



Broad and fine-scale threats on threatened Brazilian freshwater fish: variability across hydrographic regions and taxonomic groups

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Abstract: Anthropogenic environmental changes are the main cause of species extinction during the Holocene. Species have been exposed to major source of threats, such as habitat loss and fragmentation, pollution, introduced species, and harvesting, many of which are derived from specific anthropogenic activities, such as urbanization, agriculture, and damming (*i.e.* fine-scale threats). However, the importance of these threats on the species conservation status in a given region depends on the type of impacts they are exposed to and the susceptibility of species to these impacts. In this study, we used a database of threatened Brazilian freshwater fish species to test whether the major source of threats and the specific anthropogenic impacts to species vary across hydrographic regions and taxonomic groups. Our results showed that habitat loss is a ubiquitous major threat jeopardizing the conservation status of the Brazilian fish species. However, different fine-scale threats mediate this process across hydrographic regions and taxonomic groups. The combination of impacts from agriculture, deforestation, and urbanization affects most of the threatened species in the basins of the Northeast, South, and Southeast, including the species of the most threatened order, the Cyprinodontiformes. Damming is the main human activity affecting threatened species of Siluriformes, Characiformes, Gymnotiformes, and Cichliformes, especially in northern basins (Amazon and Tocantins-Araguaia). Therefore, we found that specific fine-scale threats influencing threatened species vary across hydrographic regions and taxonomic groups, probably due to geographic variability in the incidence of human activities and differential niche requirements and vulnerability of species to these activities.

Keywords: Aquatic biodiversity; Conservation; Habitat loss.

Ameaças em ampla e fina escala sobre peixes de água doce ameaçados de extinção do Brasil: variabilidade entre regiões hidrográficas e grupos taxonômicos

Resumo: Alterações ambientais antropogênicas são a principal causa de extinção das espécies no Holoceno. As espécies têm sido expostas à diferentes fontes de ameaças principais, tais como a perda e fragmentação de habitat, poluição, introdução de espécies e coleta de organismos, muitas das quais são decorrentes de atividades antropogênicas específicas, tais como urbanização, agricultura e represamento (*i.e.* ameaças de escala fina). Entretanto, a importância dessas ameaças no estado de conservação das espécies em uma dada região depende do tipo de ameaça que as espécies são expostas e da susceptibilidade das espécies a esses impactos. Neste estudo, utilizamos a base de dados de espécies de peixes dulcícolas do Brasil ameaçadas de extinção para testar se as principais ameaças e os impactos específicos às espécies variam entre as regiões hidrográficas e grupos taxonômicos. Nossos resultados mostraram que a perda de habitat é uma ameaça principal ubíqua, prejudicando o estado de conservação das espécies de peixes do Brasil. Entretanto, diferentes ameaças de escala mais fina mediam este processo entre as regiões hidrográficas e grupos taxonômicos. A combinação de impactos provenientes da agricultura, desmatamento e urbanização afeta a maior parte das espécies ameaçadas nas bacias do Nordeste, Sul e Sudeste, incluindo as espécies da ordem mais ameaçada, os Cyprinodontiformes. O represamento dos rios é a principal atividade humana afetando as espécies ameaçadas de Siluriformes, Characiformes, Gymnotiformes e Cichliformes, especialmente nas bacias do norte (Amazônica e Tocantins-Araguaia). Portanto, as ameaças em escala fina que afetam as espécies ameaçadas variam entre as regiões hidrográficas e grupos taxonômicos, provavelmente devido à variabilidade geográfica na incidência das atividades de impacto humano e em função das diferenças nos requerimentos de nicho e vulnerabilidade das espécies a essas atividades.

Palavras-chave: Biodiversidade aquática; Conservação; Perda de habitat..

