Received: 2 September 2016 | Accepted: 12 April 2017
DOI: 10.1111/faf.12228

ORIGINAL ARTICLE

WILEY FISH and FISHERIES

Neotropical freshwater fishes imperilled by unsustainable policies

Fernando M Pelicice[1] | Valter M Azevedo-Santos[2] | Jean R S Vitule[3] | Mário L Orsi[4] | Dilermando P Lima Junior[5] | André L B Magalhães[6] | Paulo S Pompeu[7] | Miguel Petrere Jr[8,9] | Angelo A Agostinho[10]

[1]Núcleo de Estudos Ambientais, Universidade Federal do Tocantins, Porto Nacional, Tocantins, Brasil
[2]Laboratório de Ictiologia, Departamento de Zoologia, Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, São Paulo, Brasil
[3]Laboratório de Ecologia e Conservação, Departamento de Engenharia Ambiental, Setor de Tecnologia, Universidade Federal do Paraná, Curitiba, Paraná, Brasil
[4]Laboratório de Ecologia de Peixes e Invasões Biológicas (LEPIB), Universidade Estadual de Londrina, Londrina, Paraná, Brasil
[5]Laboratório de Ecologia e Conservação de Ecossistemas Aquáticos, Universidade Federal de Mato Grosso, Pontal do Araguaia, Mato Grosso, Brasil
[6]Programa de Pós-Graduação em Tecnologias para o Desenvolvimento Sustentável, Universidade Federal de São João Del Rei, Ouro Branco, Minas Gerais, Brasil
[7]Departamento de Biologia, Universidade Federal de Lavras, Lavras, Minas Gerais, Brasil
[8]Campus de Sorocaba, Programa de Pós-Graduação em Planejamento e Uso de Recursos Renováveis, Universidade Federal de São Carlos, Sorocaba, São Paulo, Brasil
[9]UNISANTA, Programa de Pós-Graduação em Sustentabilidade de Ecossistemas Costeiros e Marinhos, Santos, São Paulo, Brasil
[10]Programa de Pós-Graduação em Ecologia de Ambientes Aquáticos Continentais, Universidade Estadual de Maringá, Maringá, Paraná, Brasil

Correspondence
Fernando M Pelicice, Núcleo de Estudos Ambientais, Universidade Federal do Tocantins, Jardim dos Ipês, Porto Nacional, Tocantins, Brazil.
Email: fmpelicice@gmail.com

Funding information
CNPq; CAPES

Abstract

Neotropical freshwater fishes are the most diverse on the planet (>5,500 species), although nations in Latin America have been negligent regarding their conservation. National policies have historically encouraged unsustainable practices, and recent decades have witnessed a sharp increase in harmful activities. Our aim with this review was to expose this situation and illustrate how national policies constitute the main threat to freshwater fish biodiversity. We explain that the most devastating, pervasive and systemic threats are rooted in official policies, particularly unsustainable activities (e.g. hydropower, water diversion, mining, aquaculture, agriculture and fishing), poor management/conservation (e.g. fish stocking and passages) and harmful legislation (e.g. poor licensing, non-native species). We provide a broad portrait of the Neotropical scenario, where unsustainable policies have caused considerable damage to freshwater ecosystems, and focus on major examples from Brazil, where development projects have caused large-scale losses to fish biodiversity. Such *modus operandi* of human development is incompatible with the persistence of biodiversity, and no simple solution is available to correct or minimize its effects. The current situation demands a profound behavioural shift towards better practices and policies, or these multiple high-impact activities will continue eroding freshwater fish biodiversity and impairing essential ecosystem services.

KEYWORDS
biodiversity loss, conservation, economy, ecosystem function, legislation, policy

1 | INTRODUCTION

Neotropical freshwater fishes (NFF) are the most diverse on the planet. From Central Mexico to the southern limits of South America, more than 5,000 species form a distinct biogeographical unity, heterogeneously distributed across thousands of river systems and different ecoregions (Reis, Kullander, & Ferraris, 2003). Dominated by Ostariophysi (i.e. Characiformes, Siluriformes and Gymnotiformes), NFF represent c.a. 30% of all freshwater fish species on the planet—c.a. 10% of all living vertebrate species. This high diversity includes a variety of taxonomic, phylogenetic and functional types (Lévêque, Oberdorff, Paugy, Stiassny, & Tedesco, 2008; Toussaint, Charpin, Brosse, & Villéger, 2016; Vitule, Agostinho et al., 2017), which play a range of ecosystem functions (e.g. nutrient cycling, grazing, seed dispersal) and services (e.g. professional and recreational fishing) that benefit different sectors of human society (e.g. Castello et al., 2013; Hoeinghaus et al., 2009). In addition, NFF are among the least known in the world (Ota, Message, da Graça, & Pavanelli, 2015; Vitule, Agostinho et al., 2017), indicating that this region is more diverse than currently thought.

Most countries in Latin America, however, have been careless about the preservation of fish biodiversity. National policies have historically encouraged unsustainable practices, and recent decades have witnessed a sharp increase in harmful activities, together with the approval of detrimental legislation. Consequently, multiple stressors, particularly hydrological alterations, non-native species introduction, habitat destruction and pollution, have damaged aquatic ecosystems in the region. These impacts have caused significant changes in multiple facets of freshwater fish diversity, in different latitudes, biomes, ecoregions and ecosystems (e.g. Agostinho, Gomes, Santos, Ortega, & Pelicice, 2016; Barletta et al., 2010; Carolsfeld, Harvey, Ross, & Baer, 2003; Jiménez-Segura et al., 2016; Lasso, Machado-Allison, & Taphorn, 2016; Nogueira et al., 2010; Reis et al., 2016; Vitule, da Costa et al., 2017; Winemiller et al., 2016) . This scenario is progressing rapidly, and NFF are at risk of experiencing important losses, in a way that will affect local ecosystem functioning, biogeographical patterns and evolutionary processes. In this sense, the Neotropical region may be considered a macro-hotspot for fish conservation, as the region is the most diverse on the planet, while is undergoing severe and increasing human threat.

Our aim with this essay is to illustrate how national policies constitute the main threat to the persistence of NFF. We provide a broad portrait of the Latin American scenario, and focus on examples from Brazil, a country that typifies the current state. This country holds an extraordinary diversity (>3,300 freshwater fish species; Froese & Pauly, 2016), but large-scale development projects and controversial legislation have caused considerable damage to freshwater ecosystems. With this review, we wish to inspire a much-needed discussion on the future of NFF, in the hope of planning better conservation strategies.

2 | A NUMBER OF THREATS

During the 20th century, major watersheds in the Neotropical region were disrupted by multiple human activities related to urban development, agribusiness, land use changes and the growing demand for natural resources. Many harmful activities are prohibited by local legislation (e.g. introduction of non-native species, pollution and overfishing), but the most impacting and systemic are rooted in official policies, for example hydropower, water diversion, mining, agriculture/aquaculture. These activities are widespread and expanding among Latin American countries, carried out to develop local, regional and national economies. It includes, for example, the construction of thousands of small and large hydropower dams in South America and Caribbean (e.g. Agostinho et al., 2016; Cooney & Kwak, 2013; Finer & Jenkins, 2012), the expansion of mining and oil leases in Andean/Amazon countries (e.g. Cremers, Kolen, & Theije, 2013; Ferreira et al., 2014) and the fast development of agriculture and aquaculture activities in north-eastern Mesoamerica, southern and central regions of South America (e.g. Esselman, Schmitter-Soto, & Allan, 2012; Lapola et al., 2014; Martinelli, Naylor, Vitousek, & Moutinho, 2010; Valladão, Gallani, & Pilarski, 2016). Large-scale projects have also been proposed, such as the Interoceanic Canal (Nicaragua), the Olmos Irrigation Project (Peru), the HidroAysén Dam Project (Chile), the Plan to Accelerate Growth (PAC, Brazil) and hydropower development in the Amazon (Brazil and Peru). Countries have also proposed ambitious plans with extra-continental cooperation, for example the South American Infrastructure and Planning Council (IIRSA, COSIPLAN), the Mesoamerica Integration and Development Project and the Peru-Brazil Energy Agreement. It is important to note that tropical, equatorial and Andean countries, highly diverse in terms of freshwater ecosystems and fish species, but economically vulnerable and politically unstable, are leading this wave of unsustainable development, that is Mexico, Nicaragua, Panama, Costa Rica, Colombia, Peru, Bolivia, Chile, Argentina, Paraguay and Brazil.

Unsustainable policies caused multiple disturbances and negatively affected the structure and functioning of freshwater and terrestrial ecosystems. River regulation and water diversion projects have changed the natural flow regime of most river systems (e.g. Agostinho et al., 2016; Anderson, Pringle, & Rojas, 2006; Cooney & Kwak, 2013). These activities, together with agribusiness and mining, have provoked extensive changes in land cover and degraded natural lakes, floodplains, wetlands and riparian forests (e.g. Barletta et al., 2010; Castello et al., 2013; Jiménez-Segura et al., 2016; Killeen, 2011; Swenson, Carter, Domec, & Delgado, 2011) . Aquaculture, in particular, has introduced several non-native species (e.g. Britton & Orsi, 2012; Esselman et al., 2012; Habit & Cussac, 2016; Magalhães & Jacobi, 2013; McKaye et al., 1995), and together with agriculture, urban and mining development, released heavy loads of pollutants into aquatic systems (e.g. Araújo, Pinto, & Teixeira, 2009; Barrella & Petrere Jr, 2003; Wantzen & Mol, 2013) . During the last half century, human threats transformed unique, pristine or highly diverse regions—the Maya Mountains, Caribbean drainages, Lake Nicaragua, Andean headwaters, Cerrado savannas, Caatinga semi-arid ecosystems, Atlantic rainforest remnants, Pantanal wetlands, Gran Chaco, Llanos del Orinoco and Moxos, and Chilean Patagonia (e.g. Abilhoa, Braga, Bornatowski, & Vitule, 2011; Alcorn, Zarzycki, & de la Cruz, 2010; Cooney & Kwak, 2013; Esselman et al., 2012; Habit & Cussac, 2016; Harer, Torres-Dowdall, & Meyer, 2016; Killeen, 2011; Klink & Machado, 2005; Leal, Silva, Tabarelli, & Lacher, 2005). Even the Amazon system, relatively well preserved, is under pressure by urban, hydropower, mining and agribusiness expansion (Castello et al., 2013; Lees, Peres, Fearnside, Schneider, & Zuanon, 2016; Winemiller et al., 2016)—and currently by non-native species (Bittencourt, Silva, Silva, & Tavares-Dias, 2014; Padial et al., 2017; Van Damme et al., 2015).

