Ichthyofauna from “serranias costeiras” of the Ribeira de Iguape River basin, Southeast Brazil

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Abstract: The Ribeira de Iguape River basin has about 100 fish species. This study aimed to characterize the fish community from “serranias costeiras” of the Ribeira de Iguape River basin. Samplings were conducted with electrofishing during the dry season in the years 2018-2019. The sampling effort consisted of 30 stream stretches. As a result, 50 species were captured, distributed in 37 genera, 11 families, and six orders. The species richness estimate (S_{Chao1}) was 57 species, and the coverage estimate for the entire data set was C = 0.998. Hartitia kronei and Chasmocranus lopezae are endemic species and can be used as bioindicators of streams in this river basin. We captured approximately nine species by stream stretch. Beta diversity was found to be more critical for gamma diversity than alpha diversity. This finding highlights the streams environmental heterogeneity importance for maintaining regional fish diversity. We captured eight individuals of the threatened species Spintherobolus papilliferus and this indicates an expansion in the geographic distribution of this species.

Keywords: fish communities, IUCN, endemic species.

Ichthyofauna das “serranias costeiras” da bacia do rio Ribeira de Iguape, sudeste do Brasil

Resumo: A bacia hidrográfica do rio Ribeira de Iguape possui cerca de 100 espécies de peixes. O objetivo deste estudo foi caracterizar a comunidade de peixes de riachos das serranias costeiras da bacia do rio Ribeira de Iguape. O levantamento das espécies foi realizado com uso de pesca elétrica durante a estação seca de 2018-2019. As coletas ocorreram em 30 trechos de riachos. Foram capturadas 50 espécies distribuídas em 37 gêneros, 11 famílias e seis ordens. A estimativa de riqueza de espécies (S_{Chao1}) foi de 57 espécies e a estimativa de cobertura para todo o conjunto de dados foi de C = 0,998. Hartitia kronei e Chasmocranus lopezae são espécies endêmicas e podem ser usadas como bioindicadores para os riachos nesta bacia hidrográfica. Capturamos aproximadamente nove espécies por trecho de rio. A diversidade beta foi considerada mais importante para a diversidade gama do que a diversidade alfa. Esse resultado destaca a importância da heterogeneidade ambiental dos riachos para manter a diversidade regional de peixes. Capturamos seis indivíduos de uma espécie ameaçada Spintherobolus papilliferus e, dessa forma, ocorreu uma expansão da distribuição geográfica desta espécie.

Palavras-chave: comunidades de peixes, IUCN, espécies endêmicas.
Introduction

A set of ecosystems and a mosaic of forest formations form the Atlantic Forest biome (MMA 2020). A large number of independent hydrographic basins, sea-level fluctuations, and stream capture events (Menezes et al. 2007) help us to understand the richness and distribution of about 270 freshwater fish species, 190 of which are considered endemic species (Abilhoa et al. 2011). Besides, estimates point to the existence of 500 species in the Atlantic Forest biome (Thomaz & Knowles 2018), suggesting that our knowledge on the freshwater ichthyofauna is far from being completed. On the other hand, about 100 species are considered threatened (Castro & Polaz 2020) since only 12.4% of the forest that initially existed remains. Although this biome represents only 15% of the national territory, about 70% of Brazilians reside in this biome, concentrating 80% of the national economic production (MMA 2020).

The Ribeira de Iguape River basin is the Southern limit of the Eastern coastal drainages (Langeani et al. 2009) with a complex dendritic structure, relatively small but isolated, emptying straight into the Atlantic Ocean. A low human population occupies it, and Small Hydropower Plants promote hydrological fragmentation into the Atlantic Ocean. A low human population occupies it, and Small Hydropower Plants promote hydrological fragmentation into the Atlantic Ocean. The Ribeira de Iguape River basin has large areas protected and well preserved (CBH-RB 2016). Among these coastal drainages, the Ribeira de Iguape River basin has large areas protected and well preserved (Oyakawa et al. 2006).

