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Seeking for gaps in taxonomic descriptions of endemic fishes: a pathway to challenge the Linnean shortfall in a Neotropical basin

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The Tocantins-Araguaia River basin hosts an elevated number of fish species, and new species have been continuously described. In this basin, we investigated patterns of endemic fish species descriptions examining their association with species distribution range, altitudinal gradient, fluvial hierarchy of watercourses, and sampling effort. For each species, we collected its year of taxonomic description, geographical coordinates of its holotype, body size (a proxy for species range), fluvial hierarchy of watercourses, and both altitude and sampling effort related to the locality of the holotype. The number of taxonomic descriptions was positively correlated to sampling effort, and better-sampled regions accumulated more descriptions over time. Moreover, altitude was positively correlated to the year of species description, whereas body size was negatively correlated to it. While species with recent descriptions were more associated to first to third order streams, species with recent and older descriptions were associated to high-order rivers. Therefore, fish species with broader distributions tend to have older descriptions in regions of lower altitude, whereas species with restricted distributions recent descriptions at higher altitudes. Increasing efforts in the upper regions of the Tocantins-Araguaia basin seems to be a good and fruitful strategy for reducing the Linnean shortfall.

Keywords: Brazil, Biodiversity, Threats, Tocantins-Araguaia, Wallacean shortfall.

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A bacia do rio Tocantins-Araguaia abriga elevado número de espécies de peixes e novas espécies têm sido continuamente descritas. Nesta bacia, investigamos os padrões de descrição de espécies endêmicas examinando sua associação com a abrangência de distribuição espacial das espécies, gradiente altitudinal, hierarquia fluvial dos cursos de água e esforço amostral. Para cada espécie, coletamos o ano de descrição taxonômica, coordenadas geográficas do holótipo, tamanho corporal (estimador da abrangência), hierarquia fluvial do curso d'água associado à espécie, altitude e esforço amostral na localidade do holótipo. O número de descrições taxonômicas está positivamente relacionado com o esforço e regiões com melhor amostragem acumulam mais descrições ao longo do tempo. Além disso, a altitude apresentou correlação positiva com o ano de descrição das espécies, enquanto o tamanho correlação negativa. Enquanto espécies com descrições recentes estão associadas a cursos d'água de primeira a terceira ordens, espécies com descrições antigas estão associadas a cursos de grande ordem. Logo, espécies de ampla distribuição têm descrições mais antigas em regiões de baixa altitude, enquanto as de distribuição restrita descrições mais recentes em maior altitude. Ampliar os esforços nas regiões de maior altitude da bacia do rio Tocantins-Araguaia pode ser uma estratégia eficaz para a redução da lacuna Linneana.

Palavras-chave: Ameaças, Biodiversidade, Brazil, Lacuna Wallaceana, Tocantins-Araguaia.

INTRODUCTION

Fishes provide regulating, provisioning, supporting, and cultural services for human well-being (Pelicice *et al*., 2023). Despite that, the quick growth of natural resource consumption together with other human impacts on freshwater ecosystems are causing a severe loss of biodiversity and ecosystem services worldwide (Dias *et al*., 2017; Reid *et al*., 2019; Ceballos *et al*., 2020; Su *et al*., 2021). Given this situation, there is an urgent need to accurately assess biodiversity and develop more efficient conservation strategies. Two of the greatest challenges to protect species in the 21st century rely on overcoming our ignorance on existing species (Linnean shortfall) and geographical distribution of biodiversity (Wallacean shortfall; Whittaker *et al*., 2005; Olden *et al*., 2010; Hortal *et al*., 2015). Efforts to fill these gaps have motivated taxonomists and ecologists alike (Freitas *et al*., 2021), even though this challenge is even more complex for taxonomically diverse groups such as fishes inhabiting megadiverse regions like the Neotropics where biases in research effort are still enormous (Nelson *et al*., 2016; Albert *et al*., 2020; Almeida *et al*., 2021). Thus, identifying temporal and spatial biases related to fish species studies and descriptions can serve as a valuable guide for redirecting research efforts, improving the development and the efficiency of future conservation actions.