These activities had important implications on fish diversity and associated ecosystem services (i.e. fisheries). Hundreds of scientific studies, conducted throughout the region, have consistently reported multiple changes in fish biodiversity from genes to ecosystems, for example genetic and population structure, physiology, species richness, composition, abundance/biomass, persistence, recruitment, food web structure, functional traits, ecosystem functions and services, among others (Table S1). Currently, fish assemblages in most river basins and sections are subsets of the original fauna, usually dominated by tolerant, opportunistic and sedentary species, in addition to several non-native fishes (e.g. Agostinho, Pelicice, Petry, Gomes, & Júlio Júnior, 2007; Anderson et al., 2006; Barrella & Petrere Jr, 2003; Cunico, Allan, & Agostinho, 2011; Daga, Debona, Abilhoa, Gubiani, & Vitule, 2016; Esselman et al., 2012; Jiménez-Segura et al., 2016; Vargas, Arismendi, & Gomez-Uchida, 2015). Migratory fishes, culturally iconic and highly prized in markets and in sport fishing, have virtually disappeared from many reaches, rivers and basins (Table 1), provoking shifts in traditional and commercial fisheries (e.g. Agostinho et al., 2016; Carolsfeld et al., 2003; Greathouse, Pringle, & Holquist, 2006; Hoeinghaus et al., 2009). Fish assemblages at impounded sites, in particular, are impoverished, fragmented and vulnerable, usually composed of a few small-sized species with low commercial value and non-native fishes (e.g. Agostinho, Gomes, & Pelicice, 2007; Daga et al., 2015; Petesse & Petrere Jr, 2012; Petrere Jr, 1996).

To provide a more detailed account of this scenario, we collected information and specific examples about public policies in Brazil, and analysed their effects on freshwater fish diversity. We chose Brazil because the country typifies the Neotropical context: it has continental extent (i.e. it includes all major river systems of the region, different biomes, ecoregions, hotspots and Ramsar sites), holds more than 60% of all NFF, and official policies have fostered a myriad of unsustainable development projects. Scientific studies have reported profound changes in fish diversity across the country (Table S1), and fishery stocks have declined consistently in all major river systems. The Brazilian government recently listed 312 (c.a. 10%) freshwater fish species threatened with extinction (Reis et al., 2016), but many populations are fragmented, declining or locally extirpated from several sites and regions; even though not listed in official red lists (Table 1). To expose this specific case, we gathered the most relevant threats that have their origin in Brazilian public policies, which are intense (i.e. cause large-scale disturbances), systemic (i.e. affect the whole territory), pervasive (i.e. effects spread rapidly through the ecosystem) and increasing (i.e. intensified in recent decades). These threats were grouped into three classes: (i) harmful activities, (ii) harmful management and (iii) harmful laws (Figure 1). The first class gathered a number of development activities that have promoted direct disturbances on freshwater ecosystems and biodiversity; the second included main management actions directed to restore/conserve freshwater fishes, but which showed little success or caused additional impacts; the third class summarized recent laws and projects that foster unsustainable development. All these factors have direct effects on fish diversity, but their interactions and feedbacks enhance negative links (Figure 1).

2.1 | Harmful activities

This group includes a number of activities that directly and adversely affect the maintenance of fish biodiversity: dams, water diversion, mining, aquaculture, agriculture and fishing (Table 2; Figure 1).

River regulation deserves attention because dams change the natural flow regime and cause extensive habitat losses, degradation and fragmentation (Figure 2) (Pringle, Freeman, & Freeman, 2000). In Brazil, thousands of dams (Figure 3a) were constructed over the 20th century, particularly for hydropower generation (Agostinho, Gomes et al., 2007). As a result, all major rivers are now regulated, fragmented or under the influence of dams and impoundments. In some basins, cascades of dams regulate the entire fluvial course, as observed in the Upper Paraná, Paraíba do Sul and Lower São Francisco rivers (Agostinho et al., 2016; Araújo et al., 2009; Nestler et al., 2012). Hydroelectric expansion has advanced to the Amazon basin (Figure 3b), home to thousands fish species in relatively pristine conditions (Castello et al., 2013; Lees et al., 2016). Seven large dams regulate the entire course of the Tocantins River, and the Upper Tapajós River will be regulated in the near future (Winemiller et al., 2016). Dams also block the main stem of the Madeira and Xingu rivers, not to mention the giant Balbina Reservoir and other dams constructed on smaller tributaries. The growing construction of small dams is another concern (Figure 3c), as these structures are now widespread in tributaries and headwaters of all basins, including the Amazon, Cerrado, Pantanal and Atlantic rainforest systems (Abilhoa et al., 2011; Alho & Sabino, 2011; Finer & Jenkins, 2012; Lima Junior, Magalhães, & Vitule, 2015; Nogueira et al., 2010). Along with dam construction, official policies have proposed water diversion projects to balance the water deficit between reservoirs and basins and to mitigate the misuse of water resources (e.g. pollution, loss of wetlands). This activity causes large-scale ecological impacts to both donor and receiver systems (Anderson et al., 2006; Lima Junior et al., 2015; Pringle et al., 2000), including hydrological disturbances and species invasions (Figure 2). Ambitious and controversial mega-projects aim to transfer water from the Amazon and São Francisco basins to the Brazilian semi-arid region (e.g. Projeto São Francisco). There are also projects to mitigate water shortages in large metropolises in the southeast region (Lima Junior et al., 2015) (Figure 3d), because urban freshwater ecosystems, although vital to modern societies, are much deteriorated (i.e. regulated, rectified, channelled and contaminated) (Araújo et al., 2009; Barrella & Petrere Jr, 2003; Pompeu, Alves, & Callisto, 2005).

Mining activities (Figure 3e) and oil leases constitute another major threat to freshwater fishes and aquatic ecosystems (Hughes et al., 2016; Wantzen & Mol, 2013). In addition to routine direct effects (i.e. erosion, water and soil contamination; Figure 2), there is

TABLE 1 Empirical examples of fish species and groups that are fragmented, declining or extirpated from several sites in different watersheds in Brazil. Consult Table S1 for more examples

Species	Basin	Status	Main disturbance	Key references
Large catfishes (e.g. Pimelodidae: *Brachyplatystoma filamentosum*, *B. flavicans*, *B. rousseauxii*)	Amazon	Fragmented, declining	Dams, Fishery	Barthem, Ribeiro, and Petrere Jr (1991); Petrere Jr, Barthem, Cordoba, and Gomez (2004); Duponchelle et al. (2016)
Large migratory fishes (e.g. Bryconidae: *Salminus brasiliensis*, *S. francis-canus*; Serrassalmidae: *Piaractus mesopotamicus*; Pimelodidae: *Pseudoplatystoma corruscans*, *Zungaru jahu*)	São Francisco, Upper Paraná, Uruguay	Fragmented, declining, extirpated	Dams, Fishery	Petrere Jr (1996); Carolsfeld et al. (2003); Agostinho et al. (2016)
Rheophilic fishes (e.g. Anostomidae: *Leporinus*; Cynodontidae: *Hydrolicus*; Parodontidae: *Apareiodon*; Serrassalmidae: *Mylesinus*, *Myloplus*; Bryconidae: *Brycon*, *Salminus*; Hemiodontidae: *Hemiodus*; Loricariidae: *Delturus*)	Several drainages	Fragmented, declining, extirpated	Dams	Carolsfeld et al. (2003); Nogueira et al. (2010); Agostinho et al. (2016);
Floodplain fishes (e.g. Anostomidae: *Leporinus*; Arapaimidae: *Arapaima*; Serrassalmidae: *Colossoma*; *Mylesinus*, *Myleus*, *Piaractus*. Prochilodontidae: *Prochilodus*, *Semaprochilodus*; Pimelodidae: *Sorubim*)	Several drainages	Fragmented, declining	Agriculture, Aquaculture, Dams, Fisheries, Non-native species	Agostinho, Gomes, Veríssimo, and Okada (2004); Castello et al. (2014); Costa-Pereira and Galetti (2015); Hurd et al. (2016)
Stream fishes (e.g. Characidae: *Astyanax*, *Bryconamericus*, *Knodus*; Callichthyidae: *Corydoras*; Loricariidae: *Ancistrus*; *Hisonotus*, *Hypostomus*, *Rineloricaria*; Pimelodidae: *Imparfinis*, *Pimellodela*)	Several drainages	Fragmented, declining, extirpated	Agriculture, Aquaculture, Dams, Mining, Non-native species, Water diversion	Cunico et al. (2011); Bordignon et al. (2015); Teresa et al. (2015)
Small characins in reservoirs (e.g. Characidae: *Astyanax*, *Hemigrammus*, *Hyphessobrycon*, *Moenkhausia*, *Serrapinnus*; Curimatidae: *Steindachnerina*)	Upper Paraná	Declining, extirpated	Aquaculture, Non-native species	Orsi and Britton (2014); Daga et al. (2015)
Annual fishes (e.g. Rivulidae: *Austrolebias*, *Hypsolebias*, *Leptolebias*)	Several drainages	Declining, extirpated	Agriculture, Water diversion	Volcan, Gonçalves, and Lanés (2011); Nascimento, Yamamoto, Chellappa, Rocha, and Chellappa (2015)
Small cichlids (e.g. Cichlidae: *Aequidens*; *Cichlasoma*, *Crenicichla*; *Geophagus*, *Satanoperca*)	Several drainages	Declining	Non-native species	Sanches et al. (2012); Bittencourt et al. (2014); Gois, Pelicice, Gomes, and Agostinho (2015)
Genus *Brycon* (e.g. Bryconidae: *B. gouldingi*, *B. nattereri*, *B. lundii*, *B. opalinus*, *B. orbignyanus*, *B. ortothaenia*)	Several drainages	Fragmented, declining, extirpated	Agriculture, Dams	Carolsfeld et al. (2003); Ashikaga, Orsi, Oliveira, Senhorini, and Foresti (2015)
Genus *Steindachneridium* (e.g. Pimelodidae: *S. amblyurum*, *S. doceanum*, *S. parahybae*, *S. scriptum*)	Several drainages	Fragmented, declining, extirpated	Dams	Honji, Caneppele, Hilsdorf, and Moreira (2009)

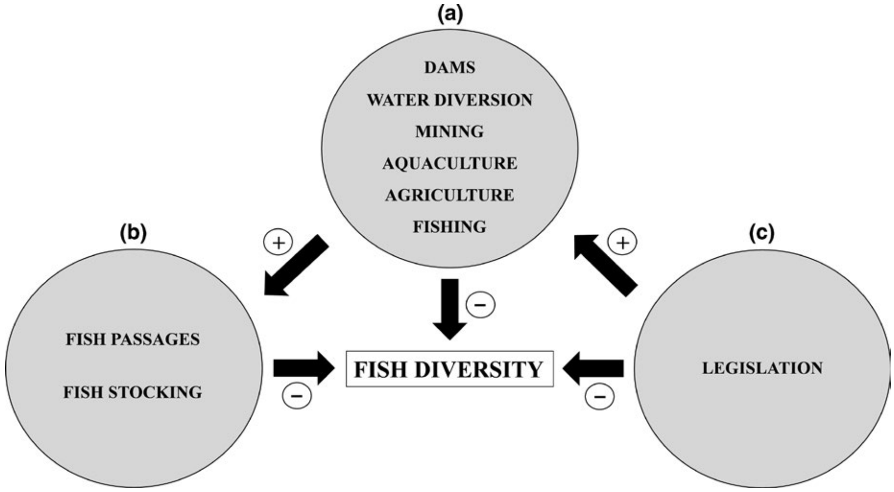

FIGURE 1 Simplified conceptual model of the main threats to Neotropical freshwater fishes, summarized as harmful activities (a), harmful management (b) and harmful legislation (c). Positive (+) and negative (-) interactions are indicated

risk of large-scale disturbances, because hundreds of dams accumulate mining wastes, and many are unstable and at full capacity (Meira et al., 2016). Not surprisingly, the breaching of mine tailing dams in the Rio Doce Valley led to profound social, economic and environmental consequences (Escobar, 2015), affecting over 300,000 people, 1,500 fishers and 80 fish species. There are c.a. 600 mining dams operating in the country (Nazareno & Vitule, 2016), and their contribution to the Brazilian gross domestic product has increased progressively (Ferreira et al., 2014), with several mining/oil leases in the Amazon basin (Castello et al., 2013).

