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SHORT COMMUNICATION

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Has a non-native cichlid of the genus *Amatitlania* (Actinopterygii, Cichlidae) adapted to the headwaters in Brazilian semi-arid?

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Abstract

Several fish species from Central America and other regions have been introduced into Brazil. In this study, we evaluated the bioecological aspects of a non-native cichlid of the genus *Amatitlania* (convict cichlid) and its possible establishment in high-altitude forest enclaves of semi-arid Northeastern Brazil. Specimens of *Amatitlania nigrofasciata* (Günther, 1867) were captured in a local stream displaying abiotic conditions like those of its natural range of distribution. The individuals collected were predominantly adult, insectivorous and displayed normal length–weight relationships, although we observed some phenotypical plasticity (variation in body depth, and a morphologically abnormal dorsal fin in three cases). Our results indicate that *A. nigrofasciata* has successfully colonized an Atlantic forest enclave in the Brazilian semi-arid region, making it necessary to adopt measures to prevent the species from spreading to other water bodies in the surroundings.

KEYWORDS
Caatinga, ichthyology, introduced fish, invasion biology, Northeastern Brazil

1 | INTRODUCTION

The genus *Amatitlania* Schmitter-Soto, 2007 comprises four species: *A. coatepeque*, *A. kanna*, *A. nigrofasciata* and *A. siquia*. However, McMahan, Matamoros, Barraza, Kutz, and Chakrabarty (2014) identified *A. coatepeque* as a junior synonym of *A. nigrofasciata*, and recent molecular studies have shown that only two species are valid (Bagley et al., 2017). Nevertheless, the taxonomy of the genus has not been fully clarified: online platforms still list nine species under the genus (Fricke, Eschmeyer, & Van der Laan, 2019; Froese & Pauly, 2019), some of which should be moved to other genera (Schmitter-Soto, 2007).

The natural distribution of the genus covers most of Central America, including the Pacific slopes of Southern Mexico, Guatemala and El Salvador and the Pacific and Atlantic slopes between Eastern Honduras and Panama (Říčan, Piálek, Dragová, & Novák, 2016). Omnivorous and monogamic, convict cichlids thrive in both lotic and lentic environments, deposit their eggs on rocky surfaces and display parental care (Conkel, 1993; Mendoza, Luna, & Aguilera, 2015; Trujillo-Jiménez, 1998). Standard length is under 100 mm (Schmitter-Soto, 2007), with females reaching sexual maturity at less than 35 mm (Ishikawa & Tachihara, 2010). The aquarium trade exports convict cichlids to many parts of the world, especially the species *A. nigrofasciata* (Duffy, Snow, & Bird, 2013; Esmaeili et al., Esmaelli et al., 2013; Herrera-R, Murcia-Castillo, & Prada-Pedreros, 2016; Ishikawa & Tachihara, 2010).

The only previous Brazilian report of the genus *Amatitlania* (identified as *A. nigrofasciata*) is from the Baturité massif (Northeastern Brazil), published in a compilation of non-native species observed in Brazil (Latini, Oporto, Lima-Júnior, Resende, & Latini, 2016). The establishment of non-native species poses a threat to endemic fauna and may lead to local extinctions (Dudgeon et al., 2006). It is therefore important to draw an ecological profile of non-native species and their possible influence on the native biota, especially in areas with high levels of endemism, such as the Caatinga—a Northeast Brazilian biome (Lima, Ramos, da Silva, & Rosa, 2017; Rodrigues-Filho et al., 2016). Thus, the purpose of this study was to confirm the taxonomic identity of a non-native cichlid occurring in the Baturité massif, based on authoritative taxonomic sources and recent revisions, and discuss the species' bioecology, risk of establishment and invasion, and expected impact on the native fish fauna.