In the state of São Paulo, there are 391 fish species, around 15% of the species richness estimated for Brazil (Oyakawa & Menezes 2011). Of this total, 97 species occur in the Ribeira de Iguape River basin. Since 2011, at least six species can be added to this list: Pimelodus multiradiatus Ribeiro, Lucena & Oyakawa 2011, Deuterodon oyakawai (Santos & Castro 2014), Atlantirivulus ribeirensis Costa 2014, Ituglanis amphipotamus Mendonça, Oyakawa & Wosiacki 2018, Trichomycterus laurii Donin, Ferrer & Carvalho 2020 and Microcambeva filamentosa Costa, Katz & Vilaro 2020. This diversity is associated with between-habitat (beta) diversity among streams (Teshima et al. 2016).

As suggested by Casatti et al. (2008), from the ichthyological point of view, an ongoing study will comprise the following actions: (i) list pertinent information from the Ribeira de Iguape River basin representing samples of activities threatening the maintenance of the ichthyofauna biotic integrity, especially the existence of micro-basins impoundments that broke the hydrological connectivity of the system; (ii) promote an ecological study of the headwater fish species of particular interest due to the sharing with adjacent basins.

Fauna inventories generate essential information for the knowledge of patterns of richness and species distribution. They support decision making in projects that will impact the environment (Silveira et al. 2010) and will assist in the definition of public policies (Fapesp 2008). In these studies, it is possible to identify the environmental heterogeneity, sites with species richness, endangered, rare, and endemic species, and detect bioindicators species with a high abundance and occurrence.

With the present list of species, our objective is to estimate the species richness and verify the contribution of beta diversity. We checked the occurrence of endemic and threatened species, and suggest possible bioindicators fish species in streams present at Serras do Mar and Paranaipiacaaba, and the plains of upper Ribeira de Iguape River basin.

Material and Methods

1. Study area

The Ribeira de Iguape River basin covers an area of approximately 27.000 km², comprising 13 municipalities from Paraná State and 23 from São Paulo State, which together house an estimated population of over 990.000 inhabitants (CBH-RB 2016).

In the São Paulo State, the Water Resources Management Unit (Unidade de Gerenciamento dos Recursos Hídricos - UGRHI 11) corresponds to the Ribeira de Iguape River basin and Southern Coastal drainages. It presents one of the most extensive natural vegetation covers in the State of São Paulo, with 12.256 km² of native forest remaining occupying approximately 72% of the area of UGRHI 11 (CBH-RB 2016). The average precipitation in the UGRHI 11 is 1400 mm/year. The UGRHI 11 has 37 Conservation Units, 15 beings of Integral Protection, and 22 of Sustainable Use (CBH-RB 2016).

The Ribeira de Iguape River basin can be divided into two great domains: the coastal plains constituted mainly by cenozoic sedimentary deposits and the “serranias costeiras” formed by ancient crystalline rocks. Within these crystalline rocks, through more hilly terrain, lay the systems of mountains and escarpments characterizing the Serras do Mar and Paranapiacaaba with Conservation Units, and a set of hills and summit surfaces of the plains of upper Ribeira de Iguape River basin (Ross 2002).

The main rivers in the basin are the Ribeira de Iguape in its lower reaches, and some of the main tributaries such as Açungui, Capivari, Pardo, Turvo, Juquiá, São Lourenço, Jaquirapuá, Una da Aldeia, and Itariri rivers. The rivers Itapirapuá, Pardo, and Ribeira de Iguape are under the Federal government domain and all the remainder are under state domain (CBH-RB 2016).

2. Ichthyofauna sampling

Sampling occurred during the dry season (July - November) of 2018 and 2019, between 10h and 18h. In the dry season, the associations between the fish assemblage and environmental structure are more evident in this period (Pinto et al. 2006). Also, it is crucial to control the effect of temporal variation.