In addition to these engineering projects, the federal government destined c.a. R$ 4.1 billion (US$ 1.32 billion) to boost intensive aquaculture with non-native species and implement aquaculture parks in reservoirs (Figure 3f). About 150 parks will be installed, covering more than 1,500 sites in main river basins (Lima, Oliveira, Giacomini, & Lima Junior, 2016). Aquaculture has many impacts on aquatic ecosystems (Figure 2), including species introduction (Figure 3g), trophic cascades, eutrophication, pollution, genetic erosion, diseases, habitat destruction (Figure 3h) and biotic homogenization (Agostinho, Gomes et al., 2007; Diana, 2009; Ortega, Júlio Júnior, Gomes, & Agostinho, 2015; Pelicice, Vitule, Lima Junior, Orsi, & Agostinho, 2014). Biological invasion is a serious concern, because 88% of licensed parks will raise non-native species (Lima et al., 2016), especially tilapias. Aquaculture has historically focused on exotic fishes, and the activity is responsible for the introduction of several non-native species in Brazil (Agostinho, Gomes et al., 2007; Britton & Orsi, 2012; Ortega et al., 2015). Some basins (e.g. Upper Paraná, São Francisco and Paraíba do Sul) are degraded to a point where few river sections remain undisturbed by exotic fishes (Araújo et al., 2009; Daga et al., 2015; Magalhães & Jacobi, 2013; Orsi & Britton, 2014). The expansion of the activity will also cause large-scale invasions in the Amazon basin (Bittencourt et al., 2014; Padial et al., 2017), where non-native fishes are largely absent.

The expansion of aquaculture followed the impressive development of agriculture, one of the main economic activities of the country. The activity already uses 55% of the water consumed in Brazil (FAOSTAT 2015), and monocultures (soybean, maize, sugar cane) cover vast areas of the country (Martinelli et al., 2010). Agribusiness activities (Figure 3i) have changed the landscape and the functioning of terrestrial and aquatic ecosystems (Figure 2) (Ferreira et al., 2014; Lapola et al., 2014; Martinelli et al., 2010), creating an important ecological debt in the short and long term (Fearnside, 2005). It has caused extensive changes in land cover and destroyed riparian areas, wetlands and springs due to deforestation, cattle trampling and stream regulation (small dams). These practices affected abiotic and hydrological conditions of aquatic ecosystems, and the systematic conversion of riparian forests (Figure 3i,j), in particular, has led to marked changes in instream habitats (Leal et al., 2016) and aquatic biodiversity (e.g. Bordignon, Casatti, Pérez-Mayorga, Teresa, & Brejão, 2015; Casatti, Ferreira, & Carvalho, 2009; Santos, Ferreira, & Esteves, 2015; Teresa, Casatti, & Cianciaruso, 2015). It is particularly evident in headwater streams, environments that harbour high levels of fish biodiversity, with complicated patterns of endemism, rarity and turnover. Water pollution is another issue (i.e. eutrophication, contamination and bio-magnification), because agribusiness uses heavy loads of fertilizers and pesticides (Martinelli et al., 2010), including some that are illegal and banned in developed countries.

Fishing has been another source of disturbances, as it has exerted a constant pressure upon some stocks, with demographic/genetic consequences (Figure 2). The activity is structured in different modalities (artisanal, commercial, industrial, sport), employs a variety of fishing methods, and is spread across different ecosystems, for example rivers, floodplains, impoundments (Batista, Inhamuns, Freitas, & Freire-Brasil, 1998; Castello, Isaac, & Thapa, 2015; Okada, Agostinho, & Gomes, 2005; Petrere Jr, 1996). Fishery activities contributed to deplete stocks in different basins (Allan et al., 2005; Castello, Arantes, McGrath, Stewart, & Sousa, 2014; Gerstner, Ortega, Sanchez, & Graham, 2006; Mateus, Penha, & Petrere Jr, 2004), but size overfishing seems to be more common, mainly among valued migratory species such as large catfishes and characins (Correa et al., 2015; Costa-Pereira & Galetti, 2015). Although specific legislation regulate the activity (e.g. minimum size, quotas, seasonal suspensions), inspections are inadequate and fisheries management is poor or non-existent (see next section). Non-professionals and authorities usually blame fishing pressure as the cause of stock collapses and declining yields, but it is likely that, in many cases, fishing plays a secondary role, as

TABLE 2 Main threats to Neotropical freshwater fishes, grouped into three classes: (A) harmful activities, (B) harmful management and (C) harmful legislation. The table shows the period of occurrence of each activity, their current trend and main impacts on fish biodiversity. Key references provide further information and examples

Threats	Period (Current trend)	Main impacts	Key references
(A) Harmful activities			
1) Dam construction (large and small dams)	20th century (Increasing)	Biogeochemical changes; flow regulation; habitat loss and degradation; introduction of non-native species; loss of connectivity	Pringle et al. (2000); Nestler et al. (2012); Daga et al. (2015); Pelicice et al. (2015); Agostinho et al. (2016)
2) Dams in Amazonia (large and small dams)	Since ~1975 (Increasing)	Biogeochemical changes; flow regulation; habitat loss and degradation; introduction of non-native species; loss of connectivity	Finer and Jenkins (2012); Castello et al. (2013); Lees et al. (2016); Winemiller et al. (2016)
3) River diversion projects	20th century (Increasing)	Hydrological changes; introduction of non-native species; loss of barriers; water deficit	Pringle et al. (2000); Lima Junior et al. (2015)
4) Mining and oil leases		Biogeochemical changes; deforestation; habitat loss and degradation; pollution	Swenson et al. (2011); Wantzen and Mol (2013); Ferreira et al. (2014); Hughes et al. (2016); Meira et al. (2016)
5) Aquaculture	20th century (Increasing)	Habitat loss and degradation; introduction of non-native species; negative biotic interactions; pollution and eutrophication	Diana (2009); Britton and Orsi (2012); Magalhães and Jacobi (2013); Ortega et al. (2015); Lima et al. (2016)
6) Agriculture	20th century (Increasing)	Deforestation; habitat loss and degradation; introduction of non-native species; pollution and eutrophication	Fearnside (2005); Martinelli et al. (2010); Ferreira et al. (2014); Lapola et al. (2014)
7) Fisheries	20th century	Genetic and demographic changes	Allan et al. (2005); Castello et al. (2014); Correa et al. (2015); Costa-Pereira and Galetti (2015)
(B) Harmful management			
8) Fish stocking	20th century (Increasing)	Genetic erosion; hybridization; introduction of non-native species; negative biotic interactions	Vitule et al. (2009); Agostinho et al. (2010); Britton and Orsi (2012)
9) Fish passages	20th century (Increasing)	Ecological traps; introduction of non-native species; malfunctioning; source-sink dynamics	Pelicice and Agostinho (2008); McLaughlin et al. (2013); Pompeu et al. (2012); Pelicice et al. (2015)
(C) Harmful legislation			
10) Forestry Code (Federal Law 12.651)	2012 (Approved)	Deforestation; habitat loss and degradation; introduction of non-native species	Martinelli et al. (2010); Magalhães et al. (2011); Nazareno et al. (2011); Ferreira et al. (2014)
11) Federal, State and Municipal laws that reduced the size of protected areas	Since ~2000 (Approved)	Deforestation; habitat loss and degradation	Bernard et al. (2014); Ferreira et al. (2014)
12) Simplified licensing of aquaculture parks in reservoirs (update of Resolution 413/2009)	2013 (Approved)	Habitat loss and degradation; introduction of non-native species; negative biotic interactions; pollution and eutrophication	Lima Junior et al. (2015); Azevedo-Santos et al. (2015); Lima et al. (2016)
13) Naturalization of non-native fishes (Federal Law 5.989/09)	2009 (Partially Approved)	Introduction of non-native species; negative biotic interactions	Vitule et al. (2009); Pelicice et al. (2014); Azevedo-Santos et al. (2015)
14) Aquaculture of non-native fishes in Amazonia (State law 76/2016	2016 (Approved)	Introduction of non-native species; negative biotic interactions	Padial et al. (2017)
15) Aquaculture of Amazonian fishes outside their native range (Normative Instruction 16/14)	2014 (Approved)	Introduction of non-native species; negative biotic interactions	Magalhães and Jacobi (2013); Magalhães and Vitule (2013); Vitule et al. (2014)
16) Transport of aquatic organisms for ornamental and fishkeeping purposes (Normative Instruction 21/14)	2014 (Approved)	Introduction of non-native species; negative biotic interactions	Magalhães and Jacobi (2013); Magalhães and Vitule (2013); Vitule et al. (2014)

(Continues)

TABLE 2 (Continued)

Threats	Period (Current trend)	Main impacts	Key references
17) Suspension of national species red lists (Order 445)	2014 (Temporarily approved)	Fishing upon threatened species	Di Dario et al. (2015)
18) Suspension of fishing prohibitions during the reproductive period (Order 192/15)	2015 (Temporarily approved)	Fishing upon reproductive fish; genetic and demographic changes;	Pinheiro et al. (2015)
19) Revision of laws to develop mining activities in protected areas (Federal Law 1610/96 and Federal Law 3682/2012)	1996 and 2012 (Partially Approved)	Biogeochemical changes; deforestation; habitat loss and degradation; pollution	Castello et al. (2013); Ferreira et al. (2014); Meira et al. (2016)
20) Simplified licensing of small hydropower dams (update of Federal Laws 9.704/95 and 9.427/96)	2014 (Partially Approved)	Biogeochemical changes; flow regulation; habitat loss and degradation; introduction of non-native species; loss of connectivity	Pringle et al. (2000); Castello and Macedo (2015); Agostinho et al. (2016)
21) Simplified licensing process for strategic mega-projects (Federal Law 654/2015)	2015 (Partially Approved)	Biogeochemical changes; deforestation; flow regulation; habitat loss and degradation; loss of connectivity; pollution and eutrophication	Fearnside (2016a)
22) Simplified licensing process for any infrastructure or development project (PEC-65)	2012 (Partially Approved)	Biogeochemical changes; deforestation; flow regulation; habitat loss and degradation; loss of connectivity; pollution and eutrophication	Fearnside (2016a)
23) Freezing of budget destined to scientific research and conservation programs (PEC-55)	2016 (Approved)	Deforestation; habitat loss and degradation; introduction of non-native species; overfishing; pollution	Angelo (2016)

stocks are substantially depressed by other human activities (e.g. river regulation, habitat losses, pollution). It means that some populations will not recover if fishing pressure ceases, because key environmental conditions were changed or lost.