2 | MATERIALS AND METHODS

The Baturité massif is covered by 38,220 ha of tropical rainforest at a maximum altitude of 1,100 m, an average temperature of 24°C and an annual rainfall of 1,700 mm (Bastos, Cordeiro, & Silva, 2017). The humid trade winds blowing in from the Atlantic produce orographic precipitation on the slopes and the plateau of the massif (Souza & Oliveira, 2006). This creates a high-altitude humid mesoclimate which provides shelter for native biota in the midst of the semi-arid Caatinga (Rosa & Groth, 2004). The massif is impacted by a range of anthropic factors, including deforestation, farming, burning, pollution, the building of numerous small barrages and the introduction of non-native species (Bastos et al., 2017; Latini et al., 2016).

Under ICMBio/SISBio licence #56416-4, we captured specimens of the genus *Amatitlania* in a stream ("Riacho Guarani") in May 2019 in the municipality of Guaramiranga (Ceará, Brazil) (Figure 1). We also collected information on flow velocity, width, depth, flow rate, temperature, pH, canopy coverage and substrate type. The fish were caught with casting nets, sieves and trawls, depending on the habitat: macrophyte beds, backwaters, pools, rapids (Mendonça, Magnusson, & Zuanon, 2005). The fish collected were placed in plastic bags, euthanized with eugenol and fixated in 10% formaldehyde for 48 hours, followed by preservation in alcohol at 70%.

The captured specimens were identified in our laboratory based on meristic and morphometric traits. Following Bagley et al. (2017) and Schmitter-Soto (2007), we registered the number of spines and soft rays in the dorsal and anal fins (Table 1), the number of scales between the base of the first dorsal spine and the lateral line, the number of circumpeduncular scales, the number of secondary pores in the lateral line on the tail fin, the number of vertebrae, the colour of the peritoneum, the colour of the axilla and pectoral finbase, the colour of the nine possible species of *Amatitlania* (sensu Catalogue of Fishes by Fricke, Eschmeyer, & Van der Laan, 2019), and the proportion between body depth (BD) and standard length (SL) compared to two valid species sensu Bagley et al. (2017).