The ichthyofauna was sampled in 30 transects of 70 m of streams in the “serranias costeiras” (Figure 1) using electrofishing (LR-24 Electrofisher - Smith-Root) in the downstream-upstream direction with a single passage and without contention nets (Permits: SISBIO 13352-1/IBAMA/MMA and Proc. SMA 006.674/2018). These transects belong to 16 micro-basins: Alto Ribeira, Teixeira, Figueira, Criminosas, Catas Altas, Palmital, Monte Alegre, Piões, Tiquiri, Pedro Cubas, Etá, Quilombo, Preto, Açungui, Ribeirão Fundo, and Juquiá-Guaçu (Table 1 and Figure 2).

Fish were anesthetized with eugenol (clove oil) and fixed for at least 48 hours in 10% formalin. All specimens are stored in 70% ethanol in the collection of Laboratório de Ecotoxicologia Animal e Análise de Integridade Ambiental de UFSCar – Sorocaba. Voucher specimens of all species were deposited in the ichthyological collection of Laboratório de Ictiologia do Departamento de Zoologia e Botânica of UNESP – câmpus de São José do Rio Preto (DZSJRP 22983 - 23048). Photographs of most species were taken using a DSLR camera with a 60mm macro lens on preserved specimens.
Figure 1. Representative stream stretch sampled from “serranias costeiras” of the Ribeira de Iguape River basin, Southeast Brazil. a) Afluente do Juquiá-Guaçu, b) Rio Ouro Fino, c) Rio Corujas, d) Ribeirão Fundo, e) Rio Bonito, f) Rio Itapirapuá.
Table 1. Geographic information of sampling transects. Conservation Units (CU): Parque Estadual do Jurupará (PEJU), Área de Proteção Ambiental da Serra do Mar (APASM), Parque Estadual Carlos Botelho (PECB), Parque Estadual Intervales (PEI), Área de Proteção Ambiental Quilombos do Médio Ribeira (APAQMR).

| Stream | Micro-basin | Lat. | Long. | CU | Municipality | State |
|--------|-------------|------|-------|----|--------------|-------|
| das Cachoeiras | Juquiá-Guaçu | -23.978 | -46.891 | - | Juquitiba | SP |
| A. Juquiá | Juquiá-Guaçu | -23.987 | -47.003 | - | Juquitiba | SP |
| Laranjeiras | Juquiá-Guaçu | -23.842 | -47.061 | - | Juquitiba | SP |
| Verde | Açungi | -23.973 | -47.573 | APASM | Tapiraí | SP |
| Cachoeira do Chá | Açungi | -24.029 | -47.575 | APASM | Tapiraí | SP |
| Corujas | Açungi | -24.060 | -47.589 | APASM | Juquiá | SP |
| Ribeirão Fundo | Ribeirão Fundo | -24.143 | -47.752 | APASM | Sete Barras | SP |
| Ouro Fino | Açungi | -24.013 | -47.812 | APASM | S.M. Arcanjo | SP |
| Ipiranga | Preto | -24.164 | -47.850 | APASM | Sete Barras | SP |
| Preto | Preto | -24.192 | -47.891 | APASM | Sete Barras | SP |
| da Serra | Quilombo | -24.185 | -47.933 | PECB | Sete Barras | SP |
| A. Preto | Preto | -24.172 | -47.962 | PECB | S.M. Arcanjo | SP |
| Temível | Preto | -24.129 | -47.985 | PECB | S.M. Arcanjo | SP |
| Bonito | Preto | -24.142 | -47.994 | PECB | S.M. Arcanjo | SP |
| Quilombo | Quilombo | -24.233 | -48.053 | APASM | Sete Barras | SP |
| Etá | Etá | -24.273 | -48.107 | APASM | Sete Barras | SP |
| A. Taquari | Taquari | -24.455 | -48.210 | APASM | Eldorado | SP |
| Pedro Cubas | Pedro Cubas | -24.461 | -48.307 | APAQMR | Eldorado | SP |
| São Pedro | Taquari | -24.290 | -48.369 | PEI | Ribeirão Grande | SP |
| Carma | Pilões | -24.306 | -48.414 | PEI | Ribeirão Grande | SP |
| Itacolomi | Pilões | -24.474 | -48.469 | APAQMR | Iporanga | SP |
| Pilões | Pilões | -24.453 | -48.509 | APAQMR | Iporanga | SP |
| Iporanga | Monte Alegre | -24.521 | -48.585 | - | Iporanga | SP |
| Palmital | Palmital | -24.573 | -48.873 | - | Apiaí | SP |
| Claro | Catas Altas | -24.441 | -49.096 | - | Barra do Chapéu | SP |
| Criminosas | Criminosas | -24.551 | -49.202 | - | Itapirapuã Paulista | SP |
| Itapirapuã | Figueira | -24.565 | -49.318 | - | Itapirapuã Paulista | SP |
| Turvo | Teixeira | -24.719 | -49.522 | - | Dr. Ulysses | PR |
| Socavão | Alto Ribeira | -24.919 | -49.552 | - | Castro | PR |
| Guabiroba | Alto Ribeira | -24.900 | -49.604 | - | Castro | PR |