We propose that these harmful activities probably interact to cause multiplicative and emergent effects, such as the common combination among river regulation, aquaculture, deforestation and fishing. For example, negative effects of fishing or aquaculture are likely magnified in impoundments, because dams affect population's growth rate, decrease the carrying capacity of the environment, and make stocks vulnerable to harvesting (i.e. downstream from dams). Agriculture may also enhance impacts on small streams when it combines deforestation with the construction of low-head dams and the release of heavy loads of fertilizers. These interactions, although poorly evaluated (e.g. Leal et al., 2016; Mateus et al., 2004), must play a significant role in the current decline of biodiversity.

2.2 | Harmful management

The decline in fish diversity has led authorities to consider two main strategies regarding fish conservation: fish stocking and the construction of fish passages (Table 2; Figure 1). Although these actions were commonplace during the 20th century, they were applied without clear objectives, prior assessments or post-monitoring; consequently, they were unable to prevent the decline of fish populations and, worse, caused additional negative effects (Figure 2).

Official agencies conducted fish stocking for decades (Figure 3k), involving dozens of species in different basins; however, there is no indication that they have recovered native populations or target fishery stocks (Agostinho, Pelicice, Gomes, & Júlio Júnior, 2010; Agostinho, Gomes et al., 2007). Worse, they introduced several non-native species, caused genetic problems in native populations and wasted money and effort (Britton & Orsi, 2012; Ortega et al., 2015; Vitule, Freire, & Simberloff, 2009). In several watersheds, for example, nuisance invasive species (e.g. freshwater croacker *Plagioscion squamosissimus*, Sciaenidae; Nile tilapia *Oreochromis niloticus*, Cichlidae) were released by official stocking programs carried out by hydropower companies. The use of fishways followed the same trend, as ladders and other devices were installed in different basins (Figure 3l), but they never restored wild populations or ecosystem services. A series of recent studies revealed that fish passages often malfunction and cause additional problems (e.g. McLaughlin et al., 2013; Pompeu, Agostinho, & Pelicice, 2012), including unidirectional passage (e.g. Agostinho, Pelicice, Marques, Soares, & Almeida, 2011), enhanced predation (e.g. Agostinho, Agostinho, Pelicice, & Marques, 2012), trait selection (e.g. Volpato, Barreto, Marcondes, Moreira, & Ferreira, 2009) and the introduction of non-native species (e.g. Júlio Júnior, Dei Tós, Agostinho, & Pavanelli, 2009). In some contexts, fishways can cause serious negative effects such as source-sink dynamics and ecological traps (Pelicice & Agostinho, 2008; Pelicice, Pompeu, & Agostinho, 2015), compromising genuine conservation efforts.

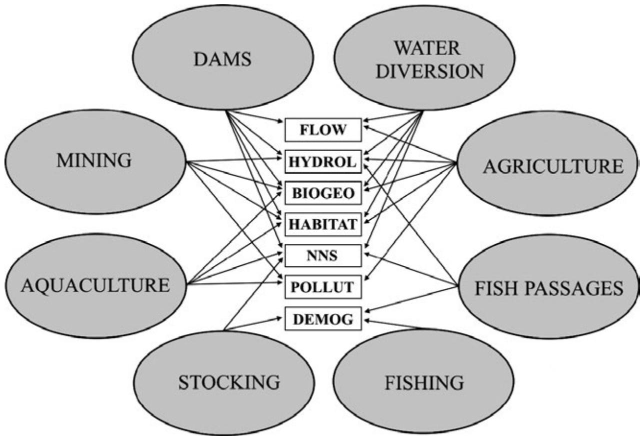

FIGURE 2 Simplified conceptual model of the main disturbances caused by harmful activities and management on Neotropical freshwater fishes. Disturbances are changes in water flow (FLOW), hydrology (HYDROL) and biogeochemistry (BIOGEO), habitats loss and degradation (HABITAT), the introduction of non-native species (NNS), pollution (POLLUT) and direct demographical effects (DEMOG)

We highlight that both measures are charismatic and have popular support, so they continue to be applied as fish stocks decline across the country. The consequence is that fish biodiversity, already threatened by multiple human activities and unprotected by effective conservation planning, suffers additional impacts from inappropriate management actions.

2.3 | Harmful legislation

Brazilian legislation is usually considered a benchmark for biological conservation (Loyola, 2014). This legislation implemented, for example, a number of protected areas across the country and established legal instruments that protect riparian forests and limit deforestation in private lands (Lapola et al., 2014). In addition, a stringent licensing process guide development projects, while specific laws enforce ecosystem management and restoration, and restrict fishing activities (e.g. Agostinho, Gomes et al., 2007; Tollefson, 2016). This beneficial framework, however, has resulted in limited practical effects, especially because inspection is inadequate or completely absent (Tollefson, 2016), and administration is weakened by heavy bureaucracy and corruption (Fearnside, 2016a). Many prohibited activities are common practices in Brazil, such as the complete removal of riparian vegetation, human settlements inside protected areas, the introduction of non-native species and illegal fishing. A matter of much greater concern, however, is the suite of recent legislation (laws, decrees and other regulations) put forth to organize and foster economic activities related to the expansion of agribusiness, aquaculture (commercial and ornamental), mining and hydropower (Table 2). Brazil is currently facing severe social/political/economic instability, so unsustainable policies became easily justified to reaccelerate and sustain economic growth.

Among this legislation, some laws have potential to accelerate habitat loss, degradation and fragmentation, such as the New Forestry Code and the downsizing of protected areas including national parks (Bernard, Penna, & Araujo, 2014; Ferreira et al., 2014; Nazareno et al., 2011). The Forestry Code, in particular, reduced the protected area of riparian buffer zones, increasing the vulnerability of aquatic ecosystems (Magalhães, Casatti, & Vitule, 2011). A matter of great concern are propositions to simplify or weaken the licensing process of infrastructure development, that is large-scale projects (Law 654/2015), small hydropower dams (Federal Laws 9.704/95 and 9.427/96), or even any development project (PEC-65; Fearnside, 2016a). If approved, these regulations will accelerate the analysis of strategic mega-projects, implicating that the quality of environmental impact assessments will decline. Brazil has also made concerted efforts to create a legislative framework supportive of mining activities. This includes draft legislation to develop new mines in protected reserves and indigenous lands (Ferreira et al., 2014), and attempts to change the restrictions imposed by the Brazilian Mining Code (Meira et al., 2016). Finally, we mention the controversial PEC-55 (previously PEC 241), an austerity plan that will freeze the national budget for the next 20 years. It means that investments on scientific research and environmental conservation will decline (Angelo, 2016). Environmental agencies will experience limited expenditure, with negative effects on the recruitment of new officials, inspections and the enforcement of regulations (Magalhães et al., 2017).

Other laws will cause the introduction and spread of alien species. We cite the bureaucratic simplification to approve aquaculture parks in public waters (Lima et al., 2016), tilapia aquaculture in the state of Amazonas (Padial et al., 2017), and laws to boost the aquaculture and commerce of Amazonian fishes outside their native region (Vitule, Sampaio, & Magalhães, 2014). Another troubling case is the law that naturalizes non-native species for aquaculture purposes (Pelicice et al., 2014), which may cause the mass invasion of different non-native species, including carp and tilapia (Figure 2g). New legislation has also decreased the protection of fishing stocks, because endangered species lists and seasonal fishing closures were both attacked and provisionally suspended during 2015 due to purely political reasons (Di Dario et al., 2015; Pinheiro et al., 2015).

3 | THE FUTURE IS NOW

Neotropical freshwater fishes are at their most fragile moment in human history, considering that official policies in Latin America have encouraged activities with strong potential to impair the functioning of freshwater ecosystems. Our specific analysis focused on Brazil, but unsustainable activities such as hydropower expansion, land use changes and the introduction of non-native organisms are widespread across the Neotropical region. The situation is more dramatic if we consider that many other activities (not considered here) are planned or in course to accelerate regional development, for example roads, railways, ports, waterways and power plants (Harer et al., 2016; Huete-Perez, Tundisi, & Alvarez, 2013; Killeen, 2011; Lapola et al., 2014; Lima Junior et al., 2015). Furthermore, prohibited harmful actions are growing across the region, such as clandestine fish