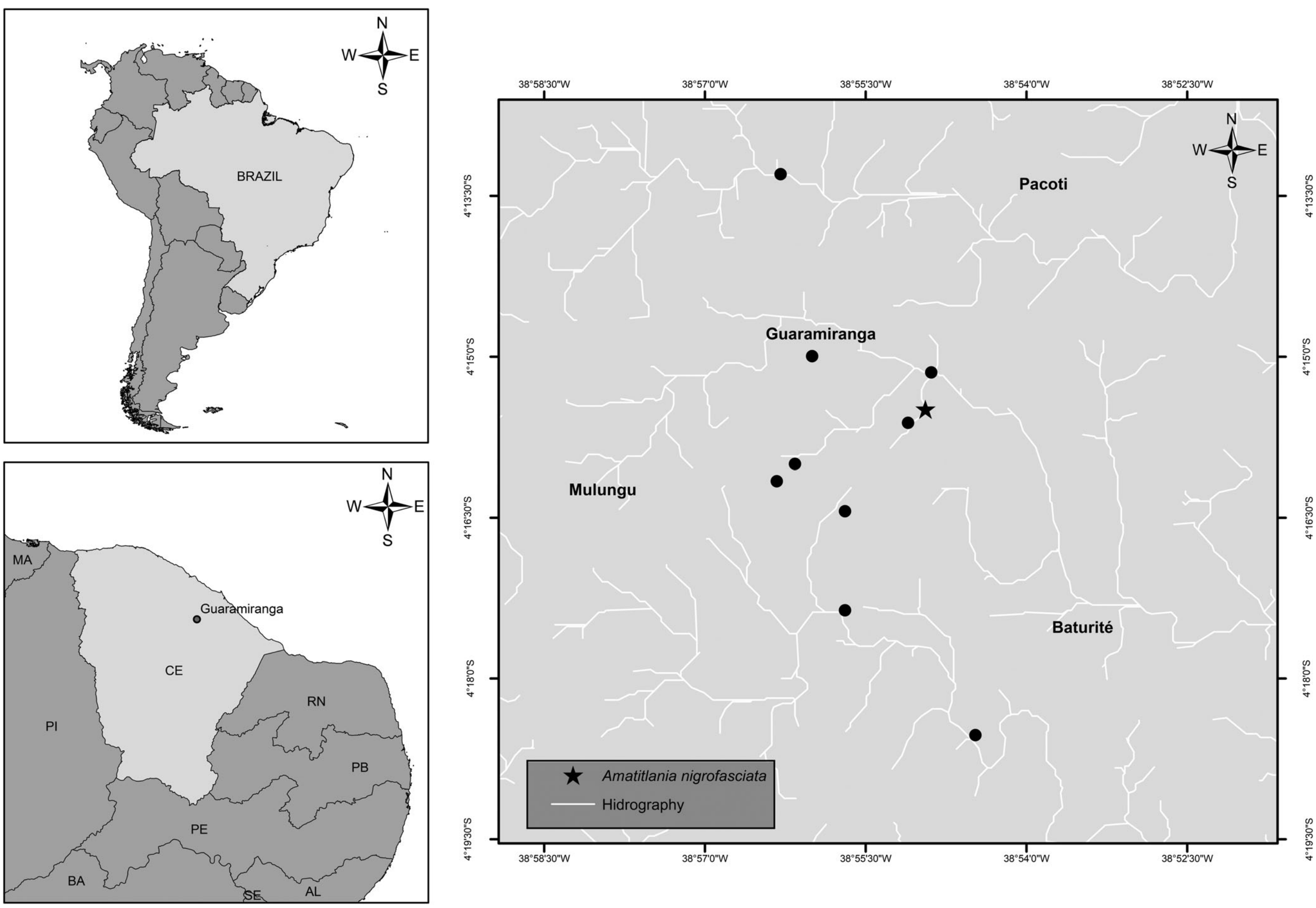

FIGURE 1 Sampled streams in the Baturité massif (Brazilian semi-arid). The star indicates the occurrence of *Amatitlania nigrofasciata* (Günther, 1867) at the stream "Riacho Guarani"

TABLE 1 Number of spines and soft rays in the dorsal (D) and anal (A) fins of species of the genus *Amatitlania* according to the identification key developed by Schmitter-Soto (2007) and overlapping counts according to more recent references of valid species

Valid species				References
A. nigrofasciata	*A. coatepeque*	*A. siquia*	*A. kanna*	Schmitter-Soto (2007)
D. XVII–XIX, 7–9	D. XVII–XIX, 7–9	D. XVII–XVIII, 8–10	D. XVIII–XIX, 8–10	
A. VIII–X, 6–7	A. VIII–X, 6–7	A. VIII–X, 7–8	A. IX–X, 7–8	
A. nigrofasciata	*A. nigrofasciata*	*A. siquia*	*A. kanna*	McMahan et al. (2014)
D. XVII–XIX, 7–9		D. XVII–XVIII, 8–10	D. XVIII–XIX, 8–10	
A. VIII–X, 6–7		A. VIII–X, 7–8	A. IX–X, 7–8	
A. nigrofasciata	*A. nigrofasciata*	*A. nigrofasciata*	*A. kanna*	Bagley et al. (2017)
D. XVII–XIX, 7–10			D. XVIII–XIX, 8–10	
A. VIII–X, 6–8			A. IX–X, 7–8	

FIGURE 2 *Amatitlania nigrofasciata* (Günther, 1867) captured in a stream ("Riacho Guarani") at the Baturité massif (Brazilian semi-arid). Left: live specimens. Right: specimen preserved in alcohol (64.65 mm SL). Note the characteristic bar pattern