Figure 2. Sub-basins and stream stretch sampled in the Ribeira de Iguape River basin.
3. Data analysis

The Chao method was used to estimate species richness (SChao1 ± standard error) and verify sampling effort. The diversity was partitioned into its components, and the statistical significance of alpha and beta was obtained. The analysis was carried with the packages SpadeR (Chao & Hsieh 2015) and vegan (Oksanen et al. 2019) in the R environment (R CoreTeam 2020). To verify fish species bioindicators, we used the frequency of occurrence. Information on endemic and threatened species was based on Oyakawa et al. (2006), Buckup et al. (2007), Menezes et al. (2007), Oyakawa & Menezes (2011) and Fricke et al. (2020) and Decree No. 60.133, dealing with threatened species of wild fauna in the State of São Paulo (São Paulo 2014).

Table 2. Stream fishes from “serranias costeiras” of the Ribeira de Iguape River basin. Endemics species are in bold (Oyakawa et al. (2006), Buckup et al. (2007), Menezes et al. (2007), Oyakawa & Menezes (2011), Fricke et al. (2020). Sub basins: Alto Ribeira (ARib), Teixeira (Tei), Figueira (Fig), Criminosas (Cri), Catas Altas (CAlt), Palmital (Pal), Monte Alegre (Male), Pilões (Pil), Taquari (Taq), Pedro Cubas (PCub), Etá (Eta), Quilombo (Qui), Preto (Pre), Açungui (Acu), Ribeirão Fundo (RFun), Juquiá-Guaçu (JGua). Threatened taxa * ICMBio (2018) and ** São Paulo (2014) without local identification. Voucher identification (DZSJRP).