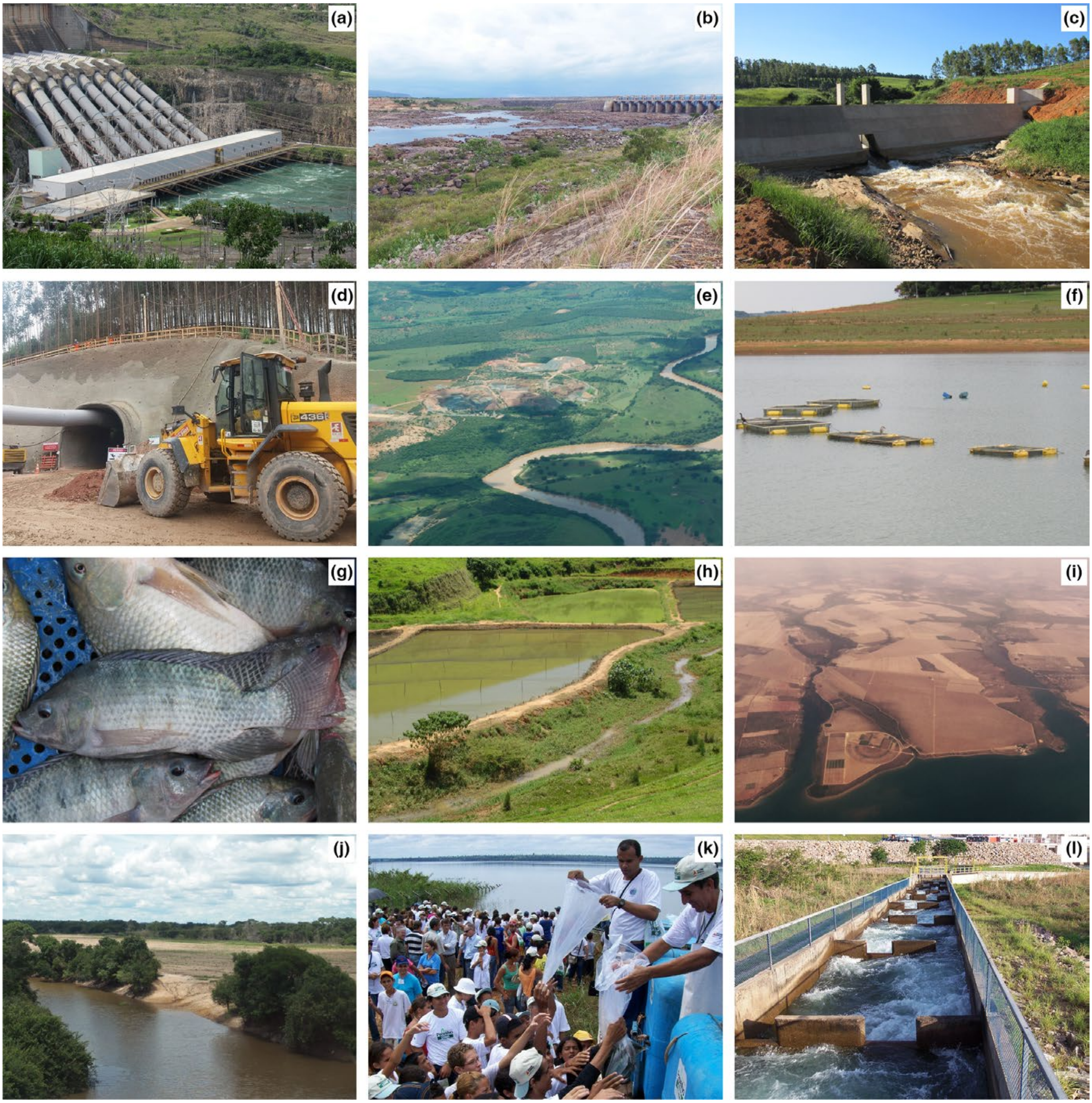

FIGURE 3 Examples of human activities in Brazil that have negatively affected Neotropical freshwater fishes, related to river regulation, non-native species, aquaculture, pollution, deforestation, habitat loss, mining and poor management. (a) The Furnas hydroelectric plant (Upper Paraná River Basin); (b) the Lajeado hydroelectric plant (Tocantins River, Amazon Basin); (c) a small dam in the Upper Paraná River Basin; (d) water diversion project to connect the Cantareira and Paraíba do Sul basins; (e) mining activities in the Paraopeba River (São Francisco River Basin); (f) cage aquaculture; and (g) Nile tilapia *Oreochromis niloticus* raised in the Furnas Reservoir; (h) aquaculture ponds with ornamental non-native species (Paraíba do Sul River Basin); (i) intensive agriculture surrounding Lajeado Reservoir; (j) loss of riparian vegetation (Upper Tocantins River Basin); (k) fish stocking in the Upper Paraná River Basin; (l) fish ladder at the Lajeado Dam. [Color figure can be viewed at wileyonlinelibrary.com].

introductions, overfishing, pollution, fires, illegal mining and deforestation (e.g. Bovarnick, Alpizar, & Schnell, 2010; Britton & Orsi, 2012; Killeen, 2011; Lapola et al., 2014; Magalhães & Vitule, 2013). In this scenario of multiple stressors, the conservation of fish biodiversity is not a problem for the future; NFF are currently at stake. Few river systems remain free of human disturbances, and the structure of fish assemblages is profoundly changed (Table S1). Several species are now threatened with extinction (e.g. Noakes & Bouvier, 2013; Reis et al., 2016), a process with global significance if we consider that NFF are unique and account for about 30% of all freshwater fish species on the planet (Lévêque et al., 2008). The sixth mass extinction induced by human activities, which has exterminated large mammals and island species (Ceballos et al., 2015), is upon freshwater fishes. We just highlight that diversity losses involve dimensions that go beyond species extinction, that is genetic erosion, demographic and community changes, local extirpations, the loss of traits, ecological relationships, functions and ecosystem services (Costa-Pereira & Galetti, 2015; Freeman, Pringle, Greathouse, & Freeman, 2003; Hoeinghaus et al., 2009; Leitão et al., 2016; Toussaint et al., 2016; Vitule, Agostinho et al., 2017). In this sense, Neotropical fish diversity is currently declining and eroded in multiple facets.

TABLE 3 Actions to improve (i) the use of natural resources, (ii) management and (iii) policies, with the potential to minimize impacts or increase the conservation of Neotropical freshwater fishes

(A) Sustainable use of resources
systematic planning to guide hydropower development in watersheds, giving equal weight to economic, environmental and social dimensions
revise the current plan to expand hydropower dams in the Amazon basin, restricting the number and distribution according to real costs and benefits to society
revise the current plan to expand small hydropower plants on tributaries, reducing their number and distribution, and making environmental impact studies mandatory
mandatory and permanent monitoring of fish populations in areas affected by dams and other large-scale projects
revise water diversion projects to include studies on fauna interchange and the opportunity for alternative measures (e.g. restoration of wetlands and riparian vegetation)
forbid waterways and other engineering projects (e.g. diversion, canalization, regulation) in river systems of great ecological relevance (e.g. Caribe, Andes, Pantanal, Amazonia, Patagonia)
constrain mining activities in river systems, especially those of great ecological relevance
mandatory sewage stations in every urban area
set programs to improve water reuse in urban areas
develop aquaculture based on principles of sustainability
encourage small-scale aquaculture with native species
encourage pond aquaculture instead of cages
forbid aquaculture activities within protected areas, including the riparian buffer zone
revise the current plan to expand cage aquaculture in reservoirs
revise the expansion of agribusiness activities over new areas
exclude agribusiness and cattle raising from wetlands, floodplains and riparian areas
revise the list of pesticides and fertilizers allowed in agribusiness, and inspect their use
encourage and preserve small-scale, familiar and organic agriculture
diversify energy sources (e.g. solar, wind, biomass)
enhance efficiency in power generation and distribution.
(B) Sound management
create freshwater protected areas (e.g. segments, habitats, rivers or basins)
prioritize the preservation of hydrological connectivity and the natural flow regime
maintain considerable free-flowing segments and landscape diversity
restore and preserve riparian vegetation
restore and preserve critical habitats for feeding, reproduction and recruitment
restore and preserve habitats important to migratory, endemic and/or threatened species
consider fish needs to guide dam operation and water releases
sustain ecological integrity in areas surrounding impoundments
consider technical studies to guide management actions
avoid fish stocking or fish passages without qualified technical support
prioritize adaptive management in altered ecosystems
encourage community-based management in fishery systems
set programs to prevent, control and eradicate non-native species
monitor every management and conservation action
encourage the use of Indexes of Biotic Integrity (IBI)

(Continues)

TABLE 3 (Continued)

(C) Adequate policy
set an administrative framework for balancing economic, environmental and societal interests in decisionmaking and legislation
set economic policies that take into account environmental consequences in the short and long term
follow Aichi Biodiversity Targets (Convention on Biological Diversity 2012)
set efforts to implement international conservation programs
set mechanisms to avoid corruption in development projects, especially mega-projects
improve communication between decisionmakers and scientists
encourage scientists to make scientific knowledge accessible to society
create consulting scientific committees to advice prosecutors and different spheres of governance (i.e. legislative, executive and judicial)
enact legislation based on the Precautionary Principle
improve the technical quality of private and public agencies responsible for environmental impact studies, inspection and monitoring
improve the scientific quality of environmental impact studies (EIA-RIMA)
assure the correct and unbiased action of agencies responsible for environmental licensing and inspection
apply risk and contingency analyses to evaluate development projects
apply the Polluter Pays Principle
fund research to improve the use of alternative energy sources (e.g. solar, wind, biomass, tide, hydrogen)
fiscal incentives for the use of sustainable energy sources
fiscal incentives for the preservation and restoration of springs, headwaters and riparian zones
fiscal incentives for land owners and municipalities to maintain protected areas
create a research centre on biological invasions in Latin America
provide environmental education at all levels of formal education.

These high-impact activities have immediate positive effects on national economies, and this is the reason why policies rely on them. Countries in Latin America have proposed strategic actions to accelerate economic growth (e.g. Alcorn et al., 2010; Anderson et al., 2006; Bellfield, 2015; Bernard et al., 2014; Castello & Macedo, 2015; Cremers et al., 2013; Finer & Jenkins, 2012; Harer et al., 2016; Killeen, 2011; Lapola et al., 2014; Lees et al., 2016; Valladão et al., 2016), and some countries (e.g. Brazil) became leading economies among emerging nations. Authorities, however, neglect long-term sustainability and costs related to the loss of biodiversity and natural capital. A critical aspect is that countries follow deficient regulatory approaches and legal frameworks, that is poor environmental planning, assessments, licensing and monitoring. Decisionmaking for new projects, for example, is heavily biased towards short-term economic returns or benefits directed to specific sectors (e.g. banks, big companies, monopolies, politicians), often with little relevance to social well-being and long-term development (Alcorn et al., 2010; Fearnside, 2016b). The licensing process, although austere in some countries, is deficient because authorities usually fail to balance costs and benefits in both economic and environmental dimensions, particularly for mega-projects (Huete-Perez et al., 2013; Killeen, 2011; Winemiller et al., 2016). High-impact activities have been approved even in cases where important ecosystem services were impaired and social return was low. The approval of large dams in the Amazon River Basin (e.g. Vera Cruz, Chadin 2 and Belo Monte), for example, was conceded under social and environmental conflicts, and based on poor scientific assessments (Lees et al., 2016; Sabaj-Pérez, 2015). The monitoring of human activities is another weak aspect, usually insufficient, precarious or absent (Magalhães & Vitule, 2013); impacts remain poorly evaluated or even unknown. The breaching of mine tailing dams in the Rio Doce Valley (Escobar, 2015), for example, could be avoided with periodic inspection of wastes and contention dams (Meira et al., 2016). Therefore, Neotropical freshwater ecosystems are vulnerable to an increasing number of threats because national policies desire rapid economic development, and legislation and development frameworks are permissive in terms of supporting unsustainable activities. These countries, consequently, are unable to find a balance between economic growth and the preservation of natural capital (Bovarnick et al., 2010; Esselman et al., 2012; Lees et al., 2016).