Introduction

Freshwater ecosystems have been negatively impacted by various anthropogenic actions (Dudgeon et al. 2006). The most deleterious threats to freshwater fish are habitat modification, fragmentation and destruction, pollution, introduction of nonnative species, and climate change (Barletta et al. 2008; Arthington et al. 2016). As consequence, freshwater biota has suffered higher extinction rates than terrestrial and marine in the last decades (Jenkins 2003, Dirzo et al. 2014). The effects of these major threats are derived from human impacting activities (i.e. fine-scale threats) (Venter et al. 2016) whose impacts are context-dependent, since their occurrences and intensities show geographic variability (Vörösmarty et al. 2010). Furthermore, species also exhibit differential susceptibility to impacts according to their biological traits (e.g. reproduction, feeding strategies) (Olden et al. 2007, Castro & Polaz 2020). Therefore, intrinsic (i.e. biological traits) and extrinsic factors (e.g. type of impact) are important drivers of species vulnerability (Olden et al. 2007).

Growing agricultural expansion, the hydropower-based energy matrix and the disorderly growth of urban centers in Brazil (Martinelli et al. 2010, Soito & Freitas 2011, Cunico et al. 2012) expose fish to many types of threats. The intensity of these threats varies regionally, probably as the result of predominant economic activities in each region. For example, there are several hydropower plants planned for the Amazon basin in the coming years, representing an important potential threat for many species (Miesen et al. 2010, Feamside 2012). Meanwhile, most of rivers of Paraná, Southeast and South Atlantic hydrographic regions are already severely impacted by dams long ago (Agostinho et al. 2007). In these regions, other threats have emerged as current main threats, such as urbanization, impacts derived from expansion of livestock and agriculture and introduction of non-native species (Pereira et al. 2017; Castro & Polaz 2020).

Many of biological traits important for the response of species to disturbance are phylogenetically conservative (Olden et al. 2007, Forero-Medina et al. 2009, Vilela et al. 2014). As consequence, the response to impacts can be similar among species of the same phylogenetic group. For example, species of Rivulidae that occur in temporary habitats, usually near urban centers or heavily mechanized agricultural areas, tend to be susceptible to habitat loss and pollution (Costa 2002, 2007, 2009, Castro & Polaz 2020). To cite another example, species of large-size of Siluriformes and Characiformes have been historically overexploited in some regions with several examples of local extirpation (Hoeinghaus et al. 2009).

In this study, we benefit from the national conservation status assessment conducted by the federal environmental agency, the Chico Mendes Institute for Conservation of Biodiversity - ICMBio, which assessed the risk of extinction for all valid freshwater fish species in Brazil (ICMBio 2018). We compiled information of broad and fine-scale threats reported as justification for the conservation status of all 311 threatened species and tested if these threats vary across hydrographic regions and taxonomic groups. We expected that the importance of different types of threats to threatened species varies among hydrographic basins, reflecting the differential incidence of types of anthropogenic interferences within regions. Additionally, we expect environmental impacts to be associated with specific taxonomic groups, reflecting differences in species susceptibility to different threats.

Materials and Methods

1. Data

We compiled information regarding threats, species range and taxonomic information for the 311 continental threatened Actinopterygii

species of Brazil listed in the Brazilian Red Book (ICMBio 2018). Threatened species included species classified as Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) (IUCN 2012).

The political delimitation of the geographical area (Brazil) is justified by the availability of high-quality information on the extinction risk to species and respective major and fine-scale threats. These data were products from workshops conducted by the Chico Mendes Institute for Conservation of Biodiversity - ICMBio, which assessed the risk of extinction of all fish species in Brazil, supported by hundreds of specialists and published in its final version in the Brazilian Red Book of Threatened Species of Fauna (Chapter VI: Fishes) (ICMBio 2018). Moreover, the geographical area considered includes many river basins that correspond to the important ecoregions for aquatic biodiversity within the Neotropical region (Abell et al. 2008).

Information about the threats was obtained from the justification for the conservation status of each species available from ICMBio (2018). We assigned each species to one or more major threats: habitat loss, habitat fragmentation, pollution, harvesting, and introduced species (Table 1). We were able to identify at least one of the major threats for 308 (99%) of the 311 threatened species. Habitat loss and fragmentation and pollution can be consequences of several specific human impacting activities (e.g. urbanization, agriculture, damming) (Venter et al. 2006, Evans et al. 2011). In order to take these specific impacts into account, we also assigned threatened species in relation to fine scale categories of threats: agriculture, damming, deforestation, ecotourism, harvesting, introduced species, mineral extraction, siltation, urbanization, and water extraction (Table 1); this was possible for 295 (94.8%) of the 311 threatened species.