Historically, the description of fish species from South America encompassed three distinct periods: i) 1750–1886, the description of economically important large fishes; ii) 1866–1930, descriptions of both large and small fishes, and iii) 1930 to date, the additions of new descriptions (Böhlke *et al*., 1978). During these three periods of description, rivers and large fishes in Brazil received more attention (Esteves, Aranha, 1999), and an increase of fish studies on smaller habitats such as streams has been observed only in recent decades (Dias *et al*., 2016; Caramaschi *et al*., 2021). Based on this information, we could expect the description of Brazilian fishes to be influenced by temporal and spatial biases: 1) older descriptions mainly relating to larger species and rivers, as these species have higher economic interest, and broader distribution areas that facilitate discoveries, whereas 2) recent descriptions relating to smaller species and streams, due to their restricted distribution areas and the recent increase of sampling efforts in smaller freshwater habitats. Nevertheless, the knowledge of fish species and their distribution is still insufficient in different regions of the country (Bichuette, 2021), and fish sampling effort in Brazil, which reflects the knowledge of local biodiversity, is clustered near to research centers, roads, protected areas, large rivers, and densely populated areas (Almeida *et al*., 2021). Therefore, identifying and understanding the spatial and temporal patterns of species descriptions may help us direct efforts to reduce both Linnean and Wallacean shortfalls.

Despite the expected differences in the patterns of fish descriptions across riverine and stream habitats due to biases in research efforts, the patterns of fish descriptions may also reflect the differential evolutionary forces operating across a basin. For example, the lowland portions of the Amazon basin have functioned as a biological museum, accumulating species over time, whereas the upland portions of the basin have undergone higher diversification rates due to allopatric speciation (Cassemiro *et al*., 2022; Melo *et al*., 2022). Therefore, the high endemism of streams draining the uplands may lead to higher densities of species descriptions/records in these areas. In contrast, given the greater connectivity of lowland habitats, species may have broader geographic distributions and lower levels of endemism, resulting in lower densities of species descriptions/records.

The Tocantins-Araguaia River basin corresponds to the largest drainage area occurring exclusively in Brazil, covering approximately 11% of its territory (Gomes *et al*., 2018). Although the largest portion of the basin drains the Cerrado biome, hydrologically, it is part of the Amazonian complex. This is the reason this basin hosts a substantial number of fish species (Abell *et al*., 2008; Bertaco, Carvalho, 2010; Bertaco *et al*., 2011; Chamon *et al*., 2022), including a considerable number of endemic species (Dagosta, de Pinna 2017, 2019). Despite that, the studies on freshwater fish diversity in this basin seem concentrated in few watercourses (Braudes-Araújo *et al*., 2019) with several localities poorly sampled and studied (Almeida *et al*., 2021). Considering the current environmental impacts that jeopardize the integrity of aquatic communities of the Tocantins-Araguaia River basin and its biodiversity (Mérona *et al*., 2010; Bittencourt *et al*., 2018; Pelicice *et al*., 2021; Bispo *et al*., 2023), such gaps on biodiversity knowledge are worrying because they limit the development of efficient strategies for nature conservation (Neto, Loyola, 2016).

Our main goal was to investigate spatial and temporal distribution patterns of taxonomic fish species descriptions in the Tocantins-Araguaia River basin, focusing on endemic species. More specifically, we sought to answer the following questions: i) was there an increase in the number of endemic fish species descriptions over time?; ii) are there biases in the description of species, *i.e*., older species being larger and more associated with riverine systems and lowlands, while more recent species are smaller and more associated with streams and uplands?, iii) is the number of species descriptions influenced by the sampling effort? We expect an increase of descriptions over time in the Tocantins-Araguaia River basin since fish studies had an expressive growth in recent decades (Castro, 1999; Dias *et al*., 2016; Caramaschi *et al*., 2021, Deprá *et al*., 2021; Tencatt *et al*., 2022). Also, given evolutionary processes (Cassemiro *et al*., 2022) and spatial/temporal biases in fish samplings (Böhlke *et al*., 1978; Dias *et al*., 2016; Caramaschi *et al*., 2021), we expect older species descriptions associated to rivers, lowlands, and species with broader distribution areas whereas recent descriptions to streams, uplands, and species with restricted distribution areas. Finally, we expect that sampling effort biases may explain the spatial and temporal distribution patterns of fish species with more sampled portions of the basin presenting greater density of endemic fish species descriptions.

MATERIAL AND METHODS

Study area. The Tocantins-Araguaia River basin has a drainage area of approximately 767,000 km^2 (Latrubesse, Stevaux, 2002; Pelicice *et al*., 2021), including the region of the Federal District and five Brazilian states (Goiás, Maranhão, Mato Grosso, Tocantins, and Pará). The basin encompasses an elevated diversity of fish species (Dagosta, de Pinna 2019; Coelho *et al*., 2020, Chamon *et al*., 2022) and in the last decades its fauna has been highly impacted by the construction of dams, agricultural/pasture activities, unorganized tourism, mining, and commercial fishing (Pelicice *et al*., 2021; Chamon *et al*., 2022). Here, we used the functional division of the basin in upper, middle, and lower sections according to Ribeiro *et al*. (1995).

