Neotropical Ichthyology

Original article

https://doi.org/10.1590/1982-0224-2022-0022

Fish biodiversity of a tropical estuary under severe anthropic pressure (Doce River, Brazil)

Vitor L. A. Rodrigues[1], Helder C. Guabiroba[1], Ciro C. Vilar[1], Ryan Andrades[1], Alexandre Villela[2], Maurício Hostim-Silva[3] and Jean-Christophe Joyeux[1]

Correspondence:
Vitor L. A. Rodrigues
vitor_leo@hotmail.com

The Doce River has undergone severe changes over the last centuries (*e.g.*, flow regulation, pollution, habitat and species loss). Here, we present the first comprehensive fish biodiversity assessment of the Doce River estuary and a summary of the main impacts and their drivers for the whole river since the early 18th century. Carangiformes, Siluriformes and Eupercaria *incertae sedis* were the most representative orders for the 115 species recorded. Most species are native (87.8%), euryhaline/peripheral (80%) and zoobenthivorous (33.9%). Threatened (*Paragenidens grandoculis*, *Genidens barbus*, and *Lutjanus cyanopterus*) and near threatened (*Cynoscion acoupa*, *Dormitator maculatus*, *Lutjanus jocu*, *Lutjanus synagris*, and *Mugil liza*) species are peripheral. Thirteen species are exotic at the country (*Butis koilomatodon*, *Coptodon rendalli*, and *Oreochromis niloticus*) or the basin level (*e.g.*, *Pygocentrus nattereri* and *Salminus brasiliensis*). The catfish *Cathorops* cf. *arenatus* is reported for the first time on the eastern coast of Brazil and *Paragenidens grandoculis*, considered extinct in the Doce River, was discovered in the estuary.

Keywords: Environmental impact, Estuarine, Ichthyofauna, Mining, Species richness.

Submitted March 23, 2022
Accepted August 24, 2022
by Osmar Luiz
Epub October 14, 2022

1 Laboratório de Ictiologia, Departamento de Oceanografia, Universidade Federal do Espírito Santo, 29075-910 Vitória, ES, Brazil. (VLAR) vitor_leo@hotmail.com (corresponding author), (HCG) helder.oceano@yahoo.com.br; (CCV) cirovilar@hotmail.com, (RA) ryanandrades@gmail.com, (JCJ) jean.joyeux@ufes.br.

2 Laboratório de Ictiologia de Altamira, Programa de Pós-graduação em Biodiversidade e Conservação, Universidade Federal do Pará, 66075-110 Altamira, PA, Brazil. (AV) a.vvribeiro@gmail.com.

3 Laboratório de Ecologia de Peixes Marinhos, Departamento de Ciências Agrárias e Biológicas, Centro Universitário Norte do Espírito Santo, 29932-540 São Mateus, ES, Brazil. (MHS) mhostim@gmail.com.

Online version ISSN 1982-0224
Print version ISSN 1679-6225

Neotrop. Ichthyol.
vol. 20, no. 3, Maringá 2022

O rio Doce tem passado por mudanças drásticas ao longo dos últimos séculos (*e.g.*, alterações na vazão, poluição, perda de espécies e habitats). Neste trabalho, apresentamos a primeira avaliação abrangente da biodiversidade de peixes no estuário do rio Doce além de um resumo dos principais impactos e suas forçantes em toda a extensão do rio desde o início do século vinte. Carangiformes, Siluriformes e Eupercaria *incertae sedis* foram as ordens mais representativas considerando as 115 espécies registradas. A maioria das espécies são nativas (87,8%), eurialinas/periféricas (80%) e zoobentívoras (33,9%). As espécies ameaçadas (*Paragenidens grandoculis*, *Genidens barbus* e *Lutjanus cyanopterus*) e quase ameaçadas (*Cynoscion acoupa*, *Dormitator maculatus*, *Lutjanus jocu*, *Lutjanus synagris* e *Mugil liza*) são periféricas. Treze espécies são exóticas a nivel de país (*Butis koilomatodon*, *Coptodon rendalli* e *Oreochromis niloticus*) ou bacia (*e.g.*, *Pygocentrus nattereri* e *Salminus brasiliensis*). O bagre *Cathorops* cf. *arenatus* é reportado pela primeira vez na costa leste do Brasil e *Paragenidens grandoculis*, considerado extinto no rio Doce, foi descoberto no estuário.