Species occurrences in river basins were obtained from the Catalog of Fishes database (<http://researcharchive.calacademy.org>) and ICMBio (2018). Species were then assigned to Brazilian hydrographic regions following the National Water Agency (ANA 2017).

2. Data analysis

We used a Chi-square test to test whether the proportion of species affected by different types of human activities varies across taxonomic groups. To represent the taxonomic group, we considered the order level. In order to test the association between the human activities influencing threatened species with the species occurrence in the hydrographic regions, we carried out a redundancy analysis (RDA). We used a matrix of presence of each species across hydrographic regions as response and a matrix of human activities representing the fine-scale threats as explanatory variable. We used the RDA instead canonical correspondence analysis (CCA) because the length of the gradient of the response variable was lower than four as estimated by detrended correspondence analysis (DCA) (ter Braak & Šmilauer 2002). We used Monte Carlo permutation test for significance at $p < 0.05$.

Results

The number of threatened species and the proportion of species of each order varied across hydrographic regions (Figure 1). Hydrographic regions with the highest number of threatened species were Southeast Atlantic, followed by Paraná, Tocantins-Araguaia, São Francisco, and Amazon. In relation to the taxonomic groups, Cyprinodontiformes was the order with highest number of threatened species (43.4% of

Table 1. Definition of major threats and human activities (fine-scale threats) negatively influencing Brazilian threatened fish species. Classification and definitions were partially derived from Venter et al. (2006) and Evans et al. (2011).

| Threats | Description |
|--|---|
| Major threats | |
| Habitat loss | Reduction or degradation of habitat due to deforestation, agricultural and livestock activities, urbanization, mining, siltation, infrastructure construction, extractive activities, and human disturbance |
| Habitat fragmentation | Reduction or interruption of connectivity between habitat patches, impairing fish movement and colonization |
| Pollution | Pesticides, herbicides, domestic and industrial effluents |
| Harvesting | Fishing and collection for aquarium purposes |
| Introduced species | Negative effects of nonnative species due to competition and predation |
| Human activities / fine-scale threats | |
| Agriculture | Crops, wood plantations, non-timber plantations, livestock (including ranching) |
| Damming | Construction of dams and impoundments |
| Deforestation | Logging of native vegetation within the catchment area |
| Ecotourism | Habitat alteration due to intensive tourist visitation |
| Mineral extraction | Mining and sand extraction |
| Siltation | Alteration of riverbed due to the deposition of terrestrial clastic material |
| Urbanization | Development of human settlements (urban, suburban, and rural), industrial and commercial buildings and roads |
| Water extraction | Draining, landfilling, depletion of groundwater and aquifers |

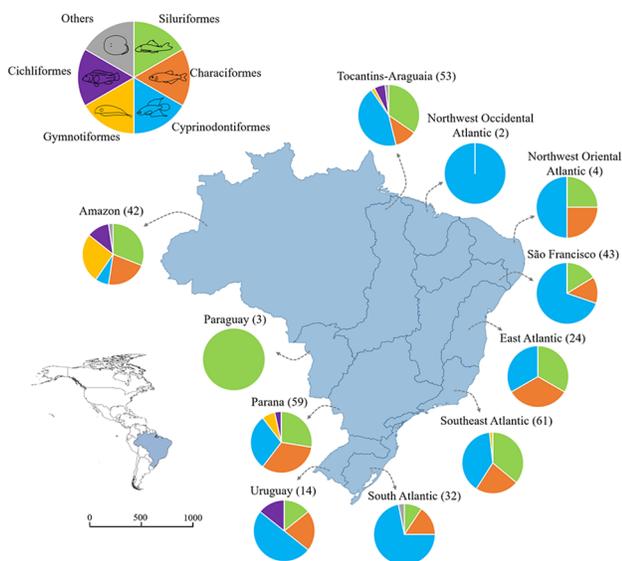


Figure 1. Distribution of the threatened freshwater fishes listed in the Brazilian Red Book among orders and hydrographic regions. Number in parenthesis represent the total number of threatened species in the respective hydrographic region. Others orders comprise Atheriniformes, Batrachoidiformes, and Myliobatiformes.

all threatened species), followed by Siluriformes, Characiformes, Gymnotiformes, and Cichliformes (28.0, 18.3, 5.5, and 3.9% of all threatened species, respectively). Other orders represent 1.0% of the threatened species. Cyprinodontiformes, mainly species of Rivulidae, were dominant among the threatened species in all hydrographic regions, except in Amazon, Paraguay and Paraná, where Siluriformes (two formers) and Characiformes (latter) were dominants (Figure 1).