Fish data. The list of endemic fish species occurring in the Tocantins-Araguaia River basin was obtained by accessing the articles of Dagosta, de Pinna (2017, 2019), Melo *et al*. (2021), Coelho *et al*. (2021), Chamon *et al*. (2022) and Shibatta, Souza-Shibatta (2023); describing a temporal window from the year of the first fish species described in the basin until the year of 2023. The criteria to consider a species as endemic was that it would have to occur only in the Tocantins-Araguaia River basin. After this initial survey, we checked for synonyms using Eschmeyer's Catalog of Fishes (Fricke *et al*., 2023). Then, for each species, we searched for the following information: i) its year of description according to Eschmeyer's Catalog of Fishes (Fricke *et al*., 2023), ii) the geographical coordinates of the holotype specimen using the Global Biodiversity Information Facility (GBIF, 2023). In this case, since the main objective is to understand the patterns of taxonomic fish species descriptions in the Tocantins-Araguaia River basin, the geographical coordinates of the holotype refer only to the locality of the original description of each species.

Data analysis. Based on the geographical coordinates, we constructed a map with the spatial distribution of the holotype localities to identify taxonomic discovery sites. To assess whether the number of taxonomic descriptions of endemic fish species increased over time, we i) constructed an accumulation curve considering the number of species described per each year and ii) performed a Pearson's correlation test between the year of species description and the proportion of fish species descriptions per year.

To perform Pearson's correlation test, we ordered the years of description from 0 (first year when a species was described, that is 1758) to 265 (last year when a species was described, 2023; Nabout *et al*., 2012).

We performed a cross-species analysis to identify the temporal dynamics of fish descriptions in relation to its distribution (broad/restricted) and the topography (altitude). We obtained the year of each species description using the current taxonomic nomenclature available, the body size of each species and the altitude of the localities of fish descriptions. The body size of fishes often has a positive correlation with the size of their distribution range (Rosenfield, 2002; Fu *et al*., 2004; Strona *et al*., 2012); therefore, fish size can be used as a reliable proxy to infer the size of species distribution range. Information for the body size of fish species were obtained from scientific articles and online databases. The altitude was determined according to a Digital Elevation Model (DEM) obtained from a relief layer of the TOPODATA database (http://www.dsr.inpe.br/topodata/). The DEM was elaborated using Shuttle Radar Topography Mission (SRTM) available from United States Geological Survey (USGS, https://www.usgs.gov/index.php/).

We performed a multiple linear regression analysis using the year of each species description as the response variable, and fish body size and altitude as explanatory variables, all log-transformed and standardized (Z-score). The collinearity between both explanatory variables was tested using the Variance Inflation Factor (VIF) criterion. Once both variables presented a VIF under 1.5, they were maintained in the analysis.

We performed a simple linear regression between the number of descriptions (response variable) and the sampling effort (explanatory variable) to test whether endemic fish descriptions are associated with the level of the sampling effort. To that, we conducted the division of the Tocantins-Araguaia River basin in cells of 0.5°× 0.5° spatial resolution. Then, in each cell we determined the number of endemic species described and measured the sampling effort based on Almeida *et al*. (2021) article, which contains a comprehensive compilation of the Brazilian records of fishes considering different databases. The sampling effort was represented by the number of sampling events per grid cell, using a unique combination of the geographical coordinates with the year of sampling (Almeida *et al*., 2021). For analysis, we considered only cells with at least one sampling record. All variables were log-transformed before analysis.

To evaluate whether older freshwater fish descriptions in the Tocantins-Araguaia River basin are related to the main channel of the river while recent descriptions to low-order tributaries, we performed a Skewness test. It measures how much a dataset is (as) symmetrically distributed along a gradient. To perform this test, we considered how the number of fish descriptions was distributed along time considering the fluvial hierarchy of watercourses. Thus, a lower (negative) skewness value indicates that descriptions are clustered in recent years, whereas a higher (positive) value indicates descriptions clustered one in older years. The skewness was calculated following Pearson's second skewness coefficient (median skewness Sk2; Doane, Seward, 2011).

To obtain the fluvial hierarchy of each watercourse where species were described, we inserted the geographical coordinates of fish descriptions into the hydrological shape of the Tocantins-Araguaia River basin. Then, we considered the fluvial hierarchy of the nearest point of the coordinate. To avoid errors in determining the exact location of the coordinate, we also overlapped the hydrological layer with satellite images from Google Earth (2022) to check the path of each watercourse. When we could not determine the fluvial hierarchy of the watercourse where the description occurred (coordinates far from any watercourse), we considered that data as not available (NA).