Palavras-chave: Estuarino, Ictiofauna, Impactos ambientais, Mineração, Riqueza de espécies.

INTRODUCTION

Estuaries are habitat-rich, highly productive ecotones between riverine and marine environments with diverse subsystems (*e.g.*, mud and sand flats, seagrass meadows and mangrove forests) that shelter complex benthic and pelagic communities (McLusky, Elliott, 2004). Despite their economic and social value (*e.g.*, providing fishing grounds, water supply, aquaculture and navigation) (Basset *et al.*, 2013), estuaries have been sorely exposed to human-driven habitat loss, the introduction of non-native species and water contamination (Lotze *et al.*, 2006).

The Doce River is among the major fluvial systems of southeastern Brazil and flows over 850 km (Lins *et al.*, 2012) through the states of Minas Gerais and Espírito Santo. It runs through the Neotropical Atlantic Forest, a hotspot biome (Ribeiro *et al.*, 2011) whose luxuriant vegetation and biodiversity was described by early European naturalists in the 19th century – Prince Maximilian in 1815; Saint-Hilaire in 1822; the Thayer Expedition in 1865 and Princess Therese in 1888 (Hartt, Agassiz, 1870; Saint-Hilaire, 1936; Wied-Neuwied, 1940; Baviera, 2013). These pioneering expeditions also produced the first reports on the fishes of the Doce River that, in particular, cite the locally extinct sawfish *Pristis pristis* (Linnaeus, 1758) (Vieira, Gasparini, 2007; Saldanha, 2018). Knowledge about the river's ichthyofauna composition (Vieira, 2009; Sarmento-Soares *et al.*, 2017; Vilar *et al.*, 2022) and its conservation status (Su *et al.*, 2021) has improved in recent years. However, estuarine fish assemblages remain poorly characterized in the Doce River estuary (DRE) (Jankowsky *et al.*, 2021) despite the area being recognized as of 'extremely high' biological importance (MMA, 2007).

Impacts caused by mining have been known for centuries (Saint-Hilaire, 1938, 1936). However, the past decades were marked by a rapid and severe degradation due

to urban growth and unsustainable use of resources (*e.g.*, wood-cycle deforestation, agriculture, industry and mining, dam construction) (Diniz *et al.*, 2014; Espindola, 2015). In this sense, biodiversity and ecological services have been threatened by habitat fragmentation, loss of basin and riparian vegetation, introduction of exotic species (Ruschi, 1965; Fragoso-Moura *et al.*, 2016; Bueno *et al.*, 2021; Su *et al.*, 2021) and widespread pollution (Agostinho *et al.*, 2005). In November 2015, the collapse of the Fundão dam (controlled by Samarco Mineração SA.) in the state of Minas Gerais, released about 40 million tons of iron ore tailings into the Doce River watershed. Environmental consequences varied from acute (such as immediate mass mortality of aquatic fauna) to chronic effects that still are under investigation (Hatje *et al.*, 2017; Bonecker *et al.*, 2019; Cordeiro *et al.*, 2019; Gabriel *et al.*, 2021).

After the dam breach, most studies carried in the Doce River have focused on socio-political, geochemistry and water quality issues (*e.g.*, Espindola, Guerra, 2018; Richard *et al.*, 2020; Longhini *et al.*, 2022). Conversely, the lack of faunal assemblages baselines (such as Gomes *et al.*, 2017; Andrades *et al.*, 2020; Bueno *et al.*, 2021; Condini *et al.*, 2022) hinders a comprehensive analysis of the effects of the released mining tailing on biodiversity.

