the prevalence and mean intensity levels. In *C. auratus* collected in fish farm from Iran, the prevalence of *D. baueri* (0.9%) was low (Mousavi 2003) compared with our results (70%). In this study, *D. anchoratus* showed prevalence of 60% in cultured *C. auratus* from Brazil, which was higher than the specimens collected in *C. carassius* (37.6%) from Porsuk River, Turkey (Koyun 2011). On the other hand, it was not observed a significant difference in the prevalence of *Dactylogyrus* sp. between cultured and wild carp (21.79 and 34.04%, respectively) (Ozer and Erdem 1999). *Dactylogyrus formosus* was the most prevalent species (38.7%) in *C. carpio* (Kritsky and Heckmann 2002) and the only species found in 63 specimens of *C. auratus* showing 100% of prevalence (Tu et al. 2015). Three out of ten fish evaluated in this study were parasitized by *D. formosus* (MI = 1.66). The mean abundance (1.43) for *D. formosus* in Guanqiao pond (Li et al. 2018) was higher than that herein recorded (0.5 ± 1.64). Concerning other records of *Dactylogyrus* in Brazil, in *C. carpio* koi, *D. extensus* and *D. minutus* presented 40% of prevalence and an average mean intensity of 4.3 ± 4.2 (Santos et al. 2017). In the results of Tancredo et al. (2018), koi carp presented 80% of prevalence by *D. minutus*.

Although we have not recorded fish mortality in this study at the collection time in the farm, monogenean parasites can become harmful inside the ponds, especially when associated with bacterial infections. Moribund

Table 1 Comparison of morphometric characters (in micrometres, expressed as range with means in parentheses) of the *Dactylogyrus* spp. from the present and previous studies

	Dactylogyrus anchoratus			*Dactylogyrus baueri*			*Dactylogyrus formosus*		
	Ogawa and Egusa (1979) (*n* = 13)	Chaudhary et al. (2017) (*n* = 5)	Present study (*n* = 10)	Ogawa and Egusa (1979) (*n* = 15)	Borisov (2013) (*n* = ni)	Present study (*n* = 15)	Ogawa and Egusa (1979) (*n* = 25)	Tu et al. (2015) (*n* = 19)	Present study (*n* = 5)
Body^{L}	465–345	345–335 (340)	500–378 (438)	445–305	–	393–305 (344)	495–240	444–283 (369)	376–322 (356)
^{W}	105–95	80–75 (77)	129–74 (99)	100–65	–	94–54 (76)	115–75	122–72 (99)	86–73 (81)
Cirrus^{L}	27–22	31–23 (27)	27–15 (22)	31–25	38–24	42–22 (34)	27–21	28–22 (26)	26–23 (25)
Anchor									
Total^{L}	103–88 (95)	116–112 (114)	120–102 (111)	51–41 (47)	49–39	51–42 (46)	60–47 (53)	57–43 (50)	59–48 (52)
Base^{L}	59–49	46–41 (44)	71–52 (62)	29–23	28–16	34–25 (27)	39–31	39–27 (33)	34–30 (32)
Inner root^{L}	66–50	52–48 (50)	68–57 (63)	25–18	25–14	30–19 (23)	31–24	31–24 (28)	32–30 (31)
Out root^{L}	1–2	–	9–2 (5)	1–2	–	4–2 (3)	1–2	–	4–3 (3)
Point^{L}	30–25	27–23 (25)	35–27 (30)	22–18	27–14	21–15 (18)	18–14	18–14 (16)	16–12 (14)
Bar^{L}	22–16	21–15 (17)	27–16 (23)	34–24	38–17	42–18 (37)	23–16	9–7 (8)	26–23 (25)
Marginal hook^{L}	25–15	27–22 (24)	28–17 (22)	20–15	20–11	26–14 (18)	25–15	28–18 (22)	22–20 (21)

L length, *W* width, *n*: measured parasites, *ni* not informed

fingerlings of *Labeo rohita*, stocked in a nursery pond, were examined and revealed heavy infestations by *Dactylogyrus* (gills), *Aeromonas hydrophila*, *A. sobria* and *Vibrio* spp. (in the internal organs) (Sugumar et al. 2002). Monogeneans can be significant pathogens of teleosts under confinement, and their presence can produce chronic debility, unsightliness, poor growth and mortality of infested hosts (Thoney and Hargis 1991). The intensive culture systems are responsible for considerable stress on farmed fish due to the high stocking densities, which create favourable conditions for parasite proliferation because of the increased probability of encountering the host (Ogawa 2015).

Ornamental goldfish imported to Australia presented the highest diversity of parasites of all species analysed, where ten species of monogeneans were found in six of the seven populations analysed, including seven and three species of *Dactylogyrus* and *Gyrodactylus*, respectively (Trujillo-González et al. 2018). In Sri Lanka, *Dactylogyrus* spp. represent the most common parasite in ornamental fish species prepared for export (Thilakaratne et al. 2003). The spread of monogenean parasites as a result of imported ornamental fish from Southeast Asia to other regions of the world may be much larger than expected (Trujillo-González et al. 2018). In Iran, there is a growing concern about the facilitated transmission of *D. vastator*, *D. formosus*, *D. extensus* and *D. baueri* from goldfish imported from Southeast Asia to cultured and wild fish (Mousavi 2003; Mousavi et al. 2009). *Cyprinus carpio* mortalities from commercial fish farming in Utah, USA, were associated with massive infestations by *D. anchoratus*, *D. baueri*, *D. dulkeiti*, *D. formosus*, *D. intermedius* and *D. minutus* (Kritsky and Heckmann 2002).

In Brazil, the introduction of goldfish was through the action of aquarium fishers and escapes of culture tanks and was already detected in the lake Paranoá (Distrito Federal) and in a stream (Boa Vista) (MMA 2016). The lack of records and official data on the production and dissemination of goldfish in Brazilian rivers and lakes increases the concern about the impacts on the national fauna. Goldfish are known to be vectors of disease introduction, predators of native fish, their eggs and larvae, as well as reducing the biomass of aquatic plants and suspending nutrients into the water column causing algae blooms, besides representing a threat to small aquatic invertebrates and fish (MMA 2016). Until the present date, just three researchers reported the occurrence of *Dactylogyrus* spp. in cultured cyprinid fish

from Brazil (Florindo et al. 2017; Santos et al. 2017; Tancredo et al. 2018).

This study reports the occurrence of *D. anchoratus*, *D. baueri* and *D. formosus* of goldfish cultured in southern Brazil. These monogenean species have been described in cyprinid fishes that have a wide geographic distribution with the result of the dissemination of the host in the world. However, information on the species occurring in cyprinid fish in Brazil, records on impacts on the native population, the parasitic fauna in ornamental exotic fish as well as treatment measures are few and need to be improved.

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Author contributions Karen Roberta Tancredo had written the article, taxonomic identification. Maurício Laterça Martins (advisor) helped in critical review of the article.

Compliance with ethical standards

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

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