The ichthyofauna of the Rio Carinhanha basin, one of the main tributaries of the Rio São Francisco

Gilberto Nepomuceno Salvador¹ ²; Ruanny Casarim³ ⁵; Gustavo Ribeiro Rosa⁴; Yuri Malta Caldeira⁶ ⁷ & Paulo Santos Pompeu³ ⁷

¹ Universidade Federal do Pará (UFPA), Instituto de Ciências Biológicas (ICB), Laboratório de Ecologia e Conservação (LABECO). Belém, PA, Brasil. ORCID: http://orcid.org/0000-0002-3598-6469. E-mail: curimata_gilbert@hotmail.com
² Pontifícia Universidade Católica de Minas Gerais (PUC-MINAS), Museu de Ciências Naturais (MCN). Belo Horizonte, MG, Brasil.
³ Universidade Federal de Lavras (UFLA), Departamento de Biologia, Setor de Ecologia e Conservação, Programa de Pós-Graduação em Ecologia Aplicada (PPGECO). Lavras, MG, Brasil.
⁴ Pontifícia Universidade Católica de Minas Gerais (PUC-MINAS), Programa de Pós Graduação em Biologia de Vertebrados. Belo Horizonte, MG, Brasil. ORCID: http://orcid.org/0000-0002-1790-1089. E-mail: gustavoribeirorosa@hotmail.com
⁵ ORCID: http://orcid.org/0000-0003-2969-1311. E-mail: rucasarim@gmail.com
⁶ ORCID: http://orcid.org/0000-0003-4297-7090. E-mail: yurimc86@gmail.com
⁷ ORCID: http://orcid.org/0000-0002-7938-1517. E-mail: pompeups@gmail.com

Abstract. The ichthyofauna of the Rio São Francisco basin is relatively well-documented. However, most of this knowledge is concentrated at the upper stretch of its catchment area. In this study, we compile a list of species encompassing almost the entire length of the Rio Carinhanha, an important tributary from upper-middle section of the Rio São Francisco, including a comprehensive diversity of environments. A total of 99 species from 8 orders and 27 families were recorded. Five species are considered non-native, six classified as long distance migrants, and three as vulnerable. The orders with the greatest richness of native species were Characiformes and Siluriformes. Characidae was the most represented family, followed by Loricariidae. The main river channels were the richest environments sampled, followed by floodplain lagoons, veredas, and streams. The Carinhanha basin has important lotic remnants, thus it has several migratory fish populations as well as endangered species. This study demonstrates the importance of cataloguing the still poorly explored tributaries of the upper-middle section of the Rio São Francisco basin.

Key-Words. Cerrado; Freshwater; Checklist; Rio Itaguari; Rio Cochá; Grande Sertão Veredas National Park.

INTRODUCTION

The ichthyofauna of the Rio São Francisco has been studied since the eighteenth century, when Prochilodus marggravii was first described by the naturalist Johann Julius Walbaum (Britski et al., 1988). After more than a century, the basin has one of the most well-known ichthyofauna in the Neotropical region with 241 recorded native species, 70% of them with confirmed occurrences in the state of Minas Gerais (Alves & Pompeu, 2010; Alves et al., 2011; Barbosa et al., 2017). Despite the significant knowledge about the fish assemblages within the catchment, the distribution of studied areas is uneven, with the greatest concentrations of research occurring around the most populous regions (Alves et al., 2011). Surveys of species in highland rivers (Casatti & Castro, 1998, Vieira et al., 2005; Alves & Leal, 2010; Alves & Pompeu, 2010; Domingos et al., 2013), some reservoirs (Silva et al., 2006; Prado & Pompeu, 2014; Sanches et al., 2014), and some floodplain lagoons of the upper and upper-middle sections of the Rio São Francisco (Sato et al., 1987; Pompeu & Godinho, 2003; Luz et al., 2012) are available. However, the fish assemblages of some of the main tributaries of the upper-middle section of the Rio São Francisco remains poorly known (Alves et al., 2009), as is the case of the Rio Carinhanha basin.

The great regional importance of the Rio Carinhanha contrasts with the scarcity of knowledge concerning the basin’s ichthyofauna. The Carinhanha constitutes one of the most preserved tributaries of the Rio São Francisco basin, running through well-preserved areas including some important protected zones such as Grande Sertão Veredas National Park (Borges & Santos, 2009). The river also is one of the largest perennial rivers in the central section of the São Francisco basin, a region of notorious water stress (Pereira et al., 2007; Mendes et al., 2015). Despite its importance, there has only been one systematic survey of the ichthyofauna in the basin (IBGE, 2007). However, that survey did not consider all its richness due to the...
restricted area sampled, nor did it evaluate the distribution of the species in the catchment’s different habitats. The Carinhana is considered a priority area for fish fauna conservation in the central area of the Rio São Francisco basin (Drummond et al., 2005; Rosa et al., 2003) because it represents an important lotic remnant of the basin. However, all of the basic requirements for adequate conservation strategies are lacking, especially because the species composition remains unknown. Therefore, in this study we compile a list of species, encompassing the full extent of the catchment and record the diversity of the basin’s habitats.