RESULTS

We identified a total of 243 endemic fish species occurring in the Tocantins-Araguaia River basin distributed among nine orders and 29 families (Tab. **S1**). Siluriformes (96 species), Characiformes (74), Cyprinodontiformes (49), and Cichliformes (12) were the most speciose orders in the Tocantins-Araguaia River basin. Characidae (48 species), Loricariidae (46), Rivulidae (46), and Cichlidae (12) were the most speciose fish families in this basin. We obtained the geographical coordinates of holotype specimens for all endemic fish species, and the oldest fish description in the basin occurred in 1758 for *Achirus achirus* (Linnaeus, 1758) (Tab. **S1**). The newest descriptions until the date of data collection occurred in the year of 2023, *Rhyacoglanis varii* Shibatta & Souza-Shibatta, 2023. Also, two species were included in the list after data analysis: *Dinotopterygium uniodon* Frainer, Carvalho, Bertaco & Malabarba, 2021 and *D. diodon* Frainer, Carvalho, Bertaco & Malabarba, 2021 (Frainer *et al*., 2021) (Tab. **S1**).

We observed that descriptions of endemic fishes were documented throughout the entire length of the Tocantins-Araguaia River basin. However, there is a variation in the number of descriptions among the upper, middle, and lower sections of the basin (Fig. 1). The upper section of the basin had a higher number of fish species described (upper Araguaia, 25 species; upper Tocantins, 79 species) compared to the middle (Araguaia, 60; Tocantins, 27) and lower sections (Tocantins-Araguaia, 52; Fig. 1). We also observed an increase in the accumulation of fish species descriptions over time, particularly after the 1980s, but the accumulation curve did not achieve an asymptote (Fig. 2). This pattern, despite not being extremely pronounced, was supported by the results of the Pearson's correlation test ($r = 0.515$, $p < 0.01$).

The number of endemic fish descriptions was positively correlated with the sampling effort ($p < 0.01$; $R^2 = 0.24$; Tab. 1; Fig. 3A), indicating that regions with more extensive sampling efforts tend to have more species described. In this analysis, we excluded 70 cells without sampling efforts out of a total of 322, leaving us with 252 cells used for the linear regression analysis. The results of the multiple linear regression analysis (cross-species analysis) indicated that the variation in the year of fish species descriptions was explained by both fish body size and altitude ($p < 0.01$, $R^2 = 0.14$). Altitude had a positive relationship with the year of description, while fish body size exhibited a negative influence (Tab. 2; Figs. 3B, C). These findings suggest that historically, endemic species with broader distribution range (larger bodies) tend to have older descriptions in regions at lower altitudes, whereas endemic ones with restricted distribution ranges (smaller bodies) tend to have more recent descriptions in regions at higher altitude (Tab. 2; Figs. 3B, C).

In the skewness test, we were able to determine the fluvial hierarchy of 243 species using their geographical coordinates. The test revealed a higher negative skewness towards low-order watercourses (1^{st} to 3^{rd} order; Fig. 4). It indicates that description of endemic fishes in low-order watercourses are more concentrated in recent decades than descriptions of endemic fishes in middle (4^{th}–6^{th} order) and high-order (7^{th} to 9^{th}) watercourses (Fig. 4).