1. Major threats in relation to hydrographic regions and taxonomic groups

Of orders with more than one threatened species, habitat loss was the main threat (ranging from 87.3 to 100% of threatened species across orders), followed by habitat fragmentation (ranging from 0 to 43.8% of threatened species across orders), and pollution (ranging from 8.3 to 26.3% of threatened species across orders) (Table 2). harvesting and introduced species negatively influenced the conservation status of a lower number of species in seven of the eight orders (Table 2).

The threatened species are distributed across 11 of the 12 hydrographic regions of Brazil. Southeast Atlantic, Paraná, and the Tocantins-Araguaia were the hydrographic regions with the highest number of threatened species (55% of all threatened species). Of the major threats, habitat loss was the main threat in all basins (93.2% of all threatened species, ranging from 66.7 to 100% in the individual basins) (Table 3); followed by habitat fragmentation (24.4% of all threatened species, ranging from 0 to 64.3% in the individual basins), and pollution (18.3% of all threatened species, ranging from 0 to 66.7% in the individual basins) (Table 3). Harvesting and introduced species were identified as threats to 5.5 and 3.2% (ranging from 0 to 23.3% in the individual basins) of the threatened species, respectively (Table 3).

2. Fine-scale threats in relation to hydrographic regions and taxonomic groups

Most of species were associated with more than one human activity representing the fine-scale threats. Damming, agriculture, urbanization and deforestation affected the conservation status of the greatest number of species (91% of the threatened species) (Figure 2). Draining, siltation, mining and ecotourism combined were associated with 24.7% of the threatened species, but most of these species (74 of 77) were also

Table 2. Distribution of the threatened freshwater fishes listed in the Brazilian Red Book among their respective orders. Number in parenthesis is the percentage in the respective order.

| Orders | Threatened species | Habitat loss | Habitat fragmentation | Pollution | Harvesting | Introduced species |
|--------------------|--------------------|--------------|-----------------------|-----------|------------|--------------------|
| All orders | 311 | 291 (93.6) | 77 (24.7) | 58 (18.6) | 18 (5.8) | 10 (3.2) |
| Cyprinodontiformes | 135 | 129 (95.6) | 25 (18.5) | 19 (14.1) | 11 (8.1) | 3 (2.2) |
| Siluriformes | 87 | 76 (87.3) | 23 (26.4) | 20 (23.0) | 3 (3.4) | 1 (1.1) |
| Characiformes | 57 | 55 (96.5) | 25 (43.8) | 15 (26.3) | 2 (3.5) | 5 (8.8) |
| Gymnotiformes | 17 | 17 (100) | 0 (0) | 3 (17.6) | 0 (0) | 0 (0) |
| Cichliformes | 12 | 12 (100) | 4 (33.3) | 1 (8.3) | 0 (0) | 0 (0) |
| Atheriniformes | 1 | 0 (0) | 0 (0) | 0 (0) | 1 (100) | 1 (100) |
| Batrachoidiformes | 1 | 1 (100) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Myliobatiformes | 1 | 1 (100) | 0 (0) | 0 (0) | 1 (100) | 0 (0) |

Table 3. Distribution of the threatened freshwater fishes listed in the Brazilian Red Book in relation to the major threats and hydrographic regions. Number in parenthesis is the percentage in the respective hydrographic region. Species may be associated with more than one threat, so that the sum of species across threats may exceed the number of species in each hydrographic region.