While threats are increasingly unabated, few and controversial conservation measures (e.g. stocking and fish passages) have been put forth to preserve fish biodiversity. Better alternatives exist (Table 3), such as the implementation of freshwater protected areas, the restoration of freshwater ecosystems and the preservation of riparian forests. Such actions, however, have received little support from authorities. Protected areas, for example, have been biased towards terrestrial ecosystems (Abell, Allan, & Lehner, 2007), and there is no river (or basin) in the Neotropical region that is substantially protected (e.g. Rodríguez-Olarte, Taphorn, & Lobon-Cerviá, 2011); river restoration is similarly incipient, and has not sought to re-establish flow regimes, connectivity and key habitats. The preservation of riparian forests also faces significant difficulties. While legislation have historically demanded their protection, conservation practices are poor and commonly ignored by landowners; in addition, recent legislation have weakened conservation demands (Fearnside, 2016a; Nazareno et al., 2011). Principles of integrated fishery management (e.g. engagement of local people, multiple stock assessments, no-take areas, control of commercial fleets) have also been overlooked, even though this management has beneficial effects on the preservation of fishery stocks (e.g. Sarstoon-Temash National Park, Belize; Pacaya-Samiria National Reserve, Peru; Mamirauá Reserve, Brazil; Gerstner et al., 2006; Esselman et al., 2012; Hurd et al., 2016). On the contrary, authorities have encouraged traditional fishers to become fish farmers (Agostinho, Gomes et al., 2007; Lima et al., 2016), as rivers are impounded and cage aquaculture grows exponentially. The point is that policy makers have consistently ignored ecological knowledge and genuine conservation actions in decisionmaking and legislation (Azevedo-Santos et al., 2017; Ferreira et al., 2014; Pelicice et al., 2014). This negligence probably has many roots, but overall ignorance and misinformation (Azevedo-Santos et al., 2015), a strong economic bias, together with private interests and systematic corruption (Fearnside, 2016a; Winemiller et al., 2016), play complimentary roles. Better alternatives must be sought immediately (e.g. Table 3), especially because they are complex, large-scale, demand careful planning and their results appear only in the long term. Furthermore, they demand the commitment of different social agencies (e.g. lawmakers, managers, educators, citizens and traditional people) and, because some river systems cross national boundaries (e.g. Hondo, Sarstoon, Usumacinta, Amazon, La Plata, Pilcomayo), conservation initiatives will demand international cooperation. Compliance with the Aichi Biodiversity Targets (Convention of Biological Diversity) is a much-needed starting point, especially because all activities listed in Table 1 are in disagreement with many targets.

The current situation demands a profound behavioural shift towards better practices and policies (Table 2), or these high-impact activities will erode biodiversity and impair essential ecosystem services, jeopardizing human activities in the long run (Mooney, 2010). If society is worried about the perpetuation of NFF, people must understand that the current *modus operandi* of human development is incompatible with the persistence of natural freshwater ecosystems, and that no simple solution is available to correct or minimize its effects. We hope that this message reaches researchers and authorities in Latin America (and beyond), and initiates a discussion on the future of freshwater fishes, especially because these countries hold a high diversity and share similar environmental conflicts. In this sense, ecologists and conservationists must tear down the ivory tower and fill the communication gap between authorities/society and scientific knowledge, so policies that combine true social development with legitimate environmental concerns are proposed (Azevedo-Santos et al., 2017). Otherwise, Neotropical fish biodiversity will undergo irreversible losses.

ACKNOWLEDGEMENTS

Fernando M. Pelicice, Jean R. S. Vitule, Paulo S. Pompeu and Angelo A. Agostinho received CNPq research grants. André L. B. Magalhães and Valter M. Azevedo-Santos received CAPES scholarships. Authors thank Sérgio Segantin Marcato, Carlos Bernardo Mascarenhas Alves (UFMG) and João de Magalhães Lopes (CEMIG) for providing pictures 2d, 2e and 2k, respectively.

REFERENCES

Abell, R., Allan, J. D., & Lehner, B. (2007). Unlocking the potential of protected areas for freshwaters. *Biological Conservation*, *134*, 48–63.

Abilhoa, V., Braga, R. R., Bornatowski, H., & Vitule, J. R. S. (2011). Fishes of the Atlantic Rain forest streams: Ecological patterns and conservation. In: O. Grillo & G. Venora (Eds.), *Changing diversity in changing environment* (pp. 259–282). Croatia: InTech.

Agostinho, A. A., Agostinho, C. S., Pelicice, F. M., & Marques, E. E. (2012). Fish ladders: Safe fish passage or hotspot for predation? *Neotropical Ichthyology*, *10*, 687–696.

Agostinho, A. A., Gomes, L. C., & Pelicice, F. M. (2007). *Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil*. Eduem: Maringá.

Agostinho, A. A., Gomes, L. C., Santos, N. C. L., Ortega, J. C. G., & Pelicice, F. M. (2016). Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. *Fisheries Research*, *173*, 26–36.

Agostinho, A. A., Gomes, L. C., Veríssimo, S., & Okada, E. K. (2004). Flood regime, dam regulation and fish in the Upper Paraná River: Effects on assemblage attributes, reproduction and recruitment. *Reviews in Fish Biology and Fisheries*, *14*, 11–19.

Agostinho, A. A., Pelicice, F. M., Gomes, L. C., & Júlio Júnior, H. F. (2010). Reservoir fish stocking: When one plus one may be less than two. *Natureza & Conservação*, *8*, 103–111.

Agostinho, C. S., Pelicice, F. M., Marques, E. E., Soares, A. B., & Almeida, D. A. A. (2011). All that goes up must come down? Absence of downstream passage through a fish ladder in a large Amazonian river. *Hydrobiologia*, *675*, 1–12.

Agostinho, A. A., Pelicice, F. M., Petry, A. C., Gomes, L. C., & Júlio Júnior, H. F. (2007). Fish diversity in the upper Paraná River basin: Habitats, fisheries, management and conservation. *Aquatic Ecosystem Health & Management*, *10*, 174–186.

Alcorn, J. B., Zarzycki, A., & de la Cruz, L. M. (2010). Poverty, governance and conservation in the Gran Chaco of South America. *Biodiversity*, *11*, 31–38.

Alho, C. J., & Sabino, J. (2011). A conservation agenda for the Pantanal's biodiversity. *Brazilian Journal of Biology*, *71*(Supplement 1), 327–335.

Allan, J. D., Abell, R., Hogan, Z. S., Revenga, C., Taylor, B. W., Welcomme, R. L., & Winemiller, K. O. (2005). Overfishing of inland waters. *BioScience*, *55*, 1041–1051.

Anderson, E. P., Pringle, C. M., & Rojas, M. (2006). Transforming tropical rivers: An environmental perspective on hydropower development in Costa Rica. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *16*, 679–693.

Angelo, C. (2016). Brazil's scientists battle to escape 20-year funding freeze. *Nature*, *539*, 480.

Araújo, F. G., Pinto, B. C. T., & Teixeira, T. P. (2009). Longitudinal patterns of fish assemblages in a large tropical river in southeastern Brazil: Evaluating environmental influences and some concepts in river ecology. *Hydrobiologia*, *618*, 89–107.

Ashikaga, F. Y., Orsi, M. L., Oliveira, C., Senhorini, J. A., & Foresti, F. (2015). The endangered species *Brycon orbignyanus*: Genetic analysis and definition of priority areas for conservation. *Environmental Biology of Fishes*, *98*(7), 1845–1855.

Azevedo-Santos, V. M., Fearnside, P. M., Oliveira, C. S., Padial, A. A., Pelicice, F. M., Lima Jr, D. P., … Vitule, J. R. S. (2017). Removing the abyss between conservation science and policy decisions in Brazil. *Biodiversity and Conservation*. In press.

Azevedo-Santos, V. M., Pelicice, F. M., Lima Junior, D. P., Magalhães, A. L. B., Orsi, M. L., Vitule, J. R. S., & Agostinho, A. A. (2015). How to avoid fish introductions in Brazil: Education and information as alternatives. *Natureza & Conservação*, *13*, 123–132.

Barletta, M., Jaureguizar, A. J., Baigun, C., Fontoura, N. F., Agostinho, A. A., Almeida-Val, V. M. F., … Corrêa, M. F. M. (2010). Fish and aquatic habitat conservation in South America: A continental overview with emphasis on neotropical systems. *Journal of Fish Biology*, *76*, 2118–2176.

Barrella, W., & Petrere Jr, M. (2003). Fish community alterations due to pollution and damming in Tietê and Paranapanema rivers (Brazil). *River Research and Applications*, *19*, 59–76.

Barthem, R., Ribeiro, M. C. L. B., & Petrere Jr, M. (1991). Life Strategies of some Long-Distance Migratory Catfish in Relation to Hydroelectric Dams in the Amazon Basin. *Biological Conservation*, *55*, 339–345.

Batista, V. S., Inhamuns, A. J., Freitas, C. E. C., & Freire-Brasil, D. (1998). Characterization of the fishery in river communities in the low-Solimoes/high-Amazon region. *Fisheries Management and Ecology*, *5*, 419–435.

Bellfield, H. (2015). *The water, energy and food security nexus in Latin America and the Caribbean - Trade-offs, strategic priorities and entry points*. Oxford: Global Canopy Programme.

Bernard, E., Penna, L. A. O., & Araujo, E. (2014). Downgrading, downsizing, degazettement, and reclassification of protected areas in Brazil. *Conservation Biology*, *28*, 939–950.

Bittencourt, L. S., Silva, U. R. L., Silva, L. M. A., & Tavares-Dias, M. (2014). Impact of the invasion from Nile tilapia on natives Cichlidae species in tributary of Amazonas River, Brazil. *Biota Amazônia*, *4*, 88–94.

Bordignon, C. R., Casatti, L., Pérez-Mayorga, M. A., Teresa, F. B., & Brejão, G. L. (2015). Fish complementarity is associated to forests in Amazonian streams. *Neotropical Ichthyology*, *13*, 579–590.

Bovarnick, A., Alpizar, F., & Schnell, C. (2010). *The importance of biodiversity and ecosystems in economic growth and equity in Latin America and the Caribbean: An economic valuation of ecosystems*. New York: United Nations Development Programme.

Britton, J. R., & Orsi, M. L. (2012). Non-native fish in aquaculture and sport fishing in Brazil: Economic benefits versus risks to fish diversity in the upper River Paraná Basin. *Reviews in Fish Biology and Fisheries*, *22*, 555–565.

Carolsfeld, J., Harvey, B., Ross, C., & Baer, A. (2003). *Migratory fishes of South America: Biology, fisheries and conservation status*. Ottawa: World Fisheries Trust, The World Bank.

Casatti, L., Ferreira, C. P., & Carvalho, F. R. (2009). Grass-dominated stream sites exhibit low fish species diversity and dominance by guppies: An assessment of two tropical pasture river basins. *Hydrobiologia*, *632*, 273–283.

Castello, L., Arantes, C. C., McGrath, D. G., Stewart, D. J., & Sousa, F. S. (2014). Understanding fishing-induced extinctions in the Amazon. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *25*(5), 587–598.

Castello, L., Isaac, V. J., & Thapa, R. (2015). Flood pulse effects on multispecies fishery yields in the Lower Amazon. *Royal Society Open Science*, *2*, 150299.

Castello, L., & Macedo, M. N. (2015). Large-scale degradation of Amazonian freshwater ecosystems. *Global Change Biology*, *22*, 990–1007.

Castello, L., McGrath, D. G., Hess, L. L., Coe, M. T., Lefebvre, P. A., Petry, P., … Arantes, C. C. (2013). The vulnerability of Amazon freshwater ecosystems. *Conservation Letters*, *6*, 217–229.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances*, *1*, e1400253.

Cooney, P. B., & Kwak, T. J. (2013). Spatial extent and dynamics of dam impacts on tropical island freshwater fish assemblages. *BioScience*, *63*, 176–190.