MATERIAL AND METHODS

Study area

The Rio São Francisco basin is one of the largest river basins in Brazil, covering five Brazilian states (Alagoas, Bahia, Minas Gerais, Pernambuco, and Sergipe), and is divided into four sections: upper, upper-middle, lower-middle, and lower (Drummond et al., 2005; Paiva, 1982; Sato & Godinho, 2003). The main tributaries of the Rio São Francisco flow into the upper-middle section (Godinho & Godinho, 2003) and include the Rio Carinhana, which divides states of Minas Gerais and Bahia (Fig. 1). The Rio Carinhana is 468 km long. Its basin exhibits an elongated shape (Viglio et al., 2011), running in an easterly direction, and covering an area of 1.7 million hectares (Borges & Santos, 2009). Although it occupies 2.7% of the total area of the Rio São Francisco basin, the Rio Carinhana drainage contributes 6.5% of the average flow of the main river (Pereira et al., 2007). This can be explained by the types of soils in the region: urucuia sandstone and deposits containing lateritic detritus, superimposed by Quartzarenic Neosols (Borges, 2009), have relatively high rates of rainwater infiltration compared to other types of soils (Gaspar et al., 2007).

There are many protected areas in the Carinhana basin (MMA/IBAMA, 2003). Six of them are part of a set of protected areas called Mosaico Sertão Veredas-Peruaçu (Moraes, 2011), which cover approximately 30% of the Carinhana drainage basin. The Grande Sertão Veredas National Park is one of the largest protected area in the region and is part of this integral protection group. The other protected areas, Porto Cajueiro, Cochá-Gibão, Veredas do Caraíba, Gibão-Flexeiras, and Triângulo I, are classified into sustainable use (Dudley, 2008).

The predominant biomes along the course of the Rio Carinhana are the Brazilian savanna (cerrado) and the tropical dry forest (caatinga). Its leads to great variability to the mean of the annual rainfall along the basin, being closer that observed in cerrado on its headwaters (near to...
1,500 mm), and closer to the caatinga on its mouth (near to 700 mm/year) (Borges, 2009; EMBRAPA, 2012; Silva et al., 2018). Veredas (Brazilian palm swamp) and floodplain lagoons are both abundant along the Carinhanha basin. The first formation occurs mainly along the upper portion of the basin. There are numerous floodplain lagoons near the mouth of the Rio Preto (more than 130 floodplain lagoons with an average size of 0.2 ha), and in the lower river (120 floodplain lagoons with an average size of 8.2 ha). Furthermore, there are also permanent ponds, a lentic environment isolated from the river channel.

**Fish Sampling and Identification**

Sampling was undertaken at 25 sites in the Rio Carinhanha basin (Fig. 1) from September 2014 to April 2015. The sampled water bodies included 3 streams, 6 veredas, 2 floodplain lagoons, 2 permanent ponds, and 12 points along the main channels of the Rio Carinhanha as well as 2 of its tributaries: the Rio Itaguari and Rio Cochá (Figs. 2 and 3; Supplementary Materials 1). We considered veredas (palm swamps) to be all streams classified as Strahler third order which flowed into hydromorphic ground and had a poorly defined channel surrounded by *buritis* (*Mauritia flexuosa*) palm trees (Silva & Bates, 2002). We differentiated floodplain lagoons from permanent ponds by its position in the drainage basin. While floodplain lagoons are located near the Rio Carinhanha channel and are directly influenced by its flood pulses, permanent ponds are a lentic environment away from the floodplains and lacking flood pulse influence (Costa, 2002; Tavares-Júnior et al., 2020).

The main river channel of the Carinhanha (Figs. 2A and 2B) and Itaguari (Fig. 2C) as well as one floodplain lagoon (Fig. 3C) were sampled using gillnets with mesh sizes ranging from 3 to 16 cm (between opposing knots) at each sampling site. The gillnets were set up in the af-
ternoon and removed the following morning, staying approximately 15 hours submerged. At each of these three locations, two seinings and an additional 15 sieve samplings were carried out as supplementary methodology. The seine was 3 m long by 1.5 m high, and the sieve had a diameter of approximately 0.2 m²; both with mesh size 0.5 mm. In the main channel of the Rio Cochá (Fig. 2D) and in another floodplain lagoon (Fig. 3D), only sieve samplings were done due to environmental conditions; at the permanent ponds (Figs. 3E and 3F), only seining was undertaken.

To sample fish communities in streams and veredas (Figs. 3A, 3B, 3E and 3F), a 150 m long section was delimited in each study site. Fish collections were undertaken against the water-flow (i.e., from downstream to upstream) with hand nets (80 cm in diameter, 1 mm stretched mesh size). Two hand nets were used for sampling, and collection time was standardized (12 minutes per cross-section, 120 minutes for each stream). Hand nets were used because of their efficiency in lower-order streams. The sampling effort was the same in all streams.

After capture, the fish were euthanized with lethal doses of anesthetic and then fixed in 10% formalin solution. In the laboratory, we transferred the fishes to 70% ethanol and identified them to the species level through dichotomous keys from Britski et al. (1988) and recent literature on the ichthyofauna of the São Francisco basin. The scientific names followed Fricke et al. (2020). Voucher specimens were deposited in the ichthyological collections of the Museum of Natural Sciences of PUC-Minas (MCNIP) and the Laboratory of Fish Ecology of the Federal University of Lavras (UFLA) (Supplementary Materials 2).

Data analysis

All analyses were undertaken using qualitative data from this field sampling. The species were classified ac-

![Figure 3. Aquatic habitats (streams (STR), floodplain lagoons (FPL), and permanent ponds (PON)) at the Rio Carinhha basin.](image-url)
According to their original distribution (native or non-native; Alves & Leal, 2010), their reproductive characteristics, sedentary or migratory (Sato & Godinho, 2003), and their conservation status (Vieira et al., 2008; MMA, 2014; IUCN, 2015).