Here we present the first ichthyofaunal inventory of the Doce River estuary. This work is inserted within a larger effort to detect and understand the assemblage structure (Condini *et al.*, 2022; Vilar *et al.*, 2022) and trophic ecology (Andrades *et al.*, 2020, 2021) of the estuarine and coastal fishes of the Doce River.

MATERIAL AND METHODS

Study area. The surveys were conducted in the lower reaches of the Doce River, located on the central coast of the state of Espírito Santo (Fig. 1; 19°39'S 39°49'W). This region belongs to the Atlantic Forest domain (IBGE, 2012), with the riparian vegetation a mosaic of pioneering freshwater plants (*e.g.*, Araceae, Cyperaceae, Poaceae), native tree-shaded cocoa farms and remnants of tropical rainforest (Rolim *et al.*, 2006; França *et al.*, 2013). The climate is tropical, with the dry season extending from April to September and the rainy season from October to March (Nimer, 1989; Alvares *et al.*, 2013). Despite a decreasing trend in the Doce River hydrological regime (Coelho, 2006), median streamflow during the wet season reaches up to 900 m^3/s (Oliveira, Quaresma, 2017), which explains the very low salinity near the river mouth (Gomes *et al.*, 2017; Vilar *et al.*, 2022). According to the geomorphological context, the Doce River mouth is a submerged deltaic system dominated by waves (Dominguez, Wanless, 1991). However, for the purpose of this study, we call this region the Doce River estuary (DRE) given the tidal influence on the river sedimentation and hydrodynamics and the perennial occurrence of marine fish species (Vilar *et al.*, 2022).

Data acquisition. Most data presented here come from two different monitoring programs. The first comprises nine expeditions conducted in November 2015 (before the mud reached the estuary), June 2016, June and November 2019, July/August and November/December 2020, June 2021, November/December 2021 and June 2022, totalizing 23 days of sampling in the marginal creeks and adjacencies of the sandbanks.