| Order/Family/Species | ARib | Tei | Fig | CAlt | Pal | MAle | Pil | Taq | PCub | Etia | Qui | Pre | Acu | RFun | JGua | DZSJRP |
|----------------------|------|-----|-----|------|-----|------|-----|-----|------|------|-----|-----|-----|------|------|--------|
| CHARACIFORMES        |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Characidae           |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Astyanax janeiroensis Eigenmann, 1908 | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | -   | -    | -    | 23036  |
| Astyanax ribeirae Eigenmann, 1911  | -    | -   | -   | -    | -   | -    | -   | -   | -    | x    | x   | -   | -   | -    | -    | 22992  |
| Bryconamericus microcephalus (Miranda Ribeiro, 1908) | -    | -   | -   | -    | x   | x    | x   | x   | x    | -    | -   | -   | -   | -    | -    | 23008  |
| Deuterodon iguape Eigenmann, 1909  | -    | -   | -   | -    | -   | x    | x   | -   | -    | -    | -   | -   | -   | x    | -    | 23034  |
| Hollandichthys multifasciatus (Eigenmann & Norris, 1900) | -    | -   | -   | -    | -   | x    | -   | -   | -    | -    | -   | -   | -   | -    | -    | 22997  |
| Hyphessobrycon bifasciatus Ellis, 1911 | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | x    | -    | -    | 23046  |
| Hyphessobrycon reticulatus Ellis, 1911 | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | -    | x    | -    | 23017  |
| Mimagoniates microlepis (Steindachner, 1877) | -    | -   | -   | -    | x   | x    | x   | -   | -    | -    | x   | -   | -   | -    | -    | 23004  |
| Spintherobolus papiliferus Eigenmann, 1911* | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | -   | -    | -    | 23020  |
| Crenuchidae           |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Characidium lanei Travassos, 1967 | -    | -   | -   | -    | -   | -    | -   | -   | -    | x    | x   | -   | -   | -    | -    | 23018  |
| Characidium lauroi Travassos, 1949** | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | -   | -    | -    | 23030  |
| Characidium pterostictum Gomes, 1947 | x    | x   | -   | -    | x   | x    | x   | x   | x    | -    | -   | x   | -   | -    | -    | 23044  |
| Characidium schubarti Travassos, 1955** | x    | x   | -   | -    | x   | x    | x   | x   | x    | -    | -   | x   | -   | -    | -    | 22995  |
| GYMNOTIFORMES         |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Gymnotidae            |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Gymnotus pantherinus (Steindachner, 1908) | -    | -   | -   | -    | -   | -    | -   | -   | -    | -    | -   | -   | x    | -    | -    | 22996  |
| SILURIFORMES          |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Callichthyidae        |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Scleromystax barbatus (Quoy & Gaimard, 1824) | -    | -   | -   | -    | -   | x    | x   | x   | x    | -    | -   | x   | -   | -    | -    | 23011  |
| Heptapteridae         |      |     |     |      |     |      |     |     |      |      |     |     |     |      |      |        |
| Acentronichthys leptos Eigenmann & Eigenmann, 1889 | -    | -   | -   | -    | -   | x    | -   | x   | x    | x    | x   | -   | x    | -    | -    | 23032  |
| Chasmocranus lopezae Miranda Ribeiro, 1968 | x    | x   | -   | -    | x   | x    | x   | x   | x    | -    | -   | x   | -   | -    | -    | 22983  |
| Pinelodella transitoria Miranda Ribeiro, 1907 | x    | -   | -   | -    | -   | x    | x   | -   | -    | -    | -   | x   | -   | -    | -    | 23039  |
| Rhamdia quelen (Quoy & Gaimard, 1824) | -    | -   | -   | -    | x   | -    | -   | -   | -    | -    | -   | x   | -   | -    | -    | 22984  |
| Rhamdioglanis transfasciatus Miranda Ribeiro, 1908 | x    | -   | -   | -    | -   | x    | x   | x   | x    | x    | x   | x   | -   | -    | -    | 23041  |

Results and Discussion

Approximately 9kg of fish were caught, with 3281 individuals representing 50 species, 37 genera, 11 families, and six orders (Table 2). Although the ichthyofauna from the State of São Paulo is relatively well known (Oyakawa & Menezes 2011), there are still many taxa to be better studied, such as the cases of Astyanax, Characidium, and Trichomycterus. Around four per cent of the individuals did not have their specific identification from genera Astyanax, Characidium, Hypostomus, Rineloricaria, and Trichomycterus. Oyakawa et al. (2006) had already mentioned some Astyanax that could be new species, and the genus needs a taxonomic review within the Ribeira de Iguape River basin to elucidate the species richness in that drainage. A single specimen of armoured catfish was a juvenile and could not be identified beyond the family level.
### Order/Family/Species