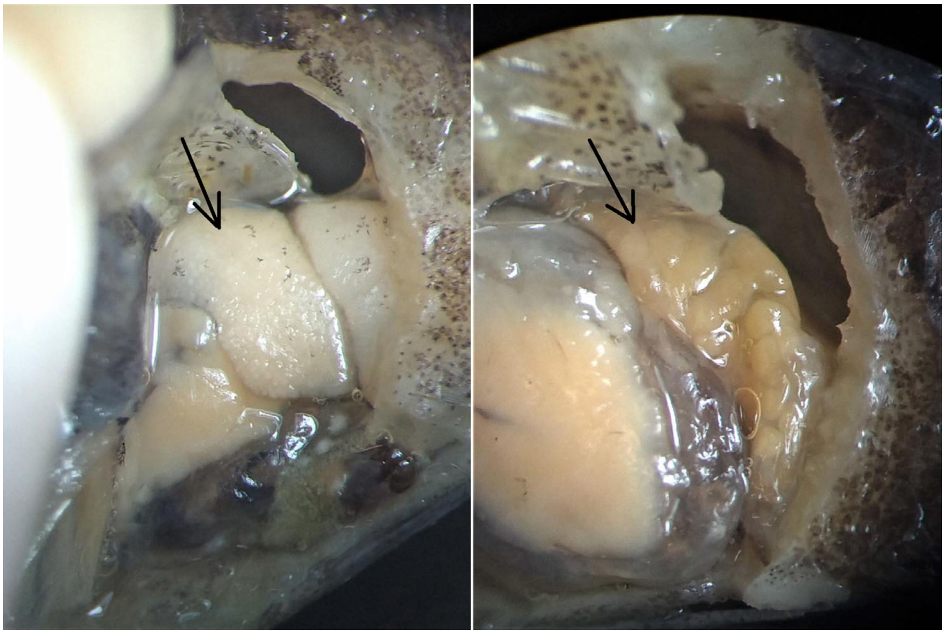

FIGURE 3 Mature gonads (left, testicle; right, ovary) occupying a large space in the abdominal cavity of *Amatitlania nigrofasciata* (Günther, 1867) collected in a stream ("Riacho Guarani") at the Baturité massif (Brazilian semi-arid)

The cichlids captured were white with seven dusky bars running down the flanks (Figure 2). On average, the body depth corresponded to 43.35% (range: 39.09–46.70%) of the standard length, making it possible to identify the specimens as *Amatitlania nigrofasciata* (Günther, 1867). Voucher specimens were deposited in the fish collection of the Federal University of Paraíba under entry #UFPB11937.

We determined the sex of each animal based on the morphology of the genital papilla and macroscopic aspects of the gonads. Individuals of uncertain sex were classified as juveniles. The difference between the actual and the expected (1:1) sex ratio was analysed with the chi-squared test (χ^2, $\alpha = 0.05$). We removed the digestive tract for content analysis. Following the method of Kawakami and Vazzoller (Kawakami & Vazzoler, 1980), we evaluated stomach and intestinal contents to determine the volume (V_i%) and frequency (O_i%) of each item *i* consumed, in the feeding index: $Ia_i = \frac{O_i V_i}{\sum O_i V_i}$. Individuals with less than 25% digestive tract fill were excluded from the analysis. We quantified and identified food items taxonomically down to the lowest possible taxon with the aid of a magnifying glass in a Sedgewick-Rafter chamber.

We calculated length–weight relationships $W = aSL^b$ and we measured the adjustment through the Coefficient of determination (r^2). Obvious outliers ($r^2 < 0.95$) did not occur when plotting log *SL* vs. log*W*. We estimated confidence intervals (95% CI) of *a* and *b* to assure the hypothetical isometry in $b = 3$ (Froese, 2006).