Individuals were classified into orders and families following Van der Laan & Fricke (2020). The relative richness of native species in each order and family was considered. The distribution of species in the following five different habitats within the basin were also evaluated: the main river channel (MRC) of Carinhanha and its tributaries, Itaguari and Cochá, streams (STR), veredas (VER), floodplain lagoons (FPL), and permanent ponds (PON). As a complement to our list, we incorporated species that were not recorded in our study, by checking the basin’s voucher species. Subsequently, a Jaccard matrix was calculated and served as the basis for a principal coordinate analysis (PCoA) to evaluate the similarity of ichthyofauna among the five different habitats.

In order to test whether sampling was adequate, a species accumulation curve was generated through the rarefaction of the data obtained by sampling site and to estimate total basin richness, the mean of Jackknife values were used, both using Vegan package in R (Oksanen et al., 2013; R Core Team, 2015).

RESULTS

A total of 99 species distributed across 8 orders and 27 families were recorded for the Rio Carinhanha basin (Table 1; Fig. 4). Characiformes was the order with the highest richness of native species (56%), followed by the Siluriformes (33%), and then both Cichliformes and Gymnotiformes (3% each) (Fig. 5). This pattern was similar in four of the five sampled habitats, with minor variations principally between the first two orders. The exception occurred in PON, in which the only two species recorded were Characiformes. Characidae was the most representative family with 23% of recorded species, followed by Loricariidae (11%), and Anostomidae (7%) (Fig. 6). Of all the families recorded in the Carinhanha basin, 70% had a richness of less than three species. The habitat MRC was the richest environment among the sampled species with 82% of the species recorded for the entire basin, followed by FPL (41%), VER (33%), and STR (20%). Of the two species recorded in PON, one is probably new to science (Characidium sp.). No single species was recorded in all habitats, but 16% were recorded in three or four sites, and 84% of the species showed a restricted distribution to just one or two habitat types (Table 1).

Five of the sampled species are considered introduced in the basin, one characiform (Metynnis lippincottianus), one siluriform (Hoplosternum littorale), and three cichliforms (Astronotus ocellatus, Cichla piquiti, and Coptodon rendalli). The distribution of the introduced species was restricted to the MRC and FPL in the lower section of the Rio Carinhanha. Six species (Brycon orthotaenia, Megaleporinus obtusidens, Prochilodus argenteus, Prochilodus costatus, Salminus franciscanus, and Pseudoplatystoma corruscans) are classified as long-distance migrants and occurred in MRC and FPL. Brycon orthotaenia, S. franciscanus, and P. corruscans were recorded only in the FPL close to the confluence of the two rivers, while the other migratory species were only recorded in the MRC of Carinhanha and Itaguari. Three species are classified as vulnerable: Brycon orthotaenia (Characiformes) (IUCN, 2015), Bagropsis reinhardtii (MMA, 2014), and Lophiosilurus alexandri (MMA, 2014). Bagropsis reinhardtii was recorded only in the upper section of the two MRC (Rio Carinhanha and Rio Itaguari), while B. orthotaenia and L. alexandri occurred in both MRC and FPL habitats and were restricted to the lower section of the Rio Carinhanha.

MRC and FPL sampling sites formed a group based on their similarities, which was distinct from the group represented by VER, STR, and PON. Among the sites belonging the different habitats, those of VER showed the highest variation (Fig. 7). The species accumulation curve stabilized (Fig. 8), and the observed richness (99 species) represented 97% of the richness estimated by Jackknife 1 (102 ± 2 species).

DISCUSSION

The Rio Carinhanha basin can be considered one of the richest tributaries of the Rio São Francisco basin, with around 40% of the known fish species for the entire São Francisco (Alves & Pompeu, 2010; Barbosa et al., 2017). With 99 species, including Hysterotus megalostomus, which was recorded only in the literature (Menezes et al., 2016), the Rio Carinhanha basin has the second-highest richness, second only to the Rio das Velhas basin (Alves & Leal, 2010). However, important tributaries, such as the Paracatu, Urucua, and Corrente rivers still lack detailed fish surveys, although some localized studies have been carried out (e.g., Belei et al., 2016). With the increase of knowledge about the fish fauna of those tributaries, we believe that some may have a similar fish richness to the Carinhanha.

The predominance of otophins Characiformes and Siluriformes species, a pattern observed in the present study, are known to be the rule in the Neotropics (Lowe-McConnell, 1987; Reis et al., 2016) and have already been observed in different studies in the Rio São Francisco basin (e.g., Britski et al., 1988; Alves & Leal, 2010). Similarly to what was found in the present study, this pattern can also be found both in small tributaries (e.g., Casatti & Castro, 1998), and large rivers (e.g., Alves & Leal, 2010; Belei et al., 2016).

The record of a larger number of species at the main river channel is in accordance with the River Continuum Concept, which predicts an increase in species richness from the headwaters towards the mouth (Vannote et al., 1980) due to the increase in habitat diversity and availability (Karr & Schlosser, 1978). The lowest richness was recorded in PON, with only two species. It can be explained by the instability of those water bodies, which almost dry out completely during the dry season (Costa,
Table 1. Species recorded in the Rio Carinhanha basin, one of the main tributaries of the Rio São Francisco. The species identified with (*) are classified as endangered. Species followed by (θ) are classified as non-native and (+) are classified as long-distance migratory species. Habitats: main river channel (MRC), streams (STR), veredas (VER), floodplain lagoons (FPL), and permanent ponds (PON).