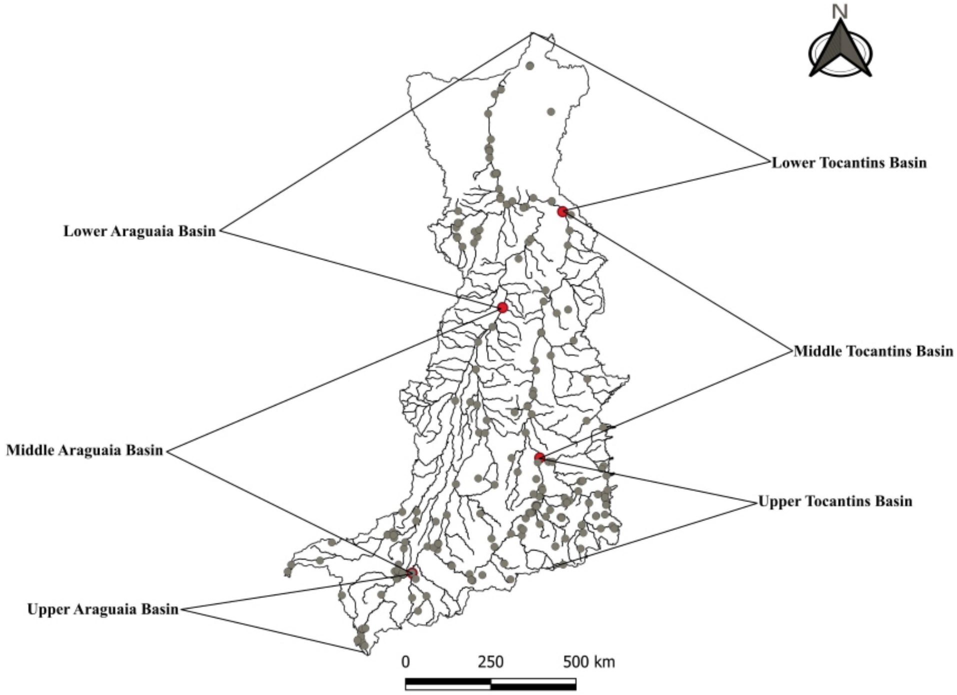

FIGURE 1 | Spatial distribution of localities where the holotype of endemic fish species was found in the Tocantins-Araguaia River basin (grey circles). The red circles delimit the transition zone between upper, middle, and lower sections of the basin.

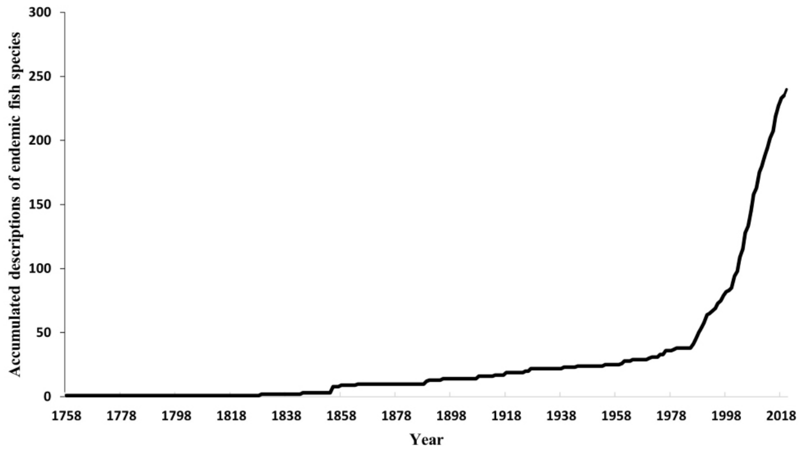

FIGURE 2 | Accumulation curve considering the taxonomic description of endemic fish species made between 1758 and 2023 in the Tocantins-Araguaia River basin, Brazil.

TABLE 1 | Statistics of the linear regression between the number of descriptions of endemic fish species and the sampling effort (Cross-sites analysis). P value in bold indicate significant results ($p < 0.05$). SE = Standard error.

	Estimate	SE	t value	p value
Intercept	-0.22	0.079	-2.88	0.004
Sampling effort	0.29	0.03	8.91	**<0.001**

TABLE 2 | Statistics of the multiple linear regression between the year of description of endemic fish species and altitude and fish body size (Cross-species analysis). P values in bold indicate significant results ($p < 0.05$). SE = Standard error.

	Estimate	SE	t value	p value
Intercept	1991.44	2.378	837,28	< 0.001
Altitude	8.03	2.445	3.28	**0.001**
Fish body size	-11.05	2.445	-4.52	**< 0.001**