| Hydrographic regions | Threatened species | Habitat loss | Habitat fragmentation | Pollution | Harvesting | Introduced species |
|-------------------------------|--------------------|--------------|-----------------------|-----------|------------|--------------------|
| All | 311 | 290 (93.2) | 76 (24.4) | 58 (18.6) | 17 (5.5) | 10 (3.2) |
| Southeast Atlantic | 61 | 53 (86.9) | 23 (37.7) | 23 (37.7) | 3 (4.9) | 3 (4.9) |
| Paraná | 59 | 56 (94.9) | 21 (35.6) | 18 (30.5) | 2 (3.4) | 4 (6.8) |
| Tocantins-Araguaia | 53 | 52 (98.1) | 7 (13.2) | 2 (3.8) | 1 (1.9) | 0 (0) |
| São Francisco | 43 | 36 (83.7) | 9 (20.9) | 10 (23.3) | 10 (23.3) | 2 (4.7) |
| Amazon | 42 | 42 (100) | 1 (2.4) | 0 (0) | 2 (4.8) | 0 (0) |
| South Atlantic | 32 | 28 (87.5) | 13 (40.6) | 4 (12.5) | 2 (6.3) | 3 (9.4) |
| East Atlantic | 24 | 23 (95.8) | 10 (41.7) | 7 (29.2) | 2 (8.3) | 3 (12.5) |
| Uruguay | 14 | 14 (100) | 9 (64.3) | 1 (7.1) | 0 (0) | 0 (0) |
| Northwest Oriental Atlantic | 4 | 4 (100) | 1 (25.0) | 1 (25.0) | 0 (0) | 0 (0) |
| Paraguay | 3 | 2 (66.7) | 0 (0) | 2 (66.7) | 0(0) | 0 (0) |
| Northwest Occidental Atlantic | 2 | 2 (100) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |

influenced by the other more representative threats. The proportion of species of each order differed significantly for four threats (damming, agriculture, urbanization, and siltation). Damming was associated with a higher proportion of Siluriformes, Characiformes, Gymnotiformes, and Cichliformes, $\chi^2 (5, n=308) = 123.9, p < 0.01$. Threatened species of Cyprinodontiformes were mainly influenced by agriculture and urbanization, $\chi^2 (5, n=308) = 12.5, p < 0.02$ (Figure 2). Among the species influenced by siltation, Siluriformes species were the most represented, $\chi^2 (5, n=308) = 20.8, p < 0.01$ (Figure 2). The proportion of species of different orders did not differ for deforestation, draining, mining, and ecotourism, $\chi^2 (5, n=308) = 10.7, p > 0.06$.

Fine-scale threats influencing threatened species were associated with the hydrographic regions (RDA, $p < 0.01$; $R^2 = 0.09$) (Figure 3). Damming was the main human activity associated with threatened species in Amazon; both damming and agriculture influenced the most of species in Tocantins-Araguaia, Northwest Oriental Atlantic, and Uruguay; Agriculture was the main threat in São Francisco, South Atlantic and Paraguay. Urbanization, deforestation and siltation were

associated with threatened species in Paraná, Southeast Atlantic, East Atlantic, and Northwest Occidental Atlantic (Figure 3).

Discussion

We studied how threats influencing the conservation status of Brazilian threatened fish species are distributed across hydrographic regions and taxonomic groups. Habitat loss or degradation are by far the biggest threats to fish, affecting all representative taxonomic groups and hydrographic regions of Brazil. However, by assessing fine scale categories of threats, we found that specific human activities influencing threatened species vary across hydrographic regions, reinforcing the context-dependency of the spatial distribution of threats. The same pattern was observed for taxonomic groups, with some human activities being more influential on specific taxonomic groups, probably reflecting differential vulnerability of species.