| Taxon                                      | MRC | STR | VER | FPL | PON |
|--------------------------------------------|-----|-----|-----|-----|-----|
| **ORDER CLupeiformes**                    |     |     |     |     |     |
| Family Engraulidae                         |     |     |     |     |     |
| Anchovella vaillanti (Steindachner 1908)   | X   |     |     |     |     |
| **ORDER CHARACIFORMES**                   |     |     |     |     |     |
| Family Crenuchidae                         |     |     |     |     |     |
| Characidium cf. fasciatum Reinhardt 1867   |     | X   |     |     |     |
| Characidium zebra Eigenmann 1909           | X   | X   |     |     |     |
| Characidium sp. A (following Britski et al., 1988) | X   |     |     |     |     |
| **Family Serrasalmidae**                   |     |     |     |     |     |
| Metynnis lipponotus (Cope 1870)            | X   |     |     |     |     |
| Mylossus micans (Lütken 1875)              | X   |     |     |     |     |
| Pygocentrus paraja (Huéver 1819)           | X   |     |     |     |     |
| Serrasalmus brasili Lütken 1875             | X   |     |     |     |     |
| **Family Anostomidae**                     |     |     |     |     |     |
| Apareiodon hasenani Eigenmann 1916         | X   | X   |     |     |     |
| Apareiodon sp. A (following Britski et al., 1988) | X   |     |     |     |     |
| **Family Cichlidae**                       |     |     |     |     |     |
| Cichlasoma Sanctifranciscense               | X   |     |     |     |     |
| **ORDER PERCIFORMES**                     |     |     |     |     |     |
| Family Sciaenidae                          |     |     |     |     |     |
| Bryconops sp.                              |     |     |     |     |     |
| **ORDER SYNBRANCHIFORMES**                |     |     |     |     |     |
| Family Loricariidae                        |     |     |     |     |     |
| Hypostomus velhochico                       |     |     |     |     |     |
| Hypostomus francisci                        |     |     |     |     |     |
| Hypostomus sp.                             |     |     |     |     |     |
| **ORDER CIPRINODONTIFORMES**               |     |     |     |     |     |
| Family Characidida                         |     |     |     |     |     |
| Astyanax lacustris (Kleber 1875)           | X   |     |     |     |     |
| Astyanax sp.                               |     |     |     |     |     |
| **ORDER CYPRINIFORMES**                   |     |     |     |     |     |
| Family Characidae                          |     |     |     |     |     |
| Astyanax fasciatum (Kleber 1875)           | X   |     |     |     |     |
| Astyanax lacustris (Kleber 1875)           | X   |     |     |     |     |
| Astyanax ritteri (Kleber 1875)             | X   |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOPIMELODIDAE**                |     |     |     |     |     |
| Family Auchenipteridae                     |     |     |     |     |     |
| **ORDER HAPLOPSIIDAE**                     |     |     |     |     |     |
| Haplocheilos sp.                           |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CIPRINODONTIFORMES**               |     |     |     |     |     |
| Family Characidae                          |     |     |     |     |     |
| Astyanax fasciatum (Kleber 1875)           | X   |     |     |     |     |
| Astyanax sp.                               |     |     |     |     |     |
| Family Cichlididae                         |     |     |     |     |     |
| Astronotus daltoni (Kleber 1875)           | X   |     |     |     |     |
| Astronotus sp.                             |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
| **ORDER Auchenipteridae**                  |     |     |     |     |     |
| **ORDER PSEUDOCATFISHES**                  |     |     |     |     |     |
| Family Pseudocatfishes                     |     |     |     |     |     |
| Pseudonannostes sp.                        |     |     |     |     |     |
| **ORDER CICHLIDAE**                        |     |     |     |     |     |
| Cichlasoma altum                           |     |     |     |     |     |
| Cichlasoma englesi (Kleber 1875)           | X   |     |     |     |     |
| Cichlasoma sp.                             |     |     |     |     |     |
**Figure 4.** Representative species belonging to the Characiformes, Siluriformes, Gymnotiformes, Cichliformes and Synbranchiformes orders from the Rio Carinhana basin. ML = Maximum length recorded by Froese & Pauly (2020). * Maximum length of Bryconops sp. was obtained by measuring specimens collected in the Rio Carinhana basin. Photos: Gilberto N. Salvador and Ruanny Casarim.
Siluriformes

*Hypostomus margaritifer* (ML = 33 cm)  
*Pterygoplichthys etentaculatus* (ML = 30 cm)  

*Bagropsis reinhardtii* (ML = 22 cm)  
*Cephalosilurus fowlerii* (ML = 40 cm)  

*Lophiosilurus alexandri* (ML = 72 cm)  
*Franciscodors marmoratus* (ML = 36 cm)  

*Centromochlus bockmanni* (ML = 4.8 cm)  
*Phenacorhamdia tenebrosa* (ML = 7.5 cm)  

*Figure 4. Continued.*
Figure 4. Continued.

Salvador, G.N. et al.: Ichthyofauna of the Rio Carinhanha basin

Gymnotiformes

Eigenmannia besouro (ML = 14.8 cm)  
Sternopygus macrurus (ML = 141 cm)

Gymnotus gr. carapo (ML = 76 cm)

Perciformes

Geophagus brasiliensis (ML = 28 cm)  
Cichlasoma sanctifranciscense (ML = 8.8 cm)

Crenicichla lepidota (ML = 20.9 cm)

Synbranchiformes

Synbranchus sp. (ML = 150 cm)
2002). The undescribed Characidium has, so far, only been recorded for the Lagoa Bonita, a water body that is connected with the surrounding veredas only during the peak of the rain season. Therefore, preservation of the area in which the species has been recorded, and the identification of new potential sites where it may occur, are necessary for description and conservation of this undescribed species.

Despite recording a similar number (five species) of non-native species to the average observed in other tributaries of the Rio São Francisco (Alves & Leal, 2010), their occurrence in the Rio Carinhanga was restricted to the lower section of the basin. The introduction of these species have occurred at different points in the São Francisco basin (Alves & Leal, 2010; Pompeu & Godinho, 2003; Salvador Jr. & Silva, 2011). The area where this group of species was recorded coincides with the most anthropogenic disturbed section of the basin (Borges & Santos, 2009), which increases the probability of introduction. However, natural dispersal, which is a further step in establishing viable populations in the invaded environment (Blackburn et al., 2011), may also be the source of non-native species in the basin.