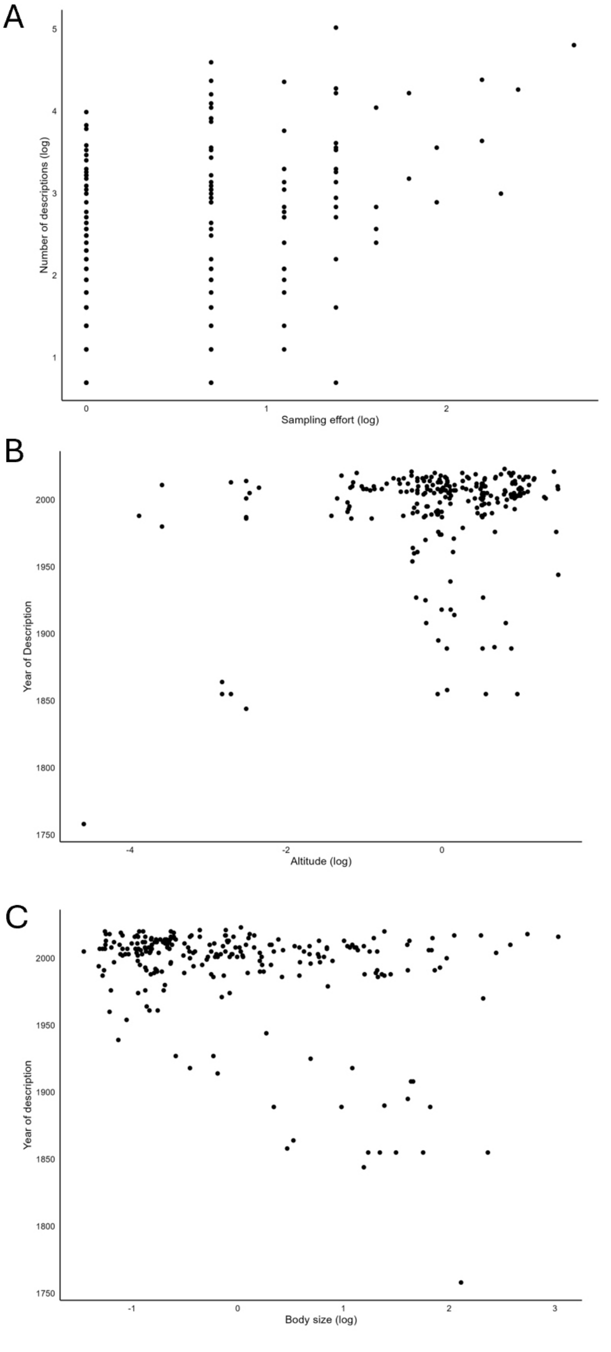

FIGURE 3 | Results of cross-site analysis between the number of endemic fish species descriptions and sampling effort (**A**), and cross-species analysis between the year of description and altitude (**B**), and fish body size of endemic species (**C**).