Broad and fine-scale threats on threatened fishes

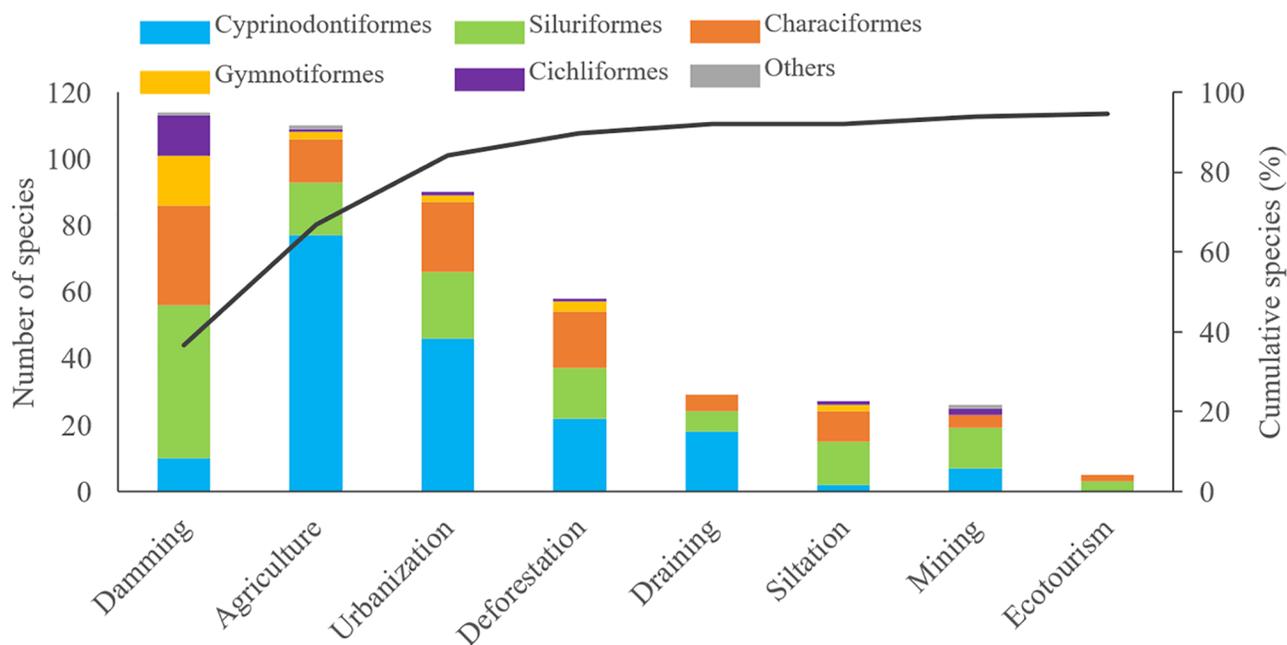


Figure 2. Number of threatened species (bars) and cumulative number of species (line) of each order of fish associated with their respective fine-scale threats.

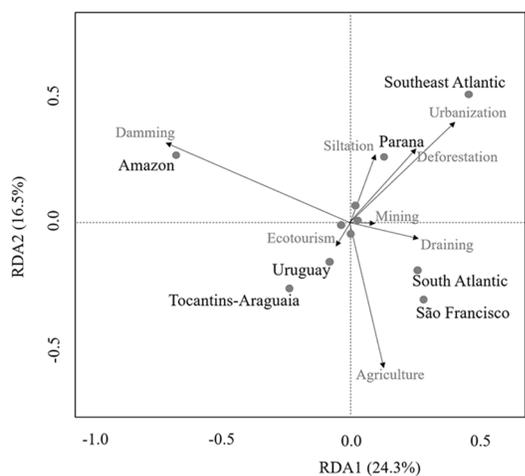


Figure 3. Biplot of Redundancy Analysis of human activities associated with fine-scale threats and hydrographic regions (gray dots). We omitted the name of the four hydrographic regions (Northwest Occidental Atlantic, Northwest Oriental Atlantic, Paraguay, and East Atlantic) which showed weak association with human activities (positioned at the center of biplot).

1. Major threats

Most of threatened species listed in the Brazilian Red Book (ICMBio 2018) have their conservation status justified due to habitat degradation and/or destruction. Damming, deforestation and the conversion of native vegetation into agriculture or urban areas are some of the most important sources of habitat degradation for threatened species. These activities result in changes in physical and chemical aspects of aquatic habitats (Arthington et al. 2016), negatively influencing conditions and resources required by species, especially those with specialized niches

with restricted distribution. In fact, many of the threatened species (most of the Critically Endangered and Endangered) are known from only a few locations, inhabiting specific biotopes which are exposed to potential impact from human activities.