Of the great migratory fish species of the Rio São Francisco, only Conorynchos conirostris was not registered in this study, and there are no recent records of such species for the section close to the Rio Carinhanga (Alves & Bockmann, 2008). Prochilodus spp. were found in practically the entire length of the Rio Carinhanga, indicating the absence of natural barriers. These species, which represent a large part of the fish biomass of the Rio São Francisco (Sato & Godinho, 2003), were recorded from the Grande Sertão Veredas Park area to the region near the mouth. However, records of P. corruscans, B. orthotaenia, and S. franciscanus were restricted to the lower section of the basin.

The Rio Carinhanga basin is home to 27% of the threatened fish species of the Rio São Francisco (Vieira et al., 2020).
et al., 2008; MMA, 2014; IUCN, 2015) (excluding rivulid fishes), a value close to that observed for the Rio Pandeiros and Rio Paraopeba basins, but lower than that observed for the Rio das Velhas (Alves & Leal, 2010). The catfish *B. reinhardtii* was the only threatened species recorded in the most conserved section of the basin (Borges & Santos, 2009). The preference for larger environments may be the main reason for the absence of other endangered species in the upper section. Spatial segregation between the two *Brycon* species is commonly observed in the Rio São Francisco basin, with *B. orthotaenia* tending to occupy the lower sections of the tributaries and the main river channel (Lima, 2017). On the other hand, *L. alexandri* inhabits more lentic environments (Santos et al., 2013), which are more common in lower sections.

The observed similarity between the main river channel and floodplain lagoons can be explained by the connectivity between these two environments during the flood pulses. Moreover, a similarity between streams and *veredas* is expected, since *veredas* are generally associated with smaller water bodies (Boaventura, 1981). The *veredas* have an important ecological significance, but they have been heavily impacted by human action (Drummond et al., 2005). Their conservation in the Carinhanka basin can allow the protection of an important portion of the basin’s fish species, since there is a high intraspecific variation in the ichthyofauna in this habitat. The segregation of the ichthyofauna from Lagoa Bonita, a permanent pond, is due to its low richness and the recording of an undescribed species (*Characium* sp.), which is so far only known for this habitat.

The fish species richness recorded during the present study represents 97% of the estimated richness for the Carinhanka basin by Jackknife methodology, reflecting the stabilization of the species accumulation curve. This reflects the sampling effort in different habitats, like the main river channel, floodplain lagoons, and streams. However, we expect an increase in the number of species with additional collections in the basin, especially in poorly sampled habitats, like floodplain lagoons and streams. The absence of collections in streams located in the lower section of the basin should also be highlighted, where there is a predominance of tropical dry forest.

In this region, located in the north of the Minas Gerais state, many streams are intermittent (Paiva, 1982) and there was no flow during the period when the surveys were done.

This study provides evidence for the importance of inventorizing the still poorly explored tributaries in the upper-middle section of the Rio São Francisco. In addition to presenting a rich fish fauna, this region may harbor species new to science, as was observed in this study. Because there are important lotic remnants, this area still contains important populations of migratory fish, as well as species threatened with extinction. Knowledge of the ichthyofauna in a key for more sound discussions about the conservation of fishes in the Rio Carinhanka basin, expanding alternatives to maintain fish biodiversity in the upper-middle section of the Rio São Francisco.

**AUTHOR CONTRIBUTIONS**

Gilberto Nepomuceno Salvador conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft. Gustavo Ribeiro Rosa analyzed the data, authored or reviewed drafts of the paper, and approved the final draft. Ruanny Casarim conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft. Yuri Malta Caldeira conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft. Paulo Santos Pompeu conceived and designed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.

**ACKNOWLEDGEMENTS**

We would like to thank Catumbi Energia, the Fundação Grupo Boticário de Proteção à Natureza, and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for financial support. We would also like to thank our colleagues Luiz Sergio Ferreira Martins and Laura V. França, managers of the Grande Sertão Veredas National Park at the time when the present study was conducted. Daniel Tregidgo and Jessica Schulte for reviewing the English, and Iago Penido for his helpful input. We also thank the residents of many places (Porto Cajueiro, Lodo, Cachoeira do Gibão, Pitarana) who welcomed us, let us set up camp in the backyard of their houses, and told us stories of the fish and the river. We would also like to thank the fisherman Edivaldo Esteves, a natural companion in fieldwork and a teacher of the art of fishing. PSP received research fellowships from CNPq (CNPq Nº 303548/2017-7) and FAPEMIG ( Nº PPM-00608/15).

**REFERENCES**

Alves, C.B.M. & Bockmann, F.A. 2008. Conorynchus conirostris. In: Rosa, R.S. & Lima, F.C.T. Livro vermelho da fauna brasileira ameaçada de extinção: Peixes. Brasília, Ministérios do Meio Ambiente. v. 6, p. 226-228.

Alves, C.B.M. & Leal, C.G. 2010. Aspectos da conservação da fauna de peixes da bacia do rio São Francisco em Minas Gerais. MG Biota, 2: 26-44.

Alves, C.B.M. & Pompeu, P.S. 2010. A fauna de peixes da bacia do rio das Velhas no final do século XX. In: Alves, C.B.M. & Pompeu, P.S. Peixes do rio das Velhas: passado e presente. Belo Horizonte, Argventurm, 167-169.