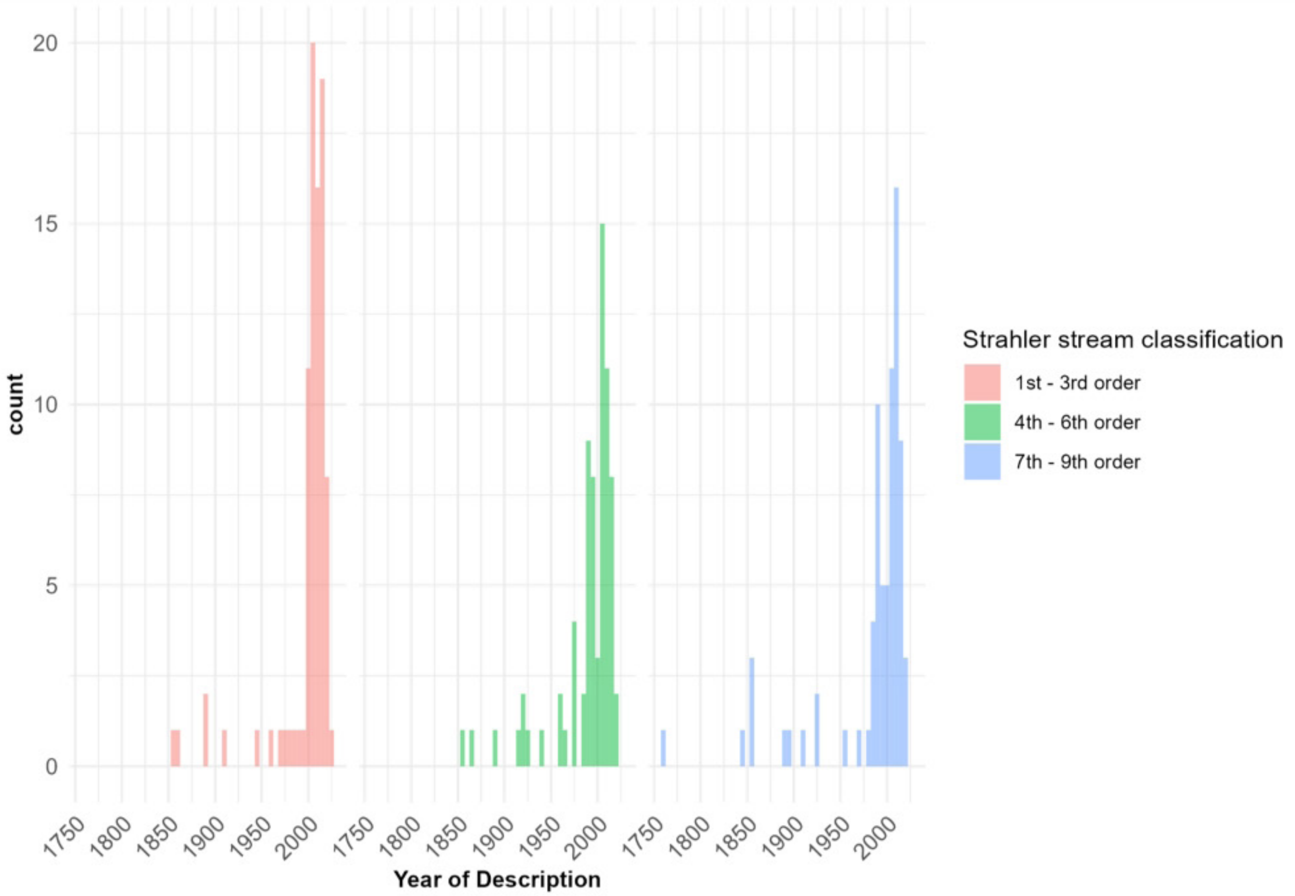

FIGURE 4 | Histograms of the year of endemic fish species descriptions according to the fluvial hierarchy of watercourses. Higher negative skewness (-3,18) in low order streams (first to third order, left histogram), and lower negative skewness (-2,57) in high order streams (seventh to ninth order, right histogram).

DISCUSSION

Challenging our lack of knowledge regarding the existence of species and their geographical distribution is fundamental for the protection of terrestrial and aquatic ecosystems worldwide (Whittaker *et al*., 2005; Olden *et al*., 2010; Hortal *et al*., 2015). However, several localities in the Neotropical region appear to be underrepresented in terms of biodiversity sampling (Azevedo *et al*., 2010; Dudgeon *et al*., 2006; Reid *et al*., 2019; Almeida *et al*., 2021). Our findings highlight an increase in the number of endemic fish species descriptions over time in the Tocantins-Araguaia River basin, a pattern that seems to be associated with an uptick in sampling efforts in recent decades, particularly in the upland areas of the basin (at higher altitudes) and smaller watercourses (low-order streams). The increase of Brazilian fish studies in low-order streams, particularly from 1990s (Dias *et al*., 2016; Caramaschi *et al*., 2021), may account for these new discoveries of endemic fishes in the Tocantins-Araguaia River basin. Nevertheless, the fact that the accumulation curve did not achieve an asymptote reinforces that fish richness in this basin is far from completeness, and the Linnean shortfall persist. This may be a result of historical spatial biases in fish studies within the basin, which have typically been conducted near major population centers, rivers, roads, protected areas, and hydropower projects (Almeida *et al*., 2021; Lima *et al*., 2021). Therefore, identifying locations where research efforts can be directed to enhance the discovery of new species in the Tocantins-Araguaia River basin is essential for the development of future conservation initiatives.

Cassemiro *et al*. (2022) revealed that upland regions of the Amazon River basin have witnessed high rates of *in situ* diversification due to allopatric speciation events, emerging as a significant source of species dispersal to other regions (Melo *et al*., 2022). As part of the broader Amazonian complex, the Tocantins-Araguaia River basin appears to follow a similar pattern, with numerous studies indicating a high number of fish species in this basin (Abell *et al*., 2008; Bertaco, Carvalho, 2010; Chamon *et al*., 2022). The upper region of the basin exhibits an elevated level of fish endemism (Dagosta, de Pinna 2017, 2019; Albert *et al*., 2020; Chamon *et al*., 2022). Our findings suggest that older descriptions of endemic fishes in the Tocantins-Araguaia basin are associated with species characterized by broader spatial distributions (larger bodies) and high-order rivers situated in regions of lower altitude. Conversely, recent descriptions of endemic fishes in the basin tend to be linked to species with restricted spatial distributions (smaller bodies) and low-order streams located in regions of higher altitude, notably in the upper reaches of the basin. These historical changes on spatial patterns of endemic fish species descriptions of the Tocantins-Araguaia River basin indicate that new taxonomic discoveries have been on the rise, particularly in the upper regions of the basin, mainly after 1990s. Collectively, such results suggest that directing new sampling efforts towards to low-order streams in the upper sections of the Tocantins-Araguaia River basin may lead to the discovery of new fish species with restricted spatial range for science, thereby contributing to the reduce the Linnean shortfall in this region.