Other major threats such as habitat fragmentation and pollution also affect a considerable number of species. Habitat fragmentation occurs due to the construction of dams, impoundments, road crossings and the draining of wetlands (Gido et al. 2016). As a consequence, the loss of connectivity among habitat patches affects fish movement and colonization dynamics, negatively influencing population persistence and even their capacity to deal with other impacts (Gido et al. 2016, Herrera-R et al. 2020). Pollution was one of the main threats for 18.6% of threatened species. These species usually inhabit small ponds or streams exposed to urban areas, agriculture or mining. The input of effluents from agriculture, industrial or urban areas usually represent additional negative effects for fish populations often already depressed by other threats (i.e. habitat loss and fragmentation).

Among the major sources of threats, harvesting and introduced species were those associated with a lower number of threatened species. Overfishing is a primary source of extinction risk for large species (Dudgeon et al. 2006), especially in marine systems (Dulvy et al. 2003). However, among the Brazilian threatened freshwater fish species, small-sized fishes captured for aquarium purposes (e.g. *Hypsolebias* spp. and *Hypancistrus zebra*) represent most of species which are jeopardized by harvesting. Despite large-sized fishes being preferable targets for fishing, most such species are broadly distributed, so that even though overfishing depresses local populations (Mateus & Penha 2007), persistence in other parts of their distribution results in lower risk under a national wide assessment (Castro & Polaz 2020). In relation to species affected by introduced species, few species were associated this threat (ICMBIO 2018). Altered habitats (e.g. artificial reservoirs) facilitate species introduction and concentrate the majority of introduced species

(Vitule et al. 2012, Pereira et al. 2017), where they are responsible for several impacts at the population, community, and ecosystem level (Vitule et al. 2009; Cucherousset 2011, Agostinho et al. 2015). However, habitat alterations preceding species introduction probably represent the primary drivers of decline of more sensitive species. This is likely the reason why introduced species are not identified as the main threat in many cases. However, it is worth considering that the difficulty of detecting the influence of biotic interactions as drivers of population trends, along with the scarcity of ecological studies on the effects of introductions may contribute to our underestimation of the effects of introduced species.

2. Human activities and fine-scale threats

Several human activities were listed as determinants of the conservation status of Brazilian threatened species. Most of these activities represent the source of the impacts underlying the habitat loss and degradation, the primary major threat for most of threatened species. Four of these human activities (damming, agriculture, urbanization, and deforestation) were associated with most of the threatened species (91%). However, the number of threatened species influenced by these activities is unevenly distributed across taxonomic groups and hydrographic regions. For Siluriformes, Characiformes, Gymnotiformes, and Cichliformes, dominant groups in Neotropical freshwaters (Nelson 2006), river damming is one of the main impacts that contribute to the risk of species extinction, especially for small-sized, specialized and rapids-dwelling species with restricted distributions. These species are highly vulnerable to hydrological alteration of their habitats due to dam construction (Liermann et al. 2012; Fitzgerald et al. 2018). To illustrate this process, *Melanocharacidium nigrum* Buckup 1993 and *Harttia depressa* Rapp Py-Daniel & Oliveira, 2001, both occurring in river rapids and rocky substrates, were locally extirpated due to the construction of dams within the Amazon basin (ICMBio 2018).

Despite the Neotropical ichthyofauna is dominated by Siluriformes and Characiformes (Castro 1999), Cyprinodontiformes is the order with the highest number of threatened species. This highlights the great vulnerability of this group, which is represented mainly by species of Rivulidae (92.6% of the threatened species of this order). Known as killifishes, these fishes inhabit permanent or temporary wetlands and many species are only known from a few populations (Costa 2002). Their high endemism and dependence on specific environmental characteristics and the regularity of rainfall regimes make this group particularly vulnerable to extinction (Berois et al. 2015). Several environmental impacts have been associated with this group, primarily habitat loss due to agricultural activities and urbanization. These activities are often also associated with the draining of wetlands which sometimes completely destroys aquatic habitats. Due to the great representativity of this group among the Brazilian threatened freshwater fish species, a nationwide conservation plan has been developed, the National Action Plan for the conservation of rivulid fish (ICMBio 2013).

Spatial distribution of human activities affecting threatened fish revealed some interesting patterns. The Amazon and Tocantins-Araguaia basins harbor high proportions of threatened species whose conservation status is associated with damming, mainly due to hydropower plant construction. River damming negatively affects fishes via several mechanisms. Damming dramatically changes the trophic structure and habitat, affecting mainly species with more specialized

habits and reduces connectivity, affecting reproductive migration and dispersal (Greathouse et al. 2006, Albrecht et al. 2009). The Amazon and Tocantins-Araguaia basins correspond to great potential for hydropower production, which generates interest in the construction of new hydropower projects (Silvano et al. 2009). In addition to already installed hydropower plants, new dams are being planned in the coming years in these areas and their construction will seriously jeopardize many of the already threatened species (Kahn et al. 2014, Lees et al. 2016, ICMBio 2018).

The processes of urbanization, expansion of intensive agriculture and changes in the flow regimes of water resources reflect regional economic developments, which causes a significant amount of deleterious environmental impacts on soil, water, and air. The hydrographic regions of the Southeast Atlantic and Paraná had similar threats listed as being the most important. In fact, these basins are in economically developed regions, with some of the most populous cities and a high road density. For example, rivers and streams of the upper portion of Paraná basin (i.e. Upper Paraná ecoregion) has been historically impacted by deforestation, siltation, drainage, and agriculture (Fialho et al. 2008). These anthropogenic interferences increase the risk of extinction for most species and challenge the conservation of terrestrial and aquatic biodiversity (Helms et al. 2005, Peressin & Cetra 2014). Threatened species from the São Francisco, Tocantins-Araguaia, Uruguay, and South Atlantic hydrographic regions are influenced mainly by agricultural activities. These river basins have extensive agricultural areas (Mendonça 2006, Grützmacher et al. 2008, Balbinot Junior et al. 2009) and the damage caused by unsustainable agricultural practices increases the environmental impacts on soil and water. Moreover, the intensification of deforestation to expand agricultural activities may reduce the areas of native vegetation, especially riparian forest, directly affecting the maintenance of water quality and conservation of aquatic biota (Pusey & Arthington 2003).

It is worth mentioning that the conservation status assessment of species performed by nations, states and conservation organizations are based on the best knowledge available regarding the threats affecting species. Despite past and future projections on population trends are also part process, the conservation status assessment of species depends primarily on the current threats affecting each species. However, human activities affecting species vary temporally, reflecting economic activities and regional development at each moment in time. Thus, threats that are currently important in some regions, may not have been relevant in the past or will not become so in the future. Currently, damming is a primary threat for fish in Amazon and Tocantins-Araguaia, but this anthropogenic phenomenon already impacted all the large rivers in other regions long ago (e.g. Paraná, São Francisco, and Southeast Atlantic basins) (Agostinho et al. 2007). Most of the large and medium-sized fish were already extirpated from these basins (Hoeinghaus et al. 2009) and currently, other impacts have become primary threats in affecting remnant populations. Therefore, cycles of impacts are underway and environmental policies directed to avoid the associated cycles of extinction are urgent. In an optimistic scenario, one could consider even the reversibility of deleterious impacts, including, for example, dam removal (Pohl 2002) and restoration of degraded landscapes (Bowles & Whelan 1994), which could significantly to reduce the extinction debt (Strassburg et al. 2019).

In summary, our results show that habitat loss is a ubiquitous major threat jeopardizing the conservation status of the Brazilian fish fauna. However, different fine-scale threats mediate this process across

hydrographic regions and taxonomic groups. Thus, regionally oriented management strategies and environmental policies may be required to mitigate the hazardous consequences of these geographically and biologically variable human impacts on biodiversity.

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Author Contributions

Murilo Luiz e Castro Santana: Substantial contribution in the concept and design of the study. Contribution to data collection. Contribution to data analysis and interpretation. Contribution to manuscript preparation. Contribution to critical revision, adding intellectual content.

Fernando Rogério de Carvalho: Contribution to data analysis and interpretation. Contribution to critical revision, adding intellectual content.

Fabrizio Barreto Teresa: Substantial contribution in the concept and design of the study. Contribution to data collection. Contribution to data analysis and interpretation. Contribution to manuscript preparation. Contribution to critical revision, adding intellectual content.

Conflicts of Interest

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

Data Availability

We used data that are already public.

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