TABLE 2 Number of *Amatitlania nigrofasciata* (Günther, 1867) individuals (*N*), according to the configuration of dorsal (D) and anal (A) fin, and body depth (BD) and standard length (SL) BD:SL ratio

Number of spines and soft rays	*N*	BD% (SL)	*N*
D. IX, 9 A. X, 7 (*) (Figure 4)	1	39.09–42.77% (*)	12
D. XII, 9 A. X, 7 (*)	1	43.05–46.70%	18
D. XV, 9 A. IX, 8 (*)	1		
D. XVII, 8 A. IX, 7	1		
D. XVII, 9 A. IX, 8	1		
D. XVIII, 8 A. IX, 7	2		
D. XVIII, 8 A. X, 6	1		
D. XVIII, 8 A. X, 7	3		
D. XVIII, 9, A. IX, 7	1		
D. XVIII, 9 A. X, 6	1		
D. XVIII, 9 A. IX, 8	1		
D. XVIII, 9 A. X, 7	6		
D. XVIII, 10 A. X, 8	1		
D. XIX, 8 A. X, 6	1		
D. XIX, 8 A. X, 7	4		
D. XIX, 9 A. IX, 6	1		
D. XIX, 9 A. IX, 7	1		
D. XIX, 9 A. X, 7	2		
Total	30		30

Note: The asterisk (*) indicates traits beyond the expected for the species.

TABLE 3 Quantification of food items in the digestive tract (Ia_i) of *Amatitlania nigrofasciata* (Günther, 1867) (*N* = 28) collected in a stream ("Riacho Guarani") at the Baturité massif (Brazilian semi-arid)

Item	Volume (Vi%)	Occurrence (Oi%)	Ia_i (%)
Sediment (accidental)	0.1	3.6	0.003
Periphyton	0.8	3.6	0.04
Vegetable	0.6	7.1	0.06
Thecamoeba	0.6	3.6	0.03
Dipteran larvae	8.5	10.7	**1.23**
Coleopteran larvae	3.9	7.1	0.38
Coleoptera	3.1	14.3	0.60
Hymenoptera	3.0	42.9	**1.71**
Insect fragments	76.3	92.9	**95.81**
Ixodida	0.2	3.6	0.008
Fish scales	0.1	3.6	0.004
Fish	2.9	3.6	0.14
Total	100		100

Note: In bold: predominant items.

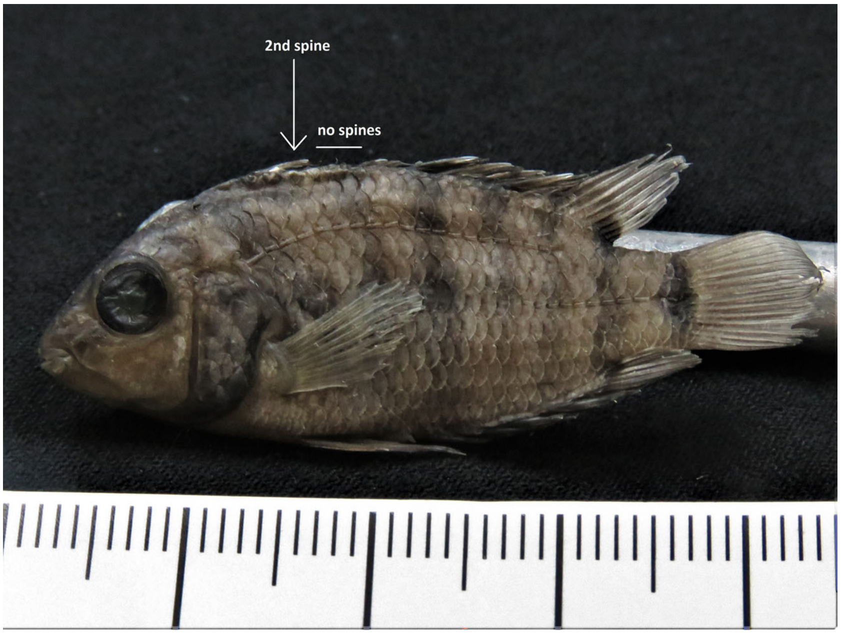

FIGURE 4 Dorsal fin of a female specimen of *Amatitlania nigrofasciata* (Günther, 1867) undergoing gonadal maturation, 35.45 mm SL, and with only nine dorsal spines (medial spines missing)