Our findings suggest that small-sized species with restricted distribution in upland regions will continue to be discovered in the Tocantins-Araguaia River basin over the years. This pattern has conservation implications, as species like these are more likely to be classified as threatened according to the International Union for Conservation of Nature (IUCN) criteria (Tagliacollo *et al*., 2021). An illustrative example in this basin is the recent description of *Aspidoras mephisto* Tencatt & Bichuette, 2017, endemic from the upper region of the Tocantins River basin in the Goiás State (Tencatt, Bichuette, 2017). The authors classified this species as Endangered (EN) given it occupies an area lower than 500 km^2, it is present in no more than five localities, and its current habitat shows a decrease of quality. In a recent review of the *Aspidoras* genus, Tencatt *et al*. (2022) propose that *A. velites* Britto, Lima & Moreira, 2002 and *A. aldebaran* Tencatt, Britto, Isbrücker & Pavanelli, 2022, both described from the upper region of the Araguaia River basin, should be considered at least as Near Threatened (NT), with a high risk of moving into the Endangered category. Therefore, focusing research efforts on the upper Araguaia and upper Tocantins River basins would not only address the Linnean shortfall but also guide future conservation actions in a critical region for freshwater fish species. Considering that the Tocantins River basin stands as the most anthropogenically altered within the Amazon core, with its headwaters widely situated in the Brazilian deforestation arc (Pelicice *et al*., 2021), the region presents a perilous combination: high endemism, undiscovered species, and environmental changes. The absence of prompt and decisive conservation actions poses a significant risk of inducing an irreversible loss of biodiversity, sounding a cautionary alert for the prospective fate of these yet-to-be-discovered and vulnerable aquatic organisms.

It is important to note that the middle region of the Araguaia River also presented a high number of described endemic species. The middle Araguaia encompasses one of the most complex and geodiverse floodplain area globally, providing not only connectivity among various aquatic habitats but also physical complexity and a significant flow of nutrients and sediments between them (Lininger, Latrubesse, 2016; Latrubesse *et al*., 2019). The diversity of (micro)habitats and resources created by the flood pulse regime, along with the interconnectivity among habitats, allow the persistence of various species. Hence, the presence of the floodplain in the middle Araguaia River may account for the high number of described endemic species in this region. Directing new research efforts to this area could also be a valuable strategy to reduce the Linnean shortfall, especially given that this fluvial system remains ecologically understudied (Latrubesse *et al*., 2019).

Unlike the upper region, lowlands areas often exhibit greater connectivity among habitats, allowing species to have broader spatial distribution ranges. In this case, we would expect to observe lower rates of endemic fish species and species descriptions, a phenomenon that has already been documented in the Western Amazonian basin (Cassemiro *et al*., 2022). Considering that the initial expeditions and fish descriptions in the Tocantins-Araguaia River basin were primarily conducted at regions of lower altitude and in large rivers, this could explain the lower rates of species descriptions over time when compared to those in the upper regions. Despite the lower density of species descriptions in the middle and low regions of the Tocantins-Araguaia basin, increasing research efforts to sample fishes in these lowland areas may contribute to our understanding of species distribution and help to reduce the Wallacean shortfall.

Junqueira *et al*. (2020), in their study of Brazilian streams, demonstrated that efforts of sampling fishes in the Tocantins-Araguaia River basin are still insufficient. Furthermore, Almeida *et al*. (2021) highlighted that sampling efforts in this basin exhibit spatial bias. Additionally, we have shown that well-sampled locations in the basin have a high number of taxonomic descriptions of endemic fishes. However, two significant challenges in contemporary taxonomy are inadequate funding and the shortage of new taxonomists (Britz *et al*., 2020). Therefore, increasing funding for new projects aimed at addressing gaps in species sampling and supporting the training of specialized human resources are essential steps to enhance our understanding on fish biodiversity and to reduce both Linnean and Wallacean shortfalls in the Tocantins-Araguaia River basin.

Biodiversity faces a challenging period as human threats to natural resources continue to advance (Ceballos *et al*., 2020; Su *et al*., 2021), and freshwater ecosystems are no exception to this trend (Hermoso *et al*., 2009; Gatti, 2016; Reid *et al*., 2019). The Tocantins-Araguaia River basin, a Neotropical basin known for its expressive diverse fish fauna (Latrubesse *et al*., 2019; Chamon *et al*., 2022), including endemic species (Dagosta, de Pinna 2017, 2019), is under severe threat from changes driven by agribusiness, mining, and hydropower projects (Pelicice *et al*., 2021). Therefore, advancing our understanding of fish biodiversity is essential to address both Linnean and Wallacean shortfalls in this region and to inform conservation efforts. By evaluating historical and current patterns of taxonomic descriptions of endemic fish species and their relationship with species distribution, topography, and sampling effort we have demonstrated that directing new research efforts towards the uplands and low-order streams of the Tocantins-Araguaia can contribute to reduce the Linnean shortfall and map fish biodiversity in a priority region for conservation. Finally, our study emphasizes the importance of improving the fundamental conditions necessary for the development of new ecological and taxonomic studies. This includes investing in research infrastructure, and training new taxonomists to help decrease the Linnean shortfall.

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