Correa, S. B., Araujo, J. K., Penha, J. M. F., Cunha, C. N., Stevenson, P. R., & Anderson, J. T. (2015). Overfishing disrupts an ancient mutualism between frugivorous fishes and plants in Neotropical wetlands. *Biological Conservation*, *191*, 159–167.

Costa-Pereira, R., & Galetti, M. (2015). Frugivore downsizing and the collapse of seed dispersal by fish. *Biological Conservation*, *191*, 809–811.

Cremers, L., Kolen, J., & Theije, M. (2013). *Small-scale gold mining in the Amazon: The cases of Bolivia, Brazil, Colombia, Peru and Suriname*. Amsterdam: CEDLA, Cuadernos del CEDLA 26.

Cunico, A. M., Allan, J. D., & Agostinho, A. A. (2011). Functional convergence of fish assemblages in urban streams of Brazil and the United States. *Ecological Indicators*, *11*, 1354–1359.

Daga, V. S., Debona, T., Abilhoa, V., Gubiani, É. A., & Vitule, J. R. S. (2016). Non-native fish invasions of a Neotropical ecoregion with high endemism: A review of the Iguaçu River. *Aquatic Invasions*, *11*, 209–223.

Daga, V. S., Skóra, F., Padial, A. A., Abilhoa, V., Gubiani, É. A., & Vitule, J. R. S. (2015). Homogenization dynamics of the fish assemblages in Neotropical reservoirs: Comparing the roles of introduced species and their vectors. *Hydrobiologia*, *746*, 327–347.

Di Dario, F., Alves, C. B., Boos, H., Frédou, F. L., Lessa, R. P. T., Mirancone, M. M., … Vieira, F. (2015). A better way forward for Brazil's fisheries. *Science*, *347*, 1079.

Diana, J. S. (2009). Aquaculture production and biodiversity conservation. *BioScience*, *59*, 27–38.

Duponchelle, F., Pouilly, M., Pécheyran, C., Hauser, M., Renno, J.-F., Panfili, J., … Baras, E. (2016). Trans-Amazonian natal homing in giant catfish. *Journal of Applied Ecology*, *53*, 1511–1520.

Escobar, H. (2015). Mud tsunami wreaks ecological havoc in Brazil. *Science*, *350*, 1138–1139.

Esselman, P. C., Schmitter-Soto, J. J., & Allan, J. D. (2012). Spatiotemporal dynamics of the spread of African tilapias (Pisces: *Oreochromis* spp.) into rivers of northeastern Mesoamerica. *Biological Invasions*, *15*(7), 1471–1491.

FAOSTAT. (2015). *Food and Agriculture Organization of the United Nations: statistics division*. Retrieved from http://faostat3.fao.org/ (Accessed November 2015).

Fearnside, P. M. (2005). Deforestation in Brazilian Amazonia: History, rates, and consequences. *Conservation Biology*, *19*(3), 680–688.

Fearnside, P. M. (2016a). Brazilian politics threaten environmental policies. *Science*, *353*, 746–748.

Fearnside, P. M. (2016b). Tropical dams: To build or not to build? *Science*, *351*, 456–457.

Ferreira, J., Aragão, L. E. O. C., Barlow, J., Barreto, P., Berenguer, E., Bustamante, M., … Zuanon, J. (2014). Brazil's environmental leadership at risk. *Science*, *346*, 706–707.

Finer, M., & Jenkins, C. N. (2012). Proliferation of hydroelectric dams in the Andean Amazon and implications for Andes-Amazon connectivity. *PLoS One*, *7*, e35126.

Freeman, M. C., Pringle, C. M., Greathouse, E. A., & Freeman, B. J. (2003). Ecosystem-level consequences of migratory faunal depletion caused by dams. *American Fisheries Society Symposium*, *35*, 255–266.

Froese, R., & Pauly, D. (2016). FishBase. Retrieved from http://www.fishbase.org/ (Accessed February 2016).

Gerstner, C. L., Ortega, H., Sanchez, H., & Graham, C. L. (2006). Effects of the freshwater aquarium trade on wild fish populations in differentially-fished areas of the Peruvian Amazon. *Journal of Fish Biology*, *68*(3), 862–875.

Gois, K. S., Pelicice, F. M., Gomes, L. C., & Agostinho, A. A. (2015). Invasion of an Amazonian cichlid in the Upper Paraná River: Facilitation by dams and decline of a phylogenetically related species. *Hydrobiologia*, *746*, 401–413.

Greathouse, E. A., Pringle, C. M., & Holquist, J. G. (2006). Conservation and management of migratory fauna: Dams in tropical streams of Puerto Rico. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *16*, 695–712.

Habit, E., & Cussac, V. (2016). Conservation of the freshwater fauna of Patagonia: An alert to the urgent need for integrative management and sustainable development. *Journal of Fish Biology*, *89*, 369–370.

Harer, A., Torres-Dowdall, J., & Meyer, A. (2016). The imperiled fish fauna in the Nicaragua Canal zone. *Conservation Biology*, *31*(1), 86–95.

Hoeinghaus, D. J., Agostinho, A. A., Gomes, L. C., Pelicice, F. M., Okada, E. K., Latini, J. D., … Winemiller, K. O. (2009). Effects of river impoundment on ecosystem services of large Tropical rivers: Embodied energy and market value of artisanal fisheries. *Conservation Biology*, *23*, 1222–1231.

Honji, R. M., Caneppele, D., Hilsdorf, A. W., & Moreira, R. G. (2009). Threatened fishes of the world: *Steindachneridion parahybae* (Steindachner, 1877) (Siluriformes: Pimelodidae). *Environmental Biology of Fishes*, *85*(3), 207–208.

Huete-Perez, J. A., Tundisi, J. G., & Alvarez, P. J. J. (2013). Will Nicaragua's Interoceanic Canal result in an environmental catastrophe for Central America? *Environmental Science & Technology*, *47*, 13217–13219.

Hughes, R. M., Amezcua, F., Chambers, D. M., Daniel, W. M., Franks, J. S., Franzin, W., … Woody, C. A. (2016). AFS position paper and policy on mining and fossil fuel extraction. *Fisheries*, *41*, 12–15.

Hurd, L. E., Sousa, R. G. C., Siqueira-Souza, F. K., Cooper, G. J., Kahn, J. R., & Freitas, C. E. C. (2016). Amazon floodplain fish communities: Habitat connectivity and conservation in a rapidly deteriorating environment. *Biological Conservation*, *195*, 118–127.

Jiménez-Segura, L. F., Galvis-Vergara, G., Cala-Cala, P., García-Alzate, C. A., Lópes-Casas, S., Ríos-Pulgarín, M. I., … Álvarez-León, R. (2016). Freshwater fish faunas, habitats and conservation challenges in the Caribbean river basins of north-western South America. *Journal of Fish Biology*, *89*, 65–101.

Júlio Júnior, H. F., Dei Tós, C., Agostinho, A. A., & Pavanelli, C. S. (2009). A massive invasion of fish species after eliminating a natural barrier in the upper rio Paraná basin. *Neotropical Ichthyology*, *7*, 709–718.

Killeen, T. J. (2011). A perfect storm in the Amazon wilderness: Development and conservation in the context of the initiative for the integration of the regional infrastructure of South America (IIRSA). *BioOne*, *7*, 8–10.

Klink, C. A., & Machado, R. B. (2005). Conservation of the Brazilian Cerrado. *Conservation Biology*, *19*(3), 707–713.

Lapola, D. M., Martinelli, L. A., Peres, C. A., Ometto, J. P. H. B., Ferreira, M. E., Nobre, C. A., … Vieira, I. C. G. (2014). Pervasive transition of the Brazilian land-use system. *Nature Climate Change*, *4*, 27–35.

Lasso, C. A., Machado-Allison, A., & Taphorn, D. C. (2016). Fishes and aquatic habitats of the Orinoco River Basin: Diversity and conservation. *Journal of Fish Biology*, *89*, 174–191.

Leal, C. G., Pompeu, P. S., Gardner, T. A., Leitão, R. P., Hughes, R. M., Kaufmann, P. R., … Barlow, J. (2016). Multi-scale assessment of human-induced changes to Amazonian instream habitats. *Landscape Ecology*, *31*(8), 1725–1745.

Leal, I. R., Silva, J. M. C., Tabarelli, M., & Lacher, T. E. Jr (2005). Changing the course of biodiversity conservation in the Caatinga of Northeastern Brazil. *Conservation Biology*, *19*, 701–706.

Lees, A. C., Peres, C. A., Fearnside, P. M., Schneider, M., & Zuanon, J. A. S. (2016). Hydropower and the future of Amazonian biodiversity. *Biodiversity and Conservation*, *25*, 451–466.

Leitão, R. P., Zuanon, J., Villéger, S., Williams, S. E., Baraloto, C., Fortunel, C., … Mouillot, D. (2016). Rare species contribute disproportionately to the functional structure of species assemblages. *Proceedings of the Royal Society B*, *283*, 20160084.

Lévêque, C., Oberdorff, T., Paugy, D., Stiassny, M. L. J., & Tedesco, P. A. (2008). Global diversity of fish (Pisces) in freshwater. *Hydrobiologia*, *595*(1), 545–567.

Lima Junior, D. P., Magalhães, A. L. B., & Vitule, J. R. S. (2015). Dams, politics and drought threat: The march of folly in Brazilian freshwaters ecosystems. *Natureza & Conservação*, *13*, 196–198.

Lima, L. B., Oliveira, F. J. M., Giacomini, H. C., & Lima Junior, D. P. (2016). Expansion of aquaculture parks and the increasing risk of non-native species invasions in Brazil. *Reviews in Aquaculture*. In press.

Loyola, R. (2014). Brazil cannot risk its environmental leadership. *Diversity and Distributions*, *20*, 1365–1367.

Magalhães, A. L. B., Casatti, L., & Vitule, J. R. S. (2011). Changes in the Brazilian Forest Law will promote non-native species of freshwater fish. *Natureza & Conservação*, *9*, 121–124.

Magalhães, A. L. B., & Jacobi, C. M. (2013). Asian aquarium fishes in a Neotropical biodiversity hotspot: Impeding establishment, spread and impacts. *Biological Invasions*, *15*, 2157–2163.

Magalhães, A. L. B., Santos, V. M. R., Lima-Junior, D. P., Azevedo-Santos, V. M., Orsi, M. L., Brito, M. F. G., & Vitule, J. R. S. (2017). Biodiversity at risk from austerity law. *Nature*, *542*, 295–296.

Magalhães, A. L. B., & Vitule, J. R. S. (2013). Aquarium industry threatens biodiversity. *Science*, *341*, 457.

Martinelli, L. A., Naylor, R., Vitousek, P. M., & Moutinho, P. (2010). Agriculture in Brazil: Impacts, costs, and opportunities for a sustainable future. *Current Opinion in Environmental Sustainability*, *2*, 431–438.

Mateus, L. A., Penha, J. M. F., & Petrere Jr, M. (2004). Fishing resources in the rio Cuiabá basin, Pantanal do Mato Grosso, Brazil. *Neotropical Ichthyology*, *2*(4), 217–227.