Alves, C.B.M.; Vieira, F. & Pompeu, P.S. 2009. Ictiofauna da Bacia Hidrográfica do Rio São Francisco. In: Vizinnt, R.R. Programa Zonamento Ecologico-Econômico: Caderno Temático – Biodiversidade. Brasilia, Ministério do Meio Ambiente/SEDR/SEB, p. 110-130.

Alves, C.B.M.; Vieira, F. & Pompeu, P.S. 2011. Ictiofauna da bacia hidrográfica do rio São Francisco. In: Ministério do Meio Ambiente Diagnostico do macrozona suno-ecológico da bacia hidrográfica do rio São Francisco. Brasilia, Ministério do Meio Ambiente. p. 226-241.
Barbosa, J.M.; Soares, E.C.; Cinfra, I.H.A.; Hermann, M. & Araújo, A.R.R. 2017. Perfil da ictiofauna da bacia do rio São Francisco. Acta of Fisheries and Aquatic Resources, 5(1): 70-90.

Belei, F.; Santana Sampaio, W.M.; Giongo, P. & Dergam, J. 2016. Ictiofauna de área prioritária para conservação, Médio São Francisco, Minas Gerais, sudeste do Brasil. Neotropical Biology & Conservation, 11(2): 94-100.

Blackburn, T.M.; Pyšek, P.; Bacher, S.; Carlton, J.T.; Duncan, R.P.; Jarosík, V.; Wilson, J.R.U. & Richardson, D.M. 2011. A proposed unified framework for biological invasions. Trends in Ecology & Evolution, 26(7): 333-339.

Boaventura, R.S. 1981. Contribuição aos estudos sobre a evolução das veredas. In: Fundação Centro Tecnológico de Minas Gerais (Orgs.). Segundo plano de desenvolvimento integrado no Noroeste Mineiro — Informe Técnico. Belo Horizonte, CETEC. v. 3. p. 13-17.

Borges, K.M.R. 2009. Avaliação da suscetibilidade erosiva da bacia do rio Carinhanga (MG-BA) por meio de EUPS – Equação Universal de Perda de Sois. (Masters Dissertation). Brasília, Universidade de Brasília.

Borges, K.M.R. & Santos, P.M.C. 2009. Modelo Linear de Mistura Espetral – MLME aplicado ao monitoramento do Cerrado, Bacia do rio Carinhanga (MG-BA). In: Epiphanio, J.C.N. & Galvão, L.S. (Eds.). Simpósio Brasileiro de Sensoriamento Remoto, 14º. Anais. São José dos Campos, Instituto Nacional de Pesquisa Espacial. p. 5663-5669.

Britski, H.A.; Sato, Y. & Rosa, A.B.S. 1988. Manual de identificação de peixes da região de Três Marias. Brasília, CODEVASF.

Casatti, L. & Castro, R.M.C. 1998. A fish community of the São Francisco River headwaters riffles, southeastern Brazil. Ichthyological Exploration of Freshwaters, 9(3): 229-242.

Costa, W.J.E.M. 2002. Peixes anuais brasileiros: diversidade e conservação. Curitiba, Editora UFRP.

Domingos, F.F.T.; Thomé, R.G.; Ribeiro, R.M.A.; Souza, H.A.V. & Santos, H.B. 2013. Assessment of fish assemblage in an urban system, Itapetereca River, upper São Francisco River basin, Divínopolis, Minas Gerais, Brazil. Check List, 9(3): 482-486.

Drummond, G.M.; Martins, C.S.; Machado, A.B.M.; Sebão, F.A. & Antonini, Y. 2005. Biodiversidade em Minas Gerais: um atlas para sua conservação. Belo Horizonte, Fundação Biodiversitas.

Dudley, N. 2008. Guidelines for applying protected area management categories. Switzerland, International Union for Conservation of Nature. 143p. (Best Practice Protected Area Guidelines Series, n. 21) Disponível em: https://portals.iucn.org/library/sites/library/files/documents/PAG-021.pdf.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). 2012. O cerrado. Available at: http://www.cpac embrapa.br/unidade/ocerrado. Access in: 10/01/2018.

Fricke, R.; Eschmeyer, W.N. & Van der Laan, R. 2020. Catalog of fishes: genera, species, references. Available at: http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. Access in: 03/03/2020.

Froese, R. & Pauly, D. 2020. FishBase. Available at: http://www.fishbase.org. Access in: 10/09/2019.

Gaspar, M.T.P.; Campos, J.E.G. & Cadamuro, A.L.M. 2007. Condições de infiltração em solos na região de recarga do sistema aquífero Urucuia no oeste da Bahia sob diferentes condições de usos. Revista Brasileira de Geociências, 37: 542-550.

Godinho, A.L. & Godinho, H.P. 2003. Breve visão do São Francisco. In: Godinho, H.P. & Godinho, A.L. (Eds.). Aguas, peixes e pescadores do São Francisco das Minas Gerais. Belo Horizonte, Editora PUC Minas. p. 15-24.

Instituto Brasileiro de Geografia e Estatística (IBGE). 2007. Inventário da biodiversidade do bioma Cerrado: peixes do Parque Nacional Grande Sertão Veredas – MG/GO. Rio de Janeiro, Instituto Brasileiro de Geografia e Estatística.

International Union for Conservation of Nature and Natural Resources (IUCN). 2015. The IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. Access in: 02/09/2015.

Karr, J.R. & Schlosser, I.J. 1978. Water resources and the land-water interface. Science, New York, 201: 229-34.

Lima, C.F.T. 2017. A revision of the cis-andean species of the genus Brycon Müller & Troschel (Characiformes: Characidae). Zootaxa, 4222(1): 1-189.