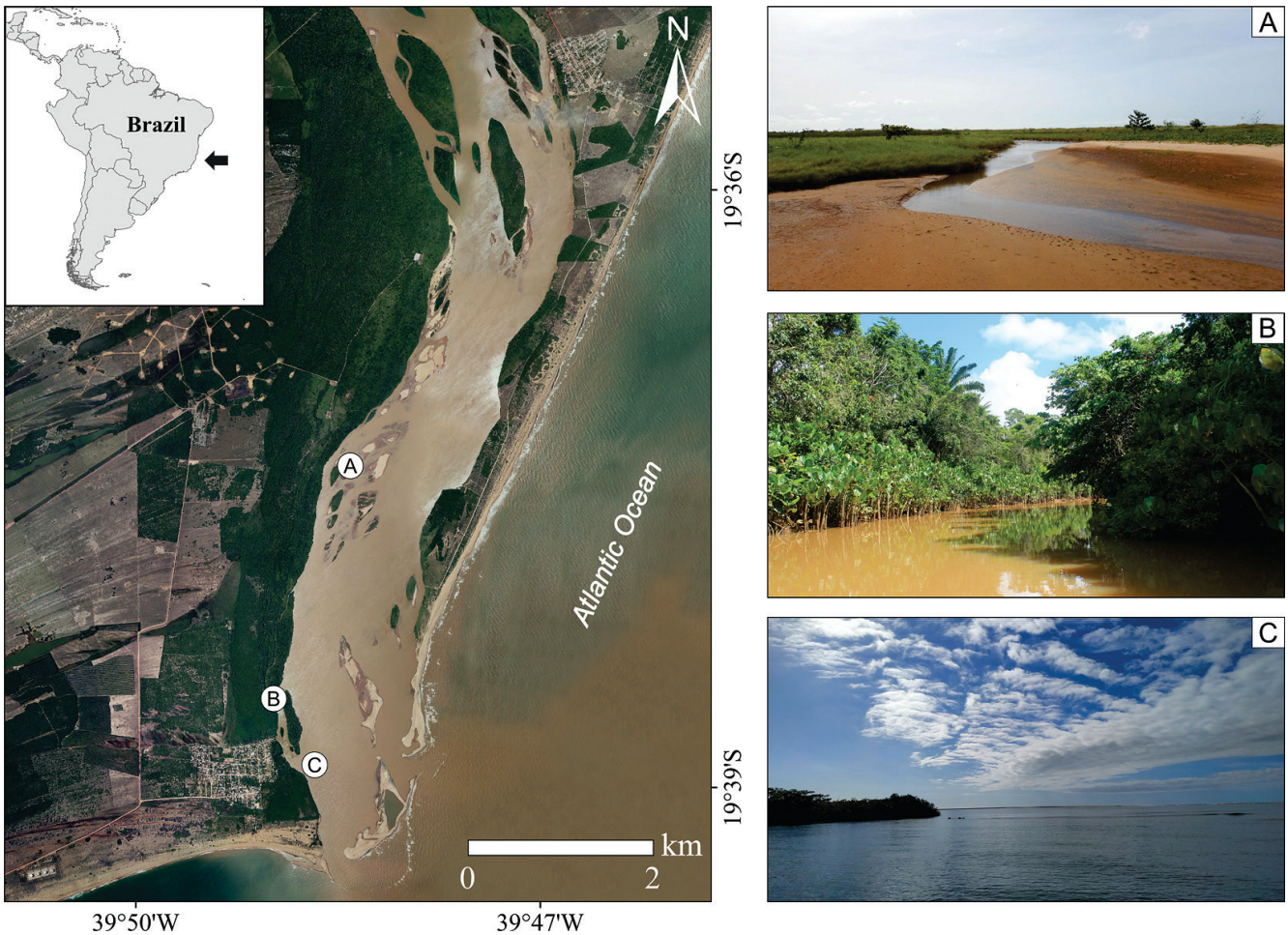

FIGURE 1 | Location of the study area in Eastern Brazil with some features detailed: **A.** Sandy banks; **B.** Marginal creek; and **C**. Main channel of the Doce River estuary (DRE). Photos: Helder C. Guabiroba (**A**; **C**), Alexandre Villela (**B**). Aerial image source: (GEOBASES, 2015).

Specimens were collected in both lotic and lentic environments by exhaustive sampling with the aid of multiple fishing gears (cast net, beach seine, dip net, and gillnets). The second sampling program was performed using a standardized bottom trawl towed by a 5-m-boat during 5-min at a speed of 2 to 3 knots (Vilar *et al*., 2022). Six sites distributed along the main channel of the DRE were monitored monthly from October 2018 to September 2019, and every three months from December 2019 to April 2022; sampling was interrupted between March and December of 2020 due to the COVID-19 pandemy. The present work also builds upon collection records available in the 'SpeciesLink' network database (http://splink.cria.org.br) that presented valid coordinates and a detailed description of the sampling area.

All collected fishes were euthanized in an ice-water slurry, kept on ice for a maximum of 48h, then frozen. After thawing and identification, representants of most species were fixed in formalin 10% and finally preserved in alcohol 70%. Selected lots were deposited at the Coleção Ictiológica da Universidade Federal do Espírito Santo, Vitória (CIUFES), see vouchers in Tab. **S1**.

Data analysis. All species were identified to the lowest possible taxonomic level with the aid of classical and current literature (*e.g.*, Figueiredo, Menezes, 1978; Menezes, 1980; Menezes, Figueiredo, 1980, 1985, 2000; Carvalho-Filho, 1999; Munroe, Nizinski, 2002; Nizinski, Munroe, 2002; Marceniuk, 2005; Kullander, Ferreira, 2006; Moura, Lindeman, 2007; Vieira *et al*., 2014, 2015; Marceniuk *et al*., 2019). Scientific names and phylogenetic arrangement of orders and families follow Betancur-R *et al*. (2017) and The Catalog of Fishes (Fricke *et al*., 2022).

Fishes were classified as 'native' or 'exotic'. The latter category was composed by 'exotic at the country-level', for non-Brazilian species and 'exotic at basin-level' for fishes native of other Brazilian river basins (ICMbio, 2018; Froese, Pauly, 2020). Fish tolerance to salinity was classified into three categories following Myers (1938) and Berra (2001): primary (freshwater fishes with low salinity tolerance); secondary (freshwater fishes with some salinity tolerance) and peripheral (marine fishes that occasionally occur in freshwater ecosystems). The current Brazilian Red List of Threatened Species (MMA, 2022) was considered for the assessment of the conservation status of native fishes. Status of exotic species from other countries was not assessed. Fish species were grouped into seven trophic categories according to literature (see Tab. **S1**): Zoobenthivore (feed primarily on benthic mobile invertebrates); Zooplanktivore (feed primarily on zooplankton); Piscivore (feed only or mostly on live fishes); Generalist carnivore (feed on both mobile invertebrates and fishes); Omnivore (feed on both plant and animal food sources); Detritivore (the main food sources are detritus and sediment); and Herbivore (feed primarily on vegetal material).

RESULTS

A total of 115 fish species, belonging to 24 orders, 44 families and 84 genera was recorded (Tab. 1). The order Carangiformes was the most speciose, with 22 species, followed by Eupercaria *incertae sedis* (12 species) and Siluriformes (11 species) (Fig. 2). The most representative families were Sciaenidae (12 species), Engraulidae (8), Carangidae, Cichlidae, and Gobiidae (7 each). Euryhaline or peripheral fishes were predominant in the DRE (92, or 80%), followed by primary (13%) and secondary fishes (7%). In terms of trophic guilds, zoobenthivores were dominant (33.9%), followed by generalist carnivores (19.1%), omnivores (14.8%), piscivores (11.3%), detritivores and zooplanktivores (8.7%). Herbivores comprised only 2.6% of species recorded.

Most species are native (101, or 87.8%), three species (2.6%) are exotic at the country level: *Coptodon rendalli* (Boulenger, 1897), *Oreochromis niloticus* (Linnaeus, 1758) and *Butis koilomatodon* (Bleeker, 1849) (Figs. 3C,D), and 11 species (9.6%) are from other Brazilian basins: *Cichla* cf. *kelberi*, *Cichla monoculus* Spix & Agassiz, 1831, *Cichlasoma dimerus* (Heckel, 1840), *Knodus* cf. *moenkhausii*, *Hypostomus scabriceps* (Eigenmann & Eigenmann, 1888), *Microglanis pataxo* Sarmento-Soares, Martins-Pinheiro, Aranda & Chamon, 2006, *Pimelodus maculatus Lacepède*, 1803, *Prochilodus argenteus* Spix & Agassiz, 1829, *Prochilodus costatus* Valenciennes, 1850, *Pygocentrus nattereri* Kner, 1858 and *Salminus brasiliensis* (Cuvier, 1816) (Figs. 3A,B). Brazilian endemics represent 19 species (16.5%); no species endemic to the Doce River basin was sampled. According to the Brazilian Red List, four species (3.5%) are currently threatened: *Parageneidens grandoculis*

TABLE 1 | Fishes of the Doce River estuary. Euryhalinity: Per, Peripheral; 1st, Primary; 2nd, Secondary. Trophic group: GC, Generalist carnivore; ZB, Zoobenthivore; ZP, Zooplanktivore; PV, Piscivore; OV, Omnivore; DT, Detritivore; HB, Herbivore; UD, Undefined. Origin: NV, Native; EX-B, Exotic at the basin level; EX-C, Exotic at the country level. Brazilian Red List: NA, Not Applied; DD, Data Deficient; LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; CR, Critically Endangered. Endemism: ED, Endemic of Brazil; NE, Non endemic of Brazil, fishing gear, vouchers and references for trophic guild are available in Tab. **S1**. *Specimens not caught in this study; † Locally extinct.

Taxa	Euryhalinity	Trophic group	Origin	Brazilian Red List	Endemism
PRISTIFORMES					
Pristidae					
Pristis pristis (Linnaeus, 1758)* †	Per	PV	NV	CR	NE
ELOPIFORMES					
Elopidae					
Elops cf. *smithi* McBride, Rocha, Ruiz-Carus & Bowen, 2010*	Per	GC	NV	LC	NE
ANGUILLIFORMES					
Ophichthidae					
Myrophis punctatus Lütken, 1852	Per	ZB	NV	LC	NE
CLUPEIFORMES					
Clupeidae					
Lilie piquitinga (Schreiner & Miranda Ribeiro, 1903)	Per	ZP	NV	LC	NE
Engraulidae					
Anchoa januaria (Steindachner, 1879)	Per	ZP	NV	LC	ED
Anchoa spinifer (Valenciennes, 1848)	Per	ZP	NV	LC	NE
Anchoa tricolor (Spix & Agassiz, 1829)	Per	ZP	NV	LC	ED
Anchovia clupeoides (Swainson, 1839)	Per	ZP	NV	LC	NE
Anchoviella cayennensis (Puyo, 1946)	Per	ZP	NV	LC	NE
Anchoviella lepidentostole (Fowler, 1911)	Per	ZP	NV	LC	NE
Cetengraulis edentulus (Cuvier, 1829)	Per	ZP	NV	LC	NE
Lycengraulis grossidens (Spix & Agassiz, 1829)	Per	GC	NV	LC	NE
Odontognathus mucronatus Lacepède, 1800	Per	ZP	NV	LC	NE
SILURIFORMES					
Callichthyidae					
Callichthys callichthys (Linnaeus, 1758)	1st	ZB	NV	LC	NE
Loricariidae					
Hypostomus scabriceps (Eigenmann & Eigenmann, 1888)	1st	DT	EX-B	LC	ED
Ariidae					
Cathorops cf. *arenatus* (Valenciennes, 1840)	Per	ZB	NV	LC	NE
Cathorops spixii (Agassiz, 1829)	Per	ZB	NV	LC	ED
Genidens barbus (Lacepède, 1803)	Per	ZB	NV	EN	NE
Genidens genidens (Cuvier, 1829)	Per	ZB	NV	LC	ED
Paragenidens grandoculis (Steindachner, 1877)	Per	ZB	NV	CR	ED
Sciades herzbergii (Bloch, 1794)	Per	ZB	NV	LC	NE
Auchenipteridae					
Pseudauchenipterus affinis (Steindachner, 1877)	1st	OV	NV	LC	ED
Pimelodidae					
Pimelodus maculatus Lacepède, 1803	1st	OV	EX-B	LC	NE
Pseudopimelodidae					
Microglanis pataxo Sarmento-Soares, Martins-Pinheiro, Aranda & Chamon, 2006	1st	OV	EX-B	LC	NE
CHARACIFORMES					
Characidae					
Astyanax cf. *lacustris* (Lütken, 1875)	1st	OV	NV	LC	ED
Deuterodon cf. *intermedius* Eigenmann, 1908	1st	OV	NV	LC	ED
Knodus cf. *moenkhausii* (Eigenmann & Kennedy, 1903)	1st	OV	EX-B	LC	NE
Bryconidae					
Salminus brasiliensis (Cuvier, 1816)	1st	PV	EX-B	LC	NE
Erythrinidae					
Hoplias intermedius (Günther, 1864)	1st	PV	NV	LC	ED

TABLE 1 | (Continued)

Taxa	Euryhalinity	Trophic group	Origin	Brazilian Red List	Endemism
Hoplias cf. *malabaricus* (Bloch, 1794)	1st	PV	NV	LC	ED
Serrasalmidae					
Pygocentrus nattereri Kner, 1858	1st	PV	EX-B	LC	NE
Prochilodontidae					
Prochilodus argenteus Spix & Agassiz, 1829	1st	DT	EX-B	LC	ED
Prochilodus costatus Valenciennes, 1850	1st	DT	EX-B	LC	ED
Anostomidae					
Megaleporinus conirostris (Steindachner, 1875)	1st	OV	NV	LC	ED
AULOPIFORMES					
Synodontidae					
Synodus foetens (Linnaeus, 1766)	Per	PV	NV	LC	NE
SCOMBRIFORMES					
Scombridae					
Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978	Per	PV	NV	LC	NE
SYNGNATHIFORMES					
Syngnathidae					
Microphis lineatus (Kaup, 1856)	Per	ZB	NV	LC	NE
GOBIIFORMES					
Eleotridae					
Butis koilomatodon (Bleeker, 1849)	Per	GC	EX-C	NA	NE
Dormitator maculatus (Bloch, 1792)	Per	OV	NV	NT	NE
Eleotris pisonis (Gmelin, 1789)	Per	GC	NV	LC	NE
Gobiidae					
Awaous tajasica (Lichtenstein, 1822)	Per	OV	NV	LC	NE
Bathygobius soporator (Valenciennes, 1837)	Per	OV	NV	LC	NE
Ctenogobius boleosoma (Jordan & Gilbert, 1882)	Per	OV	NV	LC	NE
Ctenogobius shufeldti (Jordan & Eigenmann, 1887)	Per	OV	NV	LC	NE
Evorthodus lyricus (Girard, 1858)	Per	DT	NV	LC	NE
Gobionellus oceanicus (Pallas, 1770)	Per	DT	NV	LC	NE
Microgobius meeki Evermann & Marsh, 1899	Per	ZB	NV	LC	NE
SYNBRANCHIFORMES					
Synbranchidae					
Synbranchus marmoratus Bloch, 1795	Per	PV	NV	LC	NE
CARANGIFORMES					
Centropomidae					
Centropomus parallelus Poey, 1860	Per	GC	NV	LC	NE
Centropomus undecimalis (Bloch, 1792)	Per	GC	NV	LC	NE
Polynemidae	Per				
Polydactylus oligodon (Günther, 1860)	Per	GC	NV	LC	NE
Polydactylus virginicus (Linnaeus, 1758)	Per	GC	NV	LC	NE
Carangidae					
Caranx crysos (Mitchill, 1815)	Per	PV	NV	LC	NE
Caranx hippos (Linnaeus, 1766)	Per	PV	NV	LC	NE
Caranx latus Agassiz, 1831	Per	ZB	NV	LC	NE
Chloroscombrus chrysurus (Linnaeus, 1766)*	Per	OV	NV	LC	NE
Oligoplites saliens (Bloch, 1793)	Per	PV	NV	LC	NE
Selene vomer (Linnaeus, 1758)	Per	GC	NV	LC	NE
Trachinotus goodei Jordan & Evermann, 1896	Per	GC	NV	LC	NE
Echeneidae					
Echeneis naucrates Linnaeus, 1758	Per	UD	NV	LC	NE
Paralichthyidae					
Citharichthys arenaceus Evermann & Marsh, 1900	Per	GC	NV	LC	NE
Citharichthys macrops Dresel, 1885	Per	ZB	NV	LC	NE
Citharichthys spilopterus Günther, 1862	Per	ZB	NV	LC	NE
Etropus crossotus (Jordan & Gilbert, 1882)*	Per	ZB	NV	LC	NE

TABLE 1 | (Continued)

Taxa	Euryhalinity	Trophic group	Origin	Brazilian Red List	Endemism
Achiridae					
Achirus declivis Chabanaud, 1940	Per	ZB	NV	LC	NE
Achirus lineatus (Linnaeus, 1758)	Per	ZB	NV	LC	NE
Catathyridium garmani (Jordan, 1889)	Per	ZB	NV	LC	NE
Trinectes microphthalmus (Chabanaud, 1928)	Per	ZB	NV	LC	ED
Trinectes paulistanus (Miranda Ribeiro, 1915)	Per	ZB	NV	LC	NE
Cynoglossidae					
Symphurus tessellatus (Quoy & Gaimard, 1824)	Per	ZB	NV	LC	NE
CICHLIFORMES					
Cichlidae					
Cichla cf. *kelberi* Kullander & Ferreira, 2006	2nd	PV	EX-B	LC	NE
Cichla monoculus Spix & Agassiz, 1831*	2nd	PV	EX-B	LC	NE
Cichlasoma dimerus Heckel, 1840	2nd	OV	EX-B	LC	ED
Coptodon rendalli (Boulenger, 1897)	2nd	HB	EX-C	NA	NE
Crenicichla cf. *lacustris* (Castelnau, 1855)	2nd	GC	NV	LC	NE
Geophagus cf. *brasiliensis* (Quoy & Gaimard, 1824)	2nd	OV	NV	LC	NE
Oreochromis niloticus (Linnaeus, 1758)	2nd	HB	EX-C	NA	NE
BELONIFORMES					
Belonidae					
Strongylura marina (Walbaum, 1792)	Per	GC	NV	LC	NE
CYPRINODONTIFORMES					
Poeciliidae					
Poecilia vivipara Bloch & Schneider, 1801	2nd	OV	NV	LC	NE
ATHERINIFORMES					
Atherinopsidae					
Atherinella brasiliensis (Quoy & Gaimard, 1825)	Per	ZP	NV	LC	NE
MUGILIFORMES					
Mugilidae					
Mugil brevirostris Miranda Ribeiro, 1915	Per	DT	NV	DD	NE
Mugil curema Valenciennes, 1836	Per	DT	NV	DD	NE
Mugil curvidens Valenciennes, 1836	Per	DT	NV	DD	NE
Mugil incilis Hancock, 1830	Per	DT	NV	LC	NE
Mugil liza Valenciennes, 1836	Per	DT	NV	NT	NE
BLENNIIFORMES					
Blenniidae					
Lupinoblennius paivai (Pinto, 1958)	Per	ZB	NV	LC	ED
GERREIFORMES					
Gerreidae					
Diapterus auratus Ranzani, 1842	Per	ZB	NV	LC	NE
Diapterus rhombeus (Cuvier, 1829)	Per	ZB	NV	LC	NE
Eucinostomus argenteus Baird & Girard, 1855	Per	ZB	NV	LC	NE
Eucinostomus melanopterus (Bleeker, 1863)	Per	ZB	NV	LC	NE
Eugerres brasilianus (Cuvier, 1830)	Per	ZB	NV	LC	NE
EUPERCARIA incertae sedis					
Sciaenidae					
Bairdiella goeldi Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019	Per	ZB	NV	LC	NE
Cynoscion acoupa (Lacepède, 1801)	Per	GC	NV	NT	NE
Cynoscion microlepidotus (Cuvier, 1830)	Per	GC	NV	LC	NE
Larimus breviceps Cuvier, 1830	Per	GC	NV	LC	NE
Menticirrhus americanus (Linnaeus, 1758)	Per	ZB	NV	DD	NE
Micropogonias furnieri (Desmarest, 1823)	Per	ZB	NV	LC	NE
Pachyurus adspersus Steindachner, 1879	Per	ZB	NV	DD	ED
Stellifer brasiliensis (Schultz, 1945)	Per	ZB	NV	LC	ED
Stellifer naso (Jordan, 1889)	Per	GC	NV	LC	NE

TABLE 1 | (Continued)

Taxa	Euryhalinity	Trophic group	Origin	Brazilian Red List	Endemism
Stellifer punctatissimus (Meek & Hildebrand, 1925)	Per	ZB	NV	DD	NE
Stellifer rastrifer (Jordