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ECOSYSTEMS

Local trade, spatial occurrence and conservation of *hypostomus soniae* (siluriformes, loricariidae), an ornamental fish endemic to the tapajos river, Brazil

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Abstract: *Hypostomus soniae* is a small sized armored catfish endemic to the Tapajos River basin and ranked as one of the most exploited ornamental fish in the Santarem export marketplace. This study aims to evaluate distributional patterns of *Hypostomus soniae* and contribute to the species conservation in the face of development of the ornamental fish trade in the Amazon region. We compiled data associated with geographic coordinates in public repositories, supplemented with original field records. We compared our data to published records in the literature and museum collections to check for accuracy. To investigate the fishery and commercialization of *H. soniae,* we conducted interviews with ornamental fish stakeholders from the local trade. We also made direct observations in the fishing sites and export facilities in Santarem. A cluster analysis of the geolocation data was carried out to explore the spatial distribution patterns. The volume of captures and exportation of *H. soniae* decreased during the period 2020-2023. The occurrence of *H. soniae* was associated with annual rainfall ranging from 2,000 mm to 2,500 mm and concentrated in two municipalities of the State of Mato Grosso and two of the Para State. The species distribution area has been threatened, unfortunately, by fishermen who do not respect the laws that support artisanal fishing in the Amazon.

Key words: Amazon, Distribution, Geolocation, Investigate, Kernel.

INTRODUCTION

The armored catfish (Loricariidae, Siluriformes) is a large and complex group of fish from the Neotropics. The family Loricariidae covers more than a thousand species assembled in six subfamilies: Lithogeneinae, Delturinae, Rhinelepinae, Loricariinae, Hypoptopomatinae and Hypostominae (Fricke et al. 2023). Loricariids inhabit a wide range of habitats from low elevations to upland rivers situated 3,000 meters above sea level (Nelson 2006), display nocturnal activity foraging in the riverbed (Soares et al. 2008), and have a varied trophic ecology being detritivore, algivorous, carnivore, omnivore and xylophagous (Jesus 2020).

Loricariid species are characterized with a body recovered by dermal plates and a suction cup-like ventral; however, this fish group displays high diversity in morphology, coloration and behavior (Lujan et al. 2012). Such diverse trait combinations, and their exotic appearance, have made catfish one of the main products in the international freshwater ornamental fish industry (Sousa et al. 2021, Maciel et al. 2022).

The ornamental fish industry is a large enterprise that moves billions of dollars worldwide and sells more than 2,500 species,

more than half coming from freshwater environments (Dey 2016). In Brazil, this economic sector is supported by fisheries with wild fish stocks, and the Amazon basin is the largest producing region (Araujo et al. 2017).

Brazilian authority regulates the capture of native species for commercial use in ornamental fish trade, a measure that a priori favors the conservation of natural stocks. However, the economic viability and sustainable use of fishery resources is threatened by impacts from degradation of the freshwater environment, overfishing, biopiracy (Biondo & Burki 2020, Sousa et al. 2021).

The Amazon super basin has the greatest diversity of freshwater fish (Jézéquel et al. 2020) which makes this region strategic and highly relevant for the global ornamental fish market. In the Amazon aquatic landscape, the spatial distribution of species diversity is largely heterogeneous and highly complex, however Endemic Amazonian Fish Areas (EAFA) are clearly indicated (Dagosta et al. 2020). The largest volumes of ornamental loricariid catches come from the Xingu, Tapajos and Tocantins rivers (Camargo et al. 2012, Araujo et al. 2017, Sousa et al. 2018a, Maciel et al. 2022), where the fishing grounds are located in the EAFA Brazilian shield (Dagosta et al. 2020).

The human pressure linked to the ornamental fish trade and other drives such as environment disturbance and lack of biological knowledge can potentially move a species toward extinction (Hurd et al. 2016, Biondo & Burki, 2020). An illustrative case is the critically endangered *Hypancistrus zebra*, which is endemic to a restricted sector of the Xingu River and overexploited by the ornamental fish trade (Sousa et al. 2021).

The Xingu-Tapajos region has been recognized as a priority area to support the sustainable use of ornamental loricariids for the freshwater aquarium hobby industry. The adoption of conservation policies and scientific research converging with bioeconomic planning have contributed to sustainability of the ornamental fisheries in the Amazon basin (Ramos et al. 2015).

Animal movement is one of the most remarkable biological phenomena and hence deserves strong scientific interest (Bronmark et al. 2013). Fish movement and spatial distribution along the Amazon basin remain poorly understood (Hurd et al. 2016, Dagosta & Pinna 2021). Analyses of fish spatial distribution in threatened areas, such as the endemic regions in the Tapajos, Juruena and Teles Pires (Buckup & Santos 2010, Dagosta & Pinna 2021) are relevant to support management strategies, as well as to point out the need for future revisions in the national and global lists of endangered species (Assumpcao et al. 2017).

In this study we investigated the occurrence records, spatial distribution, and trade of *Hypostomus soniae Hollanda* Carvalho & Weber, 2004 (Loricariidae, Hypostominae), a species endemic to Tapajos River basin and exploited as ornamental fish. This species is popularly named as violet plecos and commercially coded as L-137. Santarem is the exportation (Maciel et al. 2022). Between the years 2013-2016 more than 5000 individual units of *H. soniae* were exported from this trade hub (Sousa et al. 2018b).

MATERIALS AND METHODS

Description of study species

Hypostomus soniae Hollanda Carvalho & Weber 2004 (Siluriformes, Loricariidae) was described from Tapajos River between Vila Nova and Urua, municipality of Itaituba and is considered endemic to the Tapajos River basin (Figure 1). The species is allocated in the *Hypostomus cochliodon* group and distinguished by its

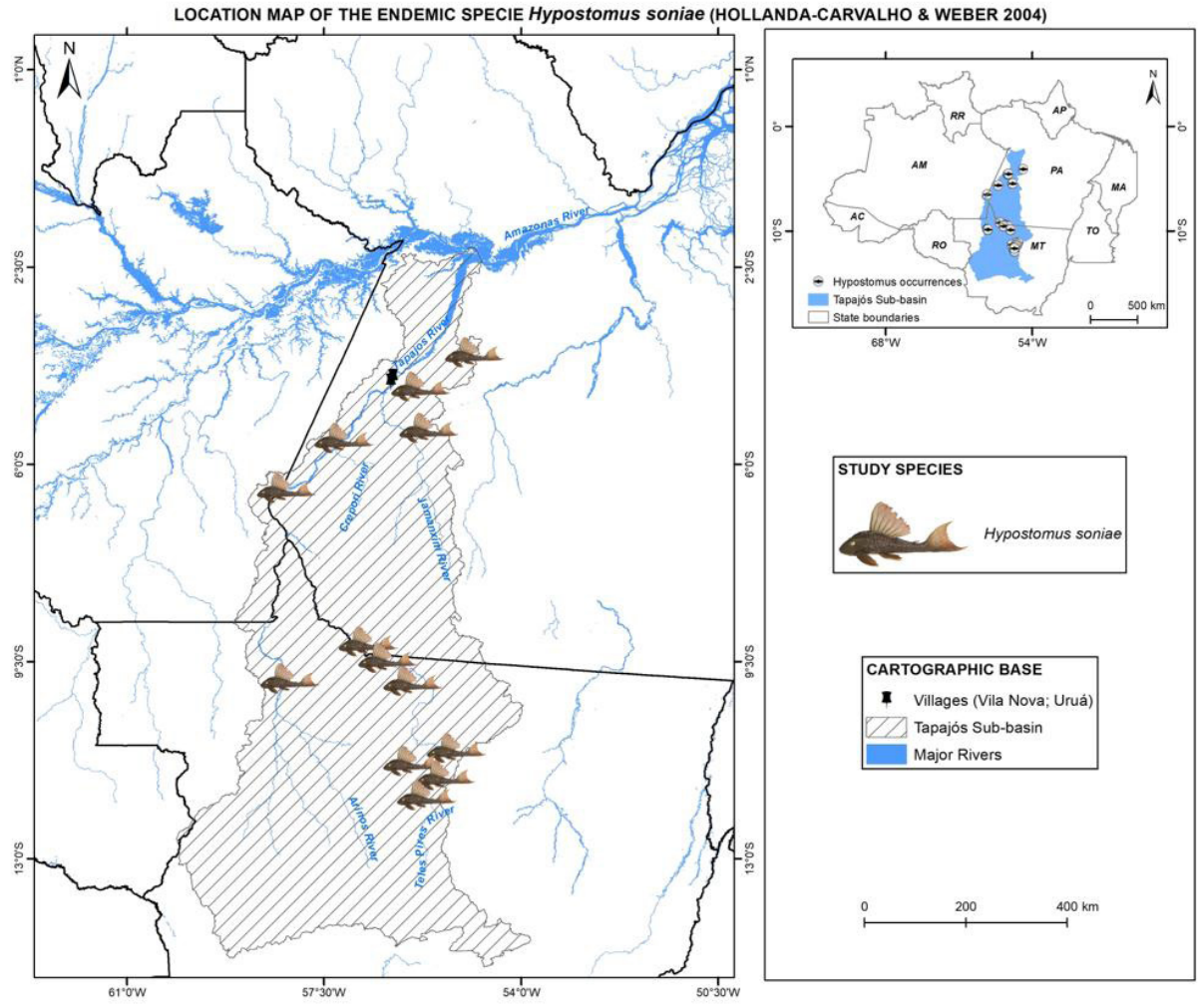

Figure 1. Map of the occurrence area of *Hypostomus soniae* Hollanda-Carvalho & Weber 2004.

particular color pattern without spots, sometimes with darker longitudinal stripes (versus spotted pattern, without stripes), its particular long and slightly curved adipose fin spine, the standard length varied from 76.4 to 145.8 mm in the type of material.

The species is endemic and restricted to a narrow distribution along the Tapajos River, where its range is enclosed in the Brazilian shield endemicity area reaching parts of the Brazilian Cerrado, a well-known world's biodiversity hotspot (Myers et al. 2000). This region has been disturbed by large scale infrastructure projects, artisanal gold mining and the increase of agricultural frontiers, which inevitably affects the fish populations due to aquatic pollution loss of habitats and genetic connectivity (Pelicice et al. 2017).

Local trade data analysis

We investigated the fishery and local commercialization of *H. soniae* from Tapajos River, Para State. Data about ornamental fishery and economic aspects of the local trade were collected from interviews with artisanal fishermen residing in the Village of Pimental (4° 34 '5.90 " S and 56° 15' 44.40" W) and ornamental fish exporters based in Santarem city. All the participants (n=16) were previously informed

about the research and gave their voluntary consent (TCLE).

This research was approved by the Ethical Committee at Federal University of Western Para (Process Number 5.476.648). Additional information was obtained by direct observations during field trips to the Village of Pimental (11-15, July 2021, LAMM), and visits to fish management facilities in the cities of Itaituba and Santarem. Data on local trade of *Hypostomus soniae*, during 2020-2023, were obtained from documental analysis in the Secretary of Environment and Sustainability (SEMAS), System of Fauna, Aquaculture and Fishery (SISFAP), from Para State.

Spatial data acquisition

Records of the species occurrence were compiled from a public digital database, Information System on Brazilian Biodiversity (SIBBR 2021). Additional geographic information was recovered from the field expeditions conducted by the research team (LRRR and LAMM) and was extracted from the scientific literature, considering the geographic coordinates of the collection areas of the target species. A database of the geographic information system for *H. soniae* is accessible in the Supp. file Table I.

Spatial data analysis

To support the analysis of the distribution of this species, an identification of abiotic characteristics associated with the areas of occurrence of the species was carried out, mainly in terms of climate typology, rainfall, and air temperature, making a cut in the database of (Martorano et al. 2017, Xavier et al. 2016).

The occurrence points were plotted using geoprocessing techniques identified by their respective geographic coordinates. From the geolocations, the data were tabulated according to the following procedures: Geolocation of the species; Plotting occurrence points using ArcGIS 10.6; Access to georeferenced geographic database usage bases, made available by the user of the Institute of Geography and Statistics (IBGE), using the shapefile format; and use of the Kernel density technique to identify occurrence patterns. Kernel Density Estimator (KDE) analysis, presented by (Parzen 1962) was adopted because it allows estimating densities

Table I. Example of variables which compose the Information System on Brazilian biodiversity.

Licence	Catalogue Number	Scientific Name	Institution	Collection Code	Locality	Latitude (m)	Longitude (m)
CC-BY-NC 4.0	MPEG.ICT 027383	*Hypostomus soniae*	MPEG	ICT	Vila de São Martins	-6.5000	-58.3000
	INPA-ICT 044426	*Hypostomus soniae*	INPA	Coleção de Vertebrados	Sete quedas	-9.3083	-56.7938
	INPA-ICT 043768	*Hypostomus soniae*	INPA	Coleção de Vertebrados (INPA)	Vila Pimental	-4.5736	-56.2925
CC-BY-NC	2967	*Hypostomus soniae*	UFMT	ABAM-I	Rio Teles Pires, TP2	-11.6673	-55.7000
CC-BY-NC	1019	*Hypostomus soniae*	UFMT	ABAM-I	Rio Teles Pires, TP2	-11.4106	-55.5200

Source: Authors.

based on local information based on non-parametric data models using the probability density function of a random variable.

It uses matrices to induce functions from the structural information contained in the data, considering only the width of the Kernel function, without the need for a priori assumptions about the shape of the generating function. Thus, density estimation allows data smoothing with inferences about populations, based on a finite data sample, where (x1, x2, ..., xn) represent a sample of an independent and identically distributed random variable with a density f unknown. The density estimate by Kernel is expressed by the following equation 1:

$$(xt) = 1\ \Sigma nK(xt - xi)$$

$$Nhi = 1$$

Where: N is the number of samples, h is the Kernel smoothing parameter and K (xt , xi) is the Kernel operator, whose integral R K(u)du must be unitary. The function argument K is actually the point where you want to estimate, since the samples xi (i = 1 . . . N) are fixed and provided to the model.

RESULTS AND DISCUSSION

Data from interviews with ornamental fishermen in the region show that fishing for *H. soniae* occurs at several fishing sites along the Tapajos River between the cities of Itaituba and Jacareacanga in Para State. Fish are collected manually by experienced fishermen using diving techniques.

During the high season, the fishermen reported staying up to six days a week at the sites where they catch the species, returning to the village only at weekends. On average, they fish for 6 hours a day, but they don't follow a fixed schedule because each fisherman plans his actions according to the specifics of the fishing area. They were unable to say how many specimens they caught each day.

The fishery of *H. soniae* occurs at several fishing sites along the Tapajos River between the cities of Itaituba and Jacareacanga in Para State. Fishes are collected manually by experienced fishermen using diving techniques. The fishing season runs from April to November and the price of each individual unit varies by body length small sized (6 cm TL) is sold for R$ 3,00 (Real) and medium sized (up to 9 cm TL) is sold for R$ 4,00, from the fishermen to the local exporters based in Santarem. Large sized individuals (> 9 cm TL) usually are not collected, aiming to preserve species reproduction.

In the period of 2020-2023, 1938 individuals of *H. soniae* were commercialized from anglers to exporters based in Santarem, while 1245 were exported from Santarem to international trade. We observed a clear reduction in the volume of captures and commercial transactions of *H. soniae* in the period of study. This could be a result of decreasing demands from ornamental fish clients; however, an alternative hypothesis could be a real decline in stock populations, which should be investigated in further studies.

For the period of the pandemic in the region, more precisely in the years 2020 and 2021, the fishermen pointed out that the main impacts of the pandemic on fishing activity were the paralysis of the activity, spending around 5 months without fishing, as well as difficulties in transporting and disposing of the fish, and a decrease in sales due to flight restrictions.

Also for the same period, information obtained from companies in the aquarium sector points to the restriction of flights and flows between cities imposed by the pandemic as the main obstacle to the sale of ornamental fish in the region, followed by an increase in the price of items used in aquarium production.

The village of Pimental is an important hub for the H. *soniae* fishery and represents the main hub for supplying ornamental fish from the Tapajos River to exporters based in Itaituba and Santarem cities. The ornamental fishery carried out in the Tapajos River meets a demand from the foreign market, being responsible for the direct export of this natural resource to at least 16 countries, mainly in the Asian continent, where China is the largest buyer of ornamental fish from Brazil (Sousa et al. 2018).

The spatial analysis of *H. soniae* occurrences revealed that most records were associated with areas with predominance of climatic typologies Am3 and Aw3.The species predominates in areas with annual rainfall ranging from 2,000 mm to 2,500 mm and average monthly values below 60 mm, fitting into these two climatic typologies (Martorano et al. 1993 and Martorano et al.2017).

Evaluating the locations of *H. soniae* occurrences using the annual rainfall base, confirms that the georeferenced information pointed to concentrations of the species in areas where rainfall throughout the year varies between 2,000 mm and 2,500 mm, in the States of Mato Grosso and Para.

In Mato Grosso, the municipalities Alta Floresta and Paranaita (Mato Grosso) and Itaituba and Jacareacanga (Para) showed the highest occurrences of *H. soniae*. It is not clear if this abundance pattern is resulted from spatial distribution of the species habitat. It is possible that there is bias associated with records originated from ornamental fishery efforts (Figure 2).

The Kernel density analysis showed that *H. soniae* geographic data present an overestimation, when negative values are compared. The estimates present high precision close to 0.796 based on the 1:1 line, showing that the more data on occurrences of this species, the more sensitive the density estimator is in pointing out the probability of existence of this species in the study area (Figure 3).

Further field research is needed to validate if the occurrence gaps represent either the species absence or lack of biodiversity knowledge. Short spatial scale movements are associated with conditions of shelter, foraging, territory guarding and dispersal because they are ecological factors that limit the scale of dynamic mobility of populations and metapopulations and their persistence in fragmented environments (Comte & Olden 2018).

Limitations regarding occurrence data were also pointed out by (Ramos et al. 2019) who identified the predominance of loricariids (plecos) and characids (piabas) for ornamental use, indicating that these two families require accurate information regarding taxonomic aspects, which is hampered by a small number of group specialists with skill to identify this ichthyofauna, at the species level. Geographic, hydrological, and climatic peculiarities are the main factors that contribute to the occurrence of the studied species.

A detailed analysis of biophysical characteristics in the Tapajos River basin and its tributaries can help indicate new potential areas of occurrence for *H. soniae*. We emphasize that the mapping of the areas of occurrence and patterns of population density are relevant information to support governance and sustainability measures for Brazilian ornamental fisheries. For instance, the areas in Para and Mato Grosso States that retain largest occurrences of *H. soniae* could be considered suitable for domestication programs and reproductive management of the species.

Ornamental fishery driven by anthropic pressure for exotic and rare species combined with the lack of biological information about the commercialized species can pose an effective threat to wild populations (Junior et al. 2009, Tavares 2020). An equitable use and conservation

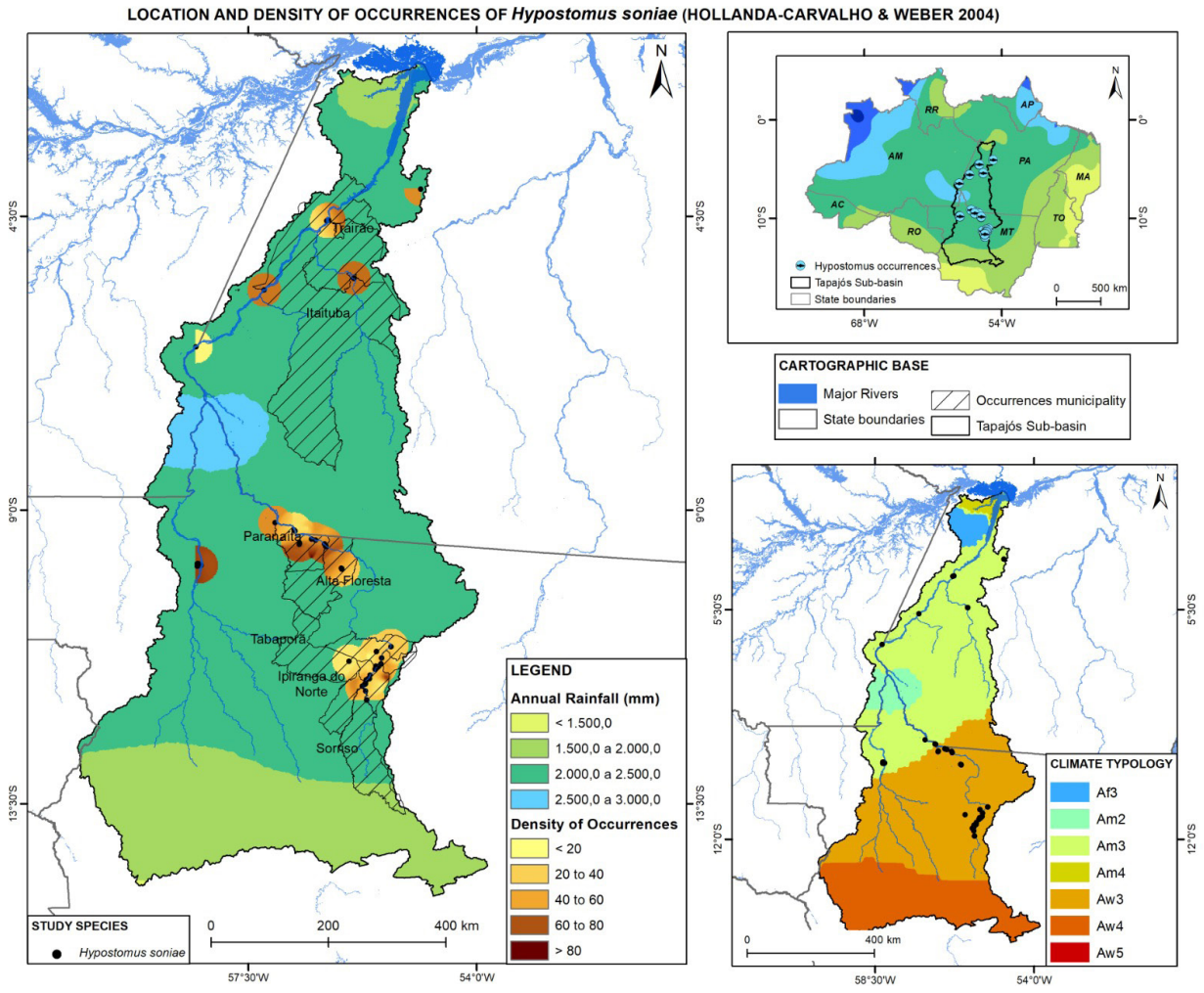

Figure 2. Climatic typology, annual rainfall and Kernel density map of *Hypostomus soniae* concentrations in the Tapajos River basin indicating the places with predominance of the violet acari.

of *H. soniae* deserves attention from both the government sector and the ornamental fish trading stakeholders.

CONCLUSIONS

Hypostomus soniae has been exploited annually in the Tapajos River for at least one decade. All trade in ornamental fish that has been exported abroad comes from points of sale in the cities of Santarem and Itaituba. The village of Pimental is the main hub of ornamental fish landing in the upper Tapajos, where a price for an individual unit of *H. soniae* is R$ 3,00 - 4,00.

The spatial occurrences of *Hypostomus soniae* is associated with areas of annual rainfall ranging from 2,000 mm to 2,500 mm and concentrated in two municipalities of the State of Mato Grosso and two of the Para State. The pressure exerted by anglers compromises the distribution area of the species. These anglers represent threats to the sustainability of ornamental fishing and to the conservation of the species.

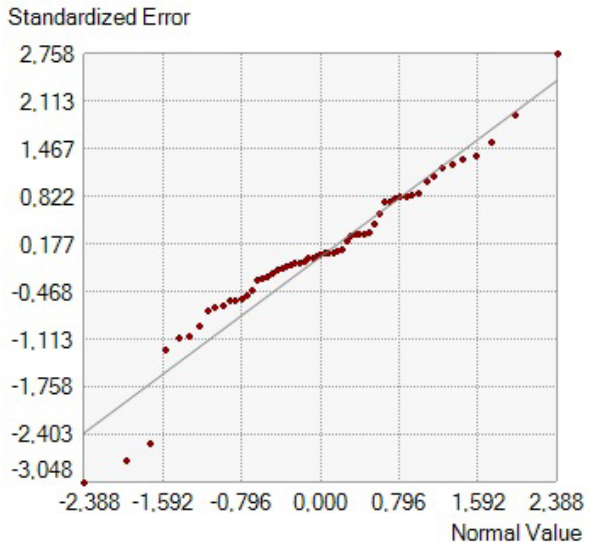

Figure 3. Statistical analysis showing the adjustments of samples of occurrences of the species *Hypostomus soniae*.

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Author contributions

The authors effectively participated in the preparation of the manuscript from the initial work conception to the conclusion, as described below, referring to the specificities in each stage: DENISON LIMA CORREA worked on the organization of the database and on the density analyzes to extract the results of the areas with the highest records of occurrences of the species of interest in this work, analysis, and discussion of the results for finalizing the manuscript and submission. LUAN AERCIO MELO MACIEL, participated in the stages of field data collection, identification of the species and standardization of scientific names, as well as in the analysis and discussion of results, formatting of the manuscript according to the journal's rules. LEILA SHEILA SILVA LISBOA worked on the evaluation of the geodatabase and on the elaboration of the final maps and discussion of the results. LUCIETA GUERREIRO MARTORANO, participated from the conception of the theme of the work, analysis of climatic variables, analysis and discussion of the results and follow- up in the different phases of the work until the conclusion and submission of the manuscript. LUIS REGINALDO RIBEIRO RODRIGUES participated during the conception phase of the work, identification of the species and standardization of scientific names, updates of bibliographic references, analysis and discussion of results and follow-up in the different phases of the work until the conclusion of the manuscript for submission.