Lowe-McConnell, R.H. 1987. Ecological studies in tropical fishes communities. Cambridge, Cambridge University Press.

Luz, S.C.; Lima, H.C. & Severi, W. 2012. Composição da ictiofauna em ambientes marginais e tributários do médio-médio rio São Francisco. Revista Brasileira de Ciências Agrárias, 7(2): 358-366.

Mendes, L.A.; de Barros, M.T.L.; Zambon, R.C. & Yeh, W.W-G. 2015. Trade-off analysis among multiple water uses in a hydropower system: case of São Francisco River Basin, Brazil. Journal of Water Resources Planning and Management, 141(10): 04015014-1-04015014-10.

Menezes, N.A.; Weitzman, S.H. & Teixeira, T.F. 2016. Redescription of Hysterotonus megalostomus (Characiformes: Characidae: Stevardiinae), a poorly known characid from tributaries of the Rio São Francisco, Brazil with comments on the conservation of the species. Journal of Fish Biology, 89(1): 495-509.

Ministério do Meio Ambiente (MMA). 2014. Portaria MMA Nº 445: lista nacional das espécies de invertebrados aquáticos e peixes ameaçados de extinção. Brasília, Ministério do Meio Ambiente. Disponível em: https://www.icmbio.gov.br/portal/images/stories/docs/plano-de-acao-ARQUIVO/00-saiba-mais/05 - PORTARIA MMA Nº 2%20BA 445 - DE 17 DE DEZ DE 2014.pdf.

Ministério do Meio Ambiente (MMA)/Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). 2003. Plano de manejo do Parque Nacional Grande Sertão Veredas. Brasília, Ministério do Meio Ambiente/Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais.

Moraes, M.B.R. 2011. Implementação das Áreas de Proteção Ambiental Federais no Brasil: o enfoque da gestão. (Doctoral Thesis), Universidade de São Paulo, São Paulo.

Oksanen, J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; McGlinn, D.; Minchin, P.R.; O’Hara, R.B.; Simpson, G.L.; Solymos, P.; Henry, M.; Stevens, H.; Szoecs, E. & Wagner, H. 2013. Package ‘vegan’. Community ecology package, 2(9): 1-295.

Paiva, M.P. 1982. Grandes represas do Brasil. Brasília, Editora.

Pereira, S.B.; Pruski, F.F.; Silva, D.D. & Ramos, M.M. 2007. Estudo do comportamento hidrológico do Rio São Francisco e seus principais afluentes. Revista Brasileira de Engenharia Agrícola e Ambiental, 22: 615-622.

Pompeu, P.S. & Godinho, H.P. 2003. Ictiofauna de três lagos marginais do médio São Francisco. In: Godinho, H.P. & Godinho, A.L. Aguas, peixes e pescadores do São Francisco das Minas Gerais. Belo Horizonte, Editora PUC Minas. p. 167-181.

Prado, I.G. & Pompeu, P.S. 2014. Vertical and seasonal distribution of fish in Três Marias reservoir. Lake and Reservoir Management, 30(4): 393-404.

R Core Team. 2015. R: A Language and Environment for Statistical Computing. Available at: https://www.R-project.org. Access in: 15/03/2018.

Reis, R.E.; Albert, J.S.; Di Dario, F.; Mincarone, M.M.; Petry, P. & Rocha, L.A. 2011. Biota aquática: áreas e ações prioritárias para a conservação. Belo Horizonte, Editora UFPR.

Rodrigues, J.C.N. & Galvão, L.S. (Eds.). Implementação das Áreas de Proteção Ambiental Federais no Brasil: o enfoque da gestão. (Doctoral Thesis), Universidade de São Paulo, São Paulo.

Salvador, G.N. et al.: Ichthyofauna of the Rio Carinhanha basin.
Supplementary Materials 1

Sampled sites along the Rio Carinhanha basin grouped by habitat. For each site, the table shows its geographic coordinates, altitude, and Strahler order.

| Group               | Latitude  | Longitude  | Alt. (m) | Order |
|---------------------|-----------|------------|----------|-------|
| Main river channel (MRC) |           |            |          |       |
| 15°01′35″S         | 45°38′38″W | 695        | 5        |
| 14°46′23″S         | 45°13′53″W | 675        | 5        |
| 14°41′41″S         | 45°2′44″W  | 628        | 5        |
| 14°39′57″S         | 44°59′51″W | 619        | 5        |
| 14°32′34″S         | 44°50′44″W | 569        | 5        |
| 14°19′40″S         | 44°30′59″W | 489        | 5        |
| 14°17′06″S         | 44°4′18″W  | 451        | 6        |
| 14°17′19″S         | 43°56′55″W | 449        | 6        |
| 14°10′37″S         | 44°45′12″W | 539        | 4        |
| 14°16′40″S         | 44°28′16″W | 496        | 5        |
| 14°25′05″S         | 44°27′55″W | 453        | 5        |
| 14°16′10″S         | 44°10′29″W | 520        | 5        |
| veredas (VER)      |           |            |          |       |
| 14°50′14″S         | 45°16′52″W | 684        | 3        |
| 15°17′49″S         | 45°54′10″W | 753        | 2        |
| 15°11′24″S         | 45°33′13″W | 725        | 2        |
| 15°10′33″S         | 45°41′10″W | 745        | 2        |
| 15°13′50″S         | 45°38′56″W | 750        | 3        |
| 15°07′01″S         | 45°28′12″W | 726        | 4        |
| Streams (STR)      |           |            |          |       |
| 15°18′38″S         | 45°57′27″W | 760        | 3        |
| 14°36′08″S         | 44°51′49″W | 605        | 3        |
| 15°19′03″S         | 45°59′05″W | 787        | 3        |
| Floodplain lagoons (FPL) |       |            |          |       |
| 14°17′03″S         | 43°57′12″W | 450        |          |
| 14°19′13″S         | 43°47′30″W | 439        |          |
| Permanent ponds (PON) |       |            |          |       |
| 14°48′31″S         | 44°56′52″W | 691        |          |
| 15°02′01″S         | 45°34′10″W | 706        |          |
### Supplementary Materials 2