TABLE 4 Length-weight relationships of *Amatitlania nigrofasciata* (Günther, 1867) captured at the Baturité massif (Brazilian semi-arid)

Specimens	*N*	SL	*W*	*a*	CI *a*	*b*	CI *b*	r^2
Total	30	16.50–64.65	0.17–10.05	0.00004	0.00003–0.00006	2.944	2.865–3.024	0.996
Normal	18	29.55–64.65	0.94–10.05	0.00005	0.00003–0.00007	2.929	2.836–3.024	0.997
Abnormal	12	16.50–54.60	0.17–5.62	0.00005	0.00002–0.0001	2.893	2.668–3.127	0.987
Large	11	40.25–64.65	2.35–10.05	0.00005	0.00002–0.0001	2.893	2.668–3.127	0.987
Small	19	16.50–38.45	0.17–2.22	0.00002	0.000007–0.00006	3.143	2.842–3.456	0.983
Males	18	25.30–64.65	0.63–10.05	0.00004	0.00002–0.00007	2.951	2.834–3.071	0.996
Females	10	31.10–45.15	1.13–3.76	0.000008	0.000004–0.00002	**3.399**	3.181–3.615	0.990

Note: Normal: individuals without morphological abnormalities. Abnormal: individuals with smaller body depth (BD) and standard length (SL), BD:SL ratio, or fewer dorsal fin spines than expected for the species. Large: individuals ≥ 40 mm SL. Small: individuals measuring < 40 mm SL. Bold *b* values indicate females with *b* > 3.

3 | RESULTS

The standard and the total lengths of the 30 specimens of *A. nigrofasciata* collected were 16.50–64.65 and 21.45–82.90 mm, respectively. The sample consisted of 18 males, 10 females and 2 juveniles (sex ratio: 1.8:1, $\chi^2 = 6.40$; $p = .01$). Males were generally larger and displayed a greater variation in standard length (males: 44.61 ± 12.79 mm, females: 35.40 ± 3.85 mm, juveniles: 18.45 ± 2.76 mm). Almost all adult individuals had well developed gonads which occupied a large space in the abdominal cavity (Figure 3). Fifteen males (83%) had mature testicles and seven females (70%) had well-developed oocytes in the ovaries. The remaining adults displayed gonads undergoing maturation or atresia.

The BD:SL ratio was lower than 43% in 12 specimens (5 male, 5 female, 2 juvenile), of which three (all female) had spines missing in the dorsal fin (Table 2; Figure 4). The number of spines and soft rays in the dorsal and anal fins of specimens with normal morphology (D. XVII–XIX, 8–10 and A. IX–X, 6–8) varied considerably (Table 2).

Only two specimens had less than 25% digestive tract fill. The remainder displayed an average fill of 61.80 ± 20.4% (males: 55.6 ± 21.1%; females: 70.0 ± 17.1%; juveniles: 77.5 ± 3.5%). *Amatitlania nigrofasciata* was classified as an insectivore due to the predominance of insect fragments (98.7%), ants and dipteran larvae in the tract (Table 3). Length–weight relationship reflected isometric growth (*b* = 3), but in females weight increased slightly faster than length (*b* > 3) (Table 4).

4 | DISCUSSION

The traits observed in the identification of the specimens ruled out *A. altoflava*, *A. myrnae*, *A. nanolutea*, *A. sajica* and *A. septemfasciata*, all of which display different colour patterns and should be moved to other genera, according to Schmitter-Soto (2007). Moreover, the BD:SL ratio was smaller for our specimens of *A. nigrofasciata* (39–46%) than for *A. kanna* (48–58%) (Schmitter-Soto, 2007), the two valid species of the genus, according to Bagley et al. (2017).