McKaye, K. R., Ryan, J. D., Stauffer, J. R. Jr, Perez, L. J. L., Vega, G. I., & van den Berghe, E. P. (1995). African Tilapia in Lake Nicaragua. *BioScience*, *45*(6), 406–411.

McLaughlin, R. L., Smyth, E. R. B., Castro-Santos, T., Jones, M. L., Koops, M. A., Pratt, T. C., & Vélez-Espino, L. A. (2013). Unintended consequences and trade-offs of fish passage. *Fish and Fisheries*, *14*, 580–604.

Meira, R. M., Peixoto, A. L., Coelho, M. A., Ponzo, A. P. L., Esteves, V. G. L., Silva, M. C., … Meira-Neto, J. A. A. (2016). Brazil's mining code under attack: Giant mining companies impose unprecedented risk to biodiversity. *Biodiversity and Conservation*, *25*, 407–409.

Mooney, H. A. (2010). The ecosystem-service chain and the biological diversity crisis. *Philosophical Transactions of the Royal Society B*, *365*, 31–39.

Nascimento, W. S., Yamamoto, M. E., Chellappa, N. T., Rocha, O., & Chellappa, S. (2015). Conservation status of an endangered annual fish *Hypsolebias antenori* (Rivulidae) from Northeastern Brazil. *Brazilian Journal of Biology*, *75*, 484–490.

Nazareno, A. G., Feres, J. M., Carvalho, D., Sebbenn, A. M., Lovejoy, T. E., & Laurence, W. F. (2011). Serious new threat to Brazilian forests. *Conservation Biology*, *26*, 5–6.

Nazareno, A. G., & Vitule, J. R. S. (2016). Too many mining disasters in Brazil. *Nature*, *531*, 580.

Nestler, J. M., Pompeu, P. S., Goodwin, R. A., Smith, D. L., Silva, L. G. M., Baigún, C. R. M., & Oldani, N. O. (2012). The river machine: A template for fish movement and habitat, fluvial geomorphology, fluid dynamics and biogeochemical cycling. *River Research and Applications*, *28*(4), 490–503.

Noakes, D. L. G., & Bouvier, L. D. (2013). Threatened fishes of the world: The end of a series. *Environmental Biology of Fishes*, *96*, 1135–1149.

Nogueira, C., Buckup, P. A., Menezes, N. A., Oyakawa, O. T., Kasecker, T. P., Neto, M. B. R., & Silva, J. M. C. (2010). Restricted-Range Fishes and the Conservation of Brazilian Freshwaters. *PLoS One*, *5*(6), e11390.

Okada, E. K., Agostinho, A. A., & Gomes, L. C. (2005). Spatial and temporal gradients in artisanal fisheries of a large Neotropical reservoir, the Itaipu Reservoir, Brazil. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*, 714–724.

Orsi, M. L., & Britton, J. R. (2014). Long-term changes in the fish assemblage of a Neotropical hydroelectric reservoir. *Journal of Fish Biology*, *84*, 1964–1970.

Ortega, J. C. G., Júlio Júnior, H. F., Gomes, L. C., & Agostinho, A. A. (2015). Fish farming as the main driver of fish introductions in Neotropical reservoirs. *Hydrobiologia*, *746*, 147–158.

Ota, R. R., Message, H. J., da Graça, W. J., & Pavanelli, C. S. (2015). Neotropical Siluriformes as a model for insights on determining biodiversity of animal groups. *PLoS One*, *10*(7), e0132913.

Padial, A. A., Agostinho, A. A., Azevedo-Santos, V. A., Frehse, F. A., Lima-Junior, D. P., Magalhães, A. L. B., … Vitule, J. R. S. (2017). The "Tilapia Law" encouraging non-native fish threatens Amazonian River basins. *Biodiversity and Conservation*, *26*, 243–246.

Pelicice, F. M., & Agostinho, A. A. (2008). Fish passage facilities as ecological traps in large Neotropical rivers. *Conservation Biology*, *22*, 180–188.

Pelicice, F. M., Pompeu, P. S., & Agostinho, A. A. (2015). Large reservoirs as ecological barriers to downstream movements of Neotropical migratory fish. *Fish and Fisheries*, *16*, 697–715.

Pelicice, F. M., Vitule, J. R. S., Lima Junior, D. P., Orsi, M. L., & Agostinho, A. A. (2014). Serious new threat to Brazilian freshwater ecosystems: The naturalization of nonnative fish by decree. *Conservation Letters*, *7*(1), 55–60.

Petesse, M. L., & Petrere Jr, M. (2012). Tendency towards homogenization in fish assemblages in the cascade reservoir system of the Tietê river basin, Brazil. *Ecological Engineering*, *48*, 109–116.

Petrere Jr, M. (1996). Fisheries in large tropical reservoirs in South America. *Lakes & Reservoirs: Research and Management*, *2*, 111–133.

Petrere Jr, M., Barthem, R. B., Cordoba, E. A., & Gomez, B. C. (2004). Review of the large catfish fisheries in the upper Amazon and the stock depletion of piraiba (*Brachyplatystoma filamentosum* Lichtenstein). *Reviews in Fish Biology and Fisheries*, *14*, 403–414.

Pinheiro, A. A., Di Dario, F., Gerhardinger, L. C., Melo, M. R. S., Moura, R. L., Reis, R. E., … Rocha, L. A. (2015). Brazilian aquatic biodiversity in peril. *Science*, *350*, 1043–1044.

Pompeu, P. S., Agostinho, A. A., & Pelicice, F. M. (2012). Existing and future challenges: The concept of successful fish passage in South America. *River Research and Applications*, *28*, 504–512.

Pompeu, P. S., Alves, C. B. M., & Callisto, M. (2005). The effects of urbanization on biodiversity and water quality in the Rio das Velhas basin, Brazil. *American Fisheries Society Symposium*, *47*, 11–22.

Pringle, C., Freeman, M. C., & Freeman, B. J. (2000). Regional effects of hydrologic alterations on riverine macrobiota in the New World: Tropical-temperate comparisons. *BioScience*, *50*, 807–823.

Reis, R. E., Albert, J. S., Di Dario, F., Mincarone, M. M., Petry, P., & Rocha, L. A. (2016). Fish biodiversity and conservation in South America. *Journal of Fish Biology*, *89*, 12–47.

Reis, R. E., Kullander, S. O., & Ferraris Jr, C. J. (2003). *Check list of the freshwater fishes of South and Central America*. Porto Alegre: EDIPUCRS.

Rodríguez-Olarte, D., Taphorn, D. C., & Lobon-Cerviá, J. (2011). Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela. *Animal Biodiversity and Conservation*, *34*, 273–285.

Sabaj-Pérez, M. (2015). Where the Xingu bends and will soon break. *American Scientist*, *103*, 396–403.

Sanches, F. H. C., Miyai, C. A., Costa, T. M., Christofoletti, R. A., Volpato, G. L., & Barreto, R. E. (2012). Aggressiveness overcomes body-size effects in fights staged between invasive and native fish species with overlapping niches. *PLoS One*, *7*(1), e29746.

Santos, F. B., Ferreira, F. C., & Esteves, K. E. (2015). Assessing the importance of the riparian zone for stream fish communities in a sugarcane dominated landscape (Piracicaba River Basin, Southeast Brazil). *Environmental Biology of Fishes*, *98*, 1895–1912.

Swenson, J. J., Carter, C. E., Domec, J.-C., & Delgado, C. I. (2011). Gold mining in the Peruvian Amazon: Global prices, deforestation, and mercury Imports. *PLoS One*, *6*(4), e18875.

Teresa, F. B., Casatti, L., & Cianciaruso, M. V. (2015). Functional differentiation between fish assemblages from forested and deforested streams. *Neotropical Ichthyology*, *13*, 361–370.

Tollefson, J. (2016). Brazil debates loosening environmental protections. *Nature*, *539*, 147–148.

Toussaint, A., Charpin, N., Brosse, S., & Villéger, S. (2016). Global functional diversity of freshwater fish is concentrated in the Neotropics while functional vulnerability is widespread. *Scientific Reports*, *6*, 22125. https://doi.org/10.1038/srep22125

Valladão, G. M. R., Gallani, S. U., & Pilarski, F. (2016). South American fish for continental aquaculture. *Reviews in Aquaculture*. In press.

Van Damme, P. A., Méndez, C. C., Zapata, M., Carvajal-Vallejos, F. M., Carolsfeld, J., & Olden, J. D. (2015). The expansion of *Arapaima cf. gigas* (Osteoglossiformes: Arapaimidae) in the Bolivian Amazon as informed by citizen and formal science. *Management of Biological Invasions*, *6*(4), 375–383.

Vargas, P. V., Arismendi, I., & Gomez-Uchida, D. (2015). Evaluating taxonomic homogenization of freshwater fish assemblages in Chile. *Revista Chilena de Historia Natural*, *88*, 16.

Vitule, J. R. S., Agostinho, A. A., Azevedo-Santos, V. M., Daga, V. S., Darwall, W. R. T., Fitzgerald, D. B., … Winemiller, K. O. (2017). We need better understanding about functional diversity and vulnerability of tropical freshwater fishes. *Biodiversity and Conservation*, *26*, 757–762.

Vitule, J. R. S., da Costa, A. P. L., Frehse, F. A., Bezerra, L. A. V., Occhi, T. V. T., Daga, V. S., & Padial, A. A. (2017). Comments on 'Fish biodiversity and conservation in South America by Reis et al. (2016)'. *Journal of Fish Biology*, *90*(4), 1182–1190.

Vitule, J. R. S., Freire, C. A., & Simberloff, D. (2009). Introduction of non-native freshwater fish can certainly be bad. *Fish and Fisheries*, *10*, 98–108.

Vitule, J. R. S., Sampaio, F. D. F., & Magalhães, A. L. B. (2014). Monitor Brazil's fish sampling closely. *Nature*, *513*, 315.

Volcan, M. V., Gonçalves, A. C., & Lanés, L. E. K. (2011). Distribution, habitat and conservation status of two threatened annual fishes (Rivulidae) from southern Brazil. *Endangered Species Research*, *13*, 79–85.

Volpato, G. L., Barreto, R. E., Marcondes, A. L., Moreira, P. S. A., & Ferreira, M. F. B. (2009). Fish ladders select fish traits on migration – still a

growing problem for natural fish populations. *Marine and Freshwater Behaviour and Physiology*, *42*, 307–313.
Wantzen, K. M., & Mol, J. H. (2013). Soil erosion from agriculture and mining: A threat to tropical stream ecosystems. *Agriculture*, *3*, 660–683.
Winemiller, K., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., … Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo and Mekong. *Science*, *351*, 128–129.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Pelicice FM, Azevedo-Santos VM, Vitule JRS, et al. Neotropical freshwater fishes imperilled by unsustainable policies. *Fish Fish*. 2017;00:1–15. https://doi.org/10.1111/faf.12228