Species vouchers of fishes caught in the Rio Carinhanha basin. Acronyms: MCNIP (Museu de Ciências Naturais da PUC Minas); CI-UFLA (Universidade Federal de Lavras); ZUEC (Museu de Zoologia da Universidade de Campinas); ANSP (The Academy of Natural Sciences of Drexel University – from Menezes et al., 2016).

| Species | Voucher |
|---------|---------|
| Acestrotrynchus britskii | MCNIP 1576 |
| Acestrotrynchus laciustris | MCNIP 1736 |
| Anchovella vaillanti | MCNIP 1575 |
| Apareiodon hasemani | MCNIP 1764/1766 |
| Apareiodon sp.A | MCNIP 1765 |
| Astyanax cf. bockmanni | CI-UFLA 0929 |
| Astyanax fasciatus | CI-UFLA 0930 |
| Astyanax laciustris | CI-UFLA 0931 |
| Astyanax rivalis | CI-UFLA 0932 |
| Bagnopis reinhardtii | MCNIP 1561 |
| Bryconops sp. | MCNIP 1745 |
| Brycon orthotaenia | ZUEC 9189 |
| Centromochlus bockmanni | CI-UFLA 0935 |
| Cephalosilurus fowleri | MCNIP 1734 |
| Cetoptehamia iheringi | CI-UFLA 0936 |
| Characidium | MCNIP 1629 |
| Characidium cf. zebra | CI-UFLA 0937/MCNIP 1579 |
| Characidium fasciatus | CI-UFLA 0938 |
| Cichlasoma sanctifranciscense | MCNIP 1573/CI-UFLA 0939 |
| Compsura heterura | MCNIP 1772 |
| Coptodon rendalli | MCNIP 1767 |
| Corydoras garbei | CI-UFLA 0940 |
| Corydoras lymnades | MCNIP 1567 |
| Corydoras multicuaudios | MCNIP 1568 |
| Crenicichla lepidota | MCNIP 1572/1578 |
| Curimatella lepidura | MCNIP |
| Eigenmannia bussoro | CI-UFLA 0941 |
| Franciscodoras mammoratus | MCNIP 1753 |
| Geophagus brasiliensis | CI-UFLA 0942 |
| Gymnotus gr. cano | CI-UFLA 0943 |
| Harouta longipinna | MCNIP 1749 |
| Hasemanus nana | MCNIP 1769 |
| Hemigrammus gr. cacilis | MCNIP 1746/1768 |
| Hemigrammus marginatus | CI-UFLA 0946 |
| Himantostomus vespucii | MCNIP |
| Hisonatus sp. | CI-UFLA 0947 |
| Hoploerythrinus unitaeniatus | MCNIP 1750 |
| Hoplias intermedius | MCNIP 1559 |
| Hoplias malabaricus | MCNIP 1739 |
| Hoplosternum littorale | MCNIP 1735 |
| Hyphessobrycon micropterus | MCNIP 1741 |
| Hypostomus affinis | MCNIP 1552/1556 |
| Hypostomus amboinensis | MCNIP 1737 |
| Hypostomus bockmanni | MCNIP 1572 |
| Hypostomus brasilensis | MCNIP 1555 |
| Hypostomus caudimaculatus | MCNIP 1748 |
| Hypostomus caudimaculatus | CI-UFLA 0952 |
| Hypostomus brasilensis | MCNIP 1546/1547 |
| Hypostomus brasilensis | MCNIP 1747 |
| Hypostomus brasilensis | MCNIP 1744 |
| Hypostomus affinis | MCNIP 1738 |
| Hypostomus affinis | MCNIP 1560 |
| Hypostomus affinis | MCNIP 1743 |
| Hypostomus affinis | MCNIP 1594 |
| Hypostomus affinis | MCNIP 1564 |
| Hypostomus affinis | MCNIP 1598 |
| Hypostomus affinis | MCNIP 1770 |
| Hypostomus affinis | MCNIP 1771 |
| Hypostomus affinis | MCNIP 1566 |
| Hypostomus affinis | MCNIP 1753 |
| Hypostomus affinis | MCNIP 1548 |
| Hypostomus affinis | MCNIP 1549 |
| Hypostomus affinis | MCNIP 1564 |
| Hypostomus affinis | MCNIP 1598 |
| Hypostomus affinis | MCNIP 1582 |
| Hypostomus affinis | MCNIP 1751 |
| Hypostomus affinis | MCNIP 1557 |
| Hypostomus affinis | MCNIP 1530/1577 |
| Hypostomus affinis | MCNIP 1590 |
| Hypostomus affinis | MCNIP 1596 |
| Hypostomus affinis | MCNIP 1580 |
| Hypostomus affinis | MCNIP 1558 |
| Hypostomus affinis | MCNIP 1574 |
| Hypostomus affinis | MCNIP 1598 |
| Hypostomus affinis | CI-UFLA 0962 |
| Hypostomus affinis | CI-UFLA 0963 |
| Hypostomus affinis | MCNIP 1740 |
| Hypostomus affinis | MCNIP 1571 |
| Hypostomus affinis | MCNIP 1581 |

---

Published with the financial support of the “Programa de Apoio às Publicações Científicas Periódicas da USP”