In some individuals, the BD:SL ratio was smaller than expected for the species, indicating phenotypical plasticity (adaptability) in the population compatible with lotic environments of the Baturité massif (Senay, Boisclair, & Peres-Neto, 2015). It may also reflect morphological abnormalities, as indicated by the absence of spines in the dorsal fin of three specimens (Figure 4).

The fact that the sampled ecosystems are similar to those of the convict cichlid's natural geographical range facilitates the establishment of the species (thermal tolerance between 17 and 36°C and preference for depositing eggs on rocky surfaces) (Conkel, 1993; Ishikawa & Tachihara, 2010; Magalhães & Jacobi, 2013). The streams in the Baturité massif are typical of tropical rainforests, such as the Atlantic forest enclaves existing in the Caatinga ecoregion. For example, the environmental parameters of "Riacho Guarani" included: flow velocity 0.27 ± 0.16 m/s, flow rate 0.38 ± 0.08 m^3/s, width 3.90 ± 1.55 m, depth 0.24 ± 0.29 m, temperature 22.2°C, pH 8.3, canopy coverage 66% and rocky substrate 74%. Under such conditions, the species was found to feed on a wide range of items, from periphyton and vegetable detritus matter to insects and fish, as expected for an opportunistic omnivorous species (Trujillo-Jiménez, 1998).

The smallest sexually mature female in our sample (31.10 mm SL) was smaller than the smallest mature females observed in a population introduced into Japan (32.20 mm SL) (Ishikawa & Tachihara, 2010). As expected, growth was isometric (Froese & Pauly, 2019), except for females. The length–weight relationship of adult females may have been influenced by reproductive processes, considering the weight of the gonads (Froese, 2006) and the species' multiple spawning pattern (Linhares, Manna, Mazzoni, Rezende, & Silva, 2014). Taken together, the observed length–weight relationships ruled out the notion of dietary deficiency and growth restrictions.

Amatitlania nigrofasciata was introduced into "Riacho Guarani" by a local resident (*personal communication*), possibly due to its ornamental value (Magalhães & Jacobi, 2010). The convict cichlid and the invasive guppy *Poecilia reticulata* Peters, 1859 predominated in the captures, despite high endemism and diversity of fish communities at the Brazilian semi-arid (Rodrigues-Filho et al., 2016), which add to cases of biotic homogenization in the region (e.g., Bezerra, Angelini, Vitule, Coll, & Sánchez-Botero, 2018). In fact, modelling the risk of invasion shows that *A. nigrofasciata* is likely to invade local ecosystems, considering its thermal tolerance, life history traits, territoriality, opportunistic feeding habits and propagule pressure (Magalhães & Jacobi, 2013; Mendoza et al., 2015). If propagated, its main local competitor would be the native cichlid species *Cichlasoma orientale* Kullander, 1983 (voucher number UFRN4836), with which it has the greatest phylogenetic relatedness and similar life history traits, including a small number of large oocytes, multiple spawning, parental care (Ishikawa & Tachihara, 2010; Linhares et al., 2014) and K-selection—a common strategy in density-dependent species (Zeug & Winemiller, 2007). Interestingly, an experimental study showed that *Cichlasoma istlanum* (Jordan & Snyder, 1899) spent more time in shelters, and fed and moved less when in the presence of *A. nigrofasciata*. The reduced use of available resources amounts to a loss of fitness (Zavala, Arce, Luna-Figueroa, & Córdoba-Aguilar, 2018).

In conclusion, the non-native species *A. nigrofasciata* experienced competitive and reproductive success in at least one of the lotic ecosystems evaluated in the Baturité massif, despite instances of morphological abnormality. The dispersal of the species to other local water bodies will depend on environmental filters and human intervention. Considering the level of anthropic impacts in the region and the connectivity between local freshwater bodies by way of canals bridging microbasins and small reservoirs, the dispersal of *A. nigrofasciata* and consequent competitive exclusion of native species in the foreseeable future is a plausible scenario. We therefore suggest conducting targeted surveys to evaluate the presence of *Amatitlania* spp. in natural habitats in Brazil.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

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