| Species                      | ARib | Tei | Fig | Cri | CalT | Pal | MAle | Pil | Taq | PCub | Eta | Qui | Pre | Acu | RFun | JGua | DZSJRIP |
|------------------------------|------|-----|-----|-----|------|-----|------|-----|-----|------|-----|-----|-----|-----|------|------|---------|
| Ancistrus multispinis (Regan, 1912) | x    | -   | -   | -   | -    | x   | x    | x   | x   | x    | x   | -   | -   | x   | -    | -      | 23043   |
| Hartia kroni (Miranda Ribeiro, 1908) | x    | x   | x   | x   | x    | -   | -    | x   | x   | x    | x   | -   | -   | x   | -    | -      | 22989   |
| Hisonotus leucofrenatus (Miranda Ribeiro, 1908) | -    | -   | -   | -   | -    | x   | x    | x   | -   | -    | -   | x   | X   | x   | -    | -      | 23006   |
| Hypostomus interruptus (Miranda Ribeiro, 1918) | x    | -   | -   | -   | -    | x   | x    | x   | -   | -    | -   | x   | X   | -   | -    | -      | 22994   |
| Isbrueckerichthys alipionis (Gosline, 1947) | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23027   |
| Isbrueckerichthys duseni (Miranda Ribeiro, 1907) ** | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23028   |
| Isbrueckerichthys epakmos Pereira & Oyakawa, 2003 ** | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23024   |
| Kronichthys lacerta (Nichols, 1919) | -    | -   | -   | -   | -    | x   | x    | x   | x   | x    | x   | -   | -   | -   | -    | -      | 23031   |
| Kronichthys subtetras (Miranda Ribeiro, 1908) | -    | -   | -   | -   | -    | x   | x    | x   | -   | -    | -   | -   | -   | -   | -    | -      | 23015   |
| Lampiella gibbosa (Miranda Ribeiro, 1908) | -    | -   | -   | -   | -    | x   | x    | x   | x   | x    | x   | -   | -   | -   | -    | -      | 23010   |
| Neoplecostomus paranaensis Langeani, 1990 | -    | x   | -   | -   | -    | -   | x    | x   | -   | -    | -   | x   | X   | -   | -    | -      | 22990   |
| Neoplecostomus robeni Langeani, 1990 | -    | -   | x   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23048   |
| Parotocinclus maculicauda (Steindachner, 1877) | -    | -   | -   | -   | -    | -   | x    | x   | -   | -    | -   | x   | X   | -   | -    | -      | 23007   |
| Pseudotothyris obtusa (Miranda Ribeiro, 1911) | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23019   |
| Rineloricaria kroni (Miranda Ribeiro, 1911) | x    | -   | -   | -   | -    | -   | x    | x   | x   | x    | x   | -   | -   | x   | -    | -      | 22998   |
| Rineloricaria lima (Kner, 1853) | -    | x   | x   | -   | -    | -   | x    | x   | x   | x    | x   | -   | -   | -   | -    | -      | 23042   |
| Schizolecis guentheri (Miranda Ribeiro, 1918) | -    | -   | -   | -   | -    | -   | x    | x   | x   | x    | x   | -   | -   | -   | -    | -      | 23040   |
| Pseudopimelodidae             |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Microganis cottooides (Boulenger, 1891) | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23003   |
| Trichomycteridae              |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Cambeva davisi (Haseman, 1911) | x    | -   | x   | -   | -    | x   | x    | -   | x   | x    | -   | x   | X   | -   | -    | -      | 22985   |
| Cambeva tupinamba (Wosiacki & Oyakawa, 2005) | -    | -   | -   | -   | -    | -   | x    | x   | x   | x    | x   | -   | -   | -   | -    | -      | 23009   |
| Homodiaetus graciosa Koch, 2002 ** |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Microcambeva ribeirae Costa, Lima & Bizerril, 2004 | -    | -   | -   | -   | -    | -   | x    | -   | -   | -    | x   | -   | -   | -   | -    | -      | 23002   |
| Trichomycterus alternatus (Eigenmann 1917) | -    | x   | x   | x   | x    | -   | x    | x   | x   | x    | x   | -   | -   | x   | -    | -      | 22988   |
| Trichomycterus laurie Donin, Ferrer & Carvalho, 2020 | x    | -   | x   | -   | -    | x   | x    | -   | x   | -    | -   | -   | -   | -   | -    | -      | 23012   |
| CYPRINODONTIFORMES            |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Pocellidae                    |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Phalloceros harpagos Lucinda, 2008 | -    | -   | x   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23038   |
| Phalloceros reisi Lucinda, 2008 | -    | -   | -   | x   | x    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23047   |
| Poecilia vivipara Bloch & Schneider, 1801 | -    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23016   |
| SYNBRANCHIFORMES              |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Synbranchidae                 |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Synbranchus aff. marmoratus Bloch, 1795 | -    | -   | -   | -   | -    | -   | x    | -   | -   | x    | -   | -   | -   | -   | -    | -      | 23000   |
| CICHLIFORMES                  |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Cichlidae                     |      |     |     |     |      |     |      |     |     |      |     |     |     |     |     |     |         |
| Crenicichla iguapina Kullander & Lucena, 2006 | -    | -   | -   | -   | -    | -   | x    | -   | -   | x    | -   | -   | -   | -   | -    | -      | 23033   |
| Geophagus iporangensis Haseman, 1911 | x    | -   | -   | -   | -    | -   | -    | -   | -   | -    | -   | -   | -   | -   | -    | -      | 23045   |

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...continue
Ichthyofauna from Ribeira de Iguape streams

About 40% of the specimens are less than 50 mm in standard length (SL), a common feature in stream fishes occupying small environments and that may complete their life cycles in restricted geographic areas (Castro 1999, Menezes et al. 2007). The orders Siluriformes and Characiformes represented most of the species richness, 61%, and 25%, respectively, reflecting a well-known pattern recognized for South American rivers (Lowe-McConnell 1999).

We have identified about 40% of the species captured by Barrella et al. (2014) in the portion between Serra de Paranapiacaba and the estuary of Iguape-Cananéia. Around 50% of the 97 species listed by Oyakawa & Menezes (2011) checklist for the Ribeira de Iguape River ichthyofauna. Approximately 70% of the species caught by Oyakawa et al. (2006) in streams from the Conservation Units of São Paulo State in the Ribeira de Iguape River basin. On the other hand, we sampled around twice the number of species identified from Frota et al. (2019) captured in headwater streams of the Ponta Grossa Arch in the Paraná State portion of Ribeira de Iguape River basin.

The species richness estimates (Schao1) was 57, with a 95% confidence interval of (51 – 92). The coverage estimate for the entire data set was C = 0.998. The coverage estimate is an objective measure of sample completeness. It represents the estimated fraction of the whole population of individuals in the community that belong to the species represented in the sample (Chao & Chiu 2014). This result indicates sampling effort with few species with one individual. With the abundance data, the estimated coefficient of variation was 1.56 that characterize the degree of heterogeneity for species discovery probabilities (CV = 0 would mean that all species are homogeneous) (Chao & Chiu 2014).

Species richness ranged from 2 to 20 per stretch stream, with mean of 9.1 species. The comparison between the observed data and those generated under the null model revealed that alpha diversity (i.e., species diversity within a stream) showed lower species richness than expected by chance. Tropical streams usually have little species richness mainly due to small water volume (Gerhard et al. 2009, Sáurez 2011). On the other hand, the diversity difference between-stream (i.e., beta diversity) was higher than expected under the null model (Figure 3). Beta diversity was found to be more critical for total diversity (i.e., gamma diversity) than the average local diversity. These findings highlight the importance of streams environmental heterogeneity for maintaining regional fish diversity (Erős 2007, Casatti et al. 2009, Teshima et al. 2016).

The Ribeira de Iguape River basin is well known for its endemic fish species (Bixerri & Lima 2000, Ribeiro 2006) (Table 2 and Figures 4, 5, and 6). Approximately 35% of the species captured herein are endemic of the Ribeira de Iguape River basin. Harttia kronei and Chasmocranus lopaeze are abundant endemic species. Few vertebrate species fulfill multiple criteria for ecosystem health indicator, as most are highly mobile generalists that lack established tolerance levels and correlations with ecosystem changes (Hilty & Merenlender, 2000). These authors indicated three general categories for selecting indicator taxa: (1) baseline information, (2) location information, (3) niche and life history attributes.

We suggest baseline studies with H. kronei and C. lopaeze regarding their tolerance to impacts and ecosystem changes, mobility, population fluctuation, reproductive rates, and food preference since they are not migratory, have a small body and are easy to find. With this information, biomonitoring programs can use these species as indicators for the biological conservation status of streams in this river basin.

Three species are new records for the Ribeira de Iguape River basin: Spintherobolus papilliferus from headwaters of the Tietê River basin, Characidium lauroi from the Paraíba do Sul River basin, and Neoplecostomus paranensis from headwaters of the Upper Paraná River basin (Buckup et al. 2007). Frota et al. (2019) captured Astyanax bifasciatus, an endemic species of the Iguacu River basin in the headwaters of Ribeira de Iguape River. The events of headwater capture between coastal drainages and those that flow into the interior of the continent could explain these biogeographic patterns (Serra et al. 2005, Frota et al. 2019). This hypothesis remains to be tested in future studies.

We captured eight individuals of Spintherobolus papilliferus that is considered a threatened species (Portaria MMA nº 445/2014) belonging to the IUCN category “Critically Endangered”, facing a very high risk of extinction in the wild (CR - B2ab(iii, iv)). Spintherobolus papilliferus is a rare and endemic species of the headwaters of the upper Tietê River basin, São Paulo state (Weitzman & Malabarba 1999, Akama et al. 2018). This record indicates an expansion in the species distribution which will be approached in a more detailed study.

The high endemicity of Ribeira de Iguape River basin coped with new records of species, the presence of threatened species, the existence of putatively new taxa, and the high beta diversity raises concerns about the conservation of its ichthyofauna.
Figure 4. Some fishes sampled in the present study. A: *Astyanax* ribeirae; B: *Bryconamerica* microcephalus; C: *Deuterodon* iguape; D: *Mimagoniates* microlepis; E: *Spintherobolus* papilliferus; F: *Characidium* lanei; G: *Characidium* lauroi; H: *Characidium* pterostictum; I: *Characidium* schubarti; J: *Gymnotus* pantherinus; K: *Phalloceros* harpagos; L: *Phalloceros* reisi; M: *Crenicichla* iguapina; N: *Geophagus* iporangensis. Scales = 1cm.
Figure 5. Some Siluriformes of the families Callichthyidae and Loricariidae sampled in the present study. A: Scleromyctes barbatus; B: Hypostomus interruptus; C: Isbrueckerichthys duseni; D: Kronichthys lacerta; E: Lampiella gibbosa; F: Neoplecostomus paranensis; G: Neoplecostomus ribeirensis; H: Parotocinclus maculicauda. Scales = 1 cm.
Figure 6. Some Siluriformes of the families Heptapteridae and Trichomycteridae sampled in this study. A: Acentronichthys leptos; B: Chasmocranus lopezae; C: Pinelodella transitoria; D: Rhamdioglanis transfasciatus; E: Cambeva davisi; F: Cambeva tapinamba; G: Microcambeva ribeirae; H: Trichomycterus alternatus; I: Trichomycterus lauryi. Scales = 1 cm.
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Author Contributions

Maurício Cetra: Contribution to the concept and design of the study, data collection, data analysis and interpretation, preparation of the manuscript, critical review adding intellectual content.

George Mattox: Contribution to the concept of the study, data analysis and interpretation, preparation of the manuscript, critical review adding intellectual content.

Perla Bahena Romero: Contribution to the data collection, data analysis and interpretation.

Stephanie Hernández Escobar: Contribution to the data collection, data analysis and interpretation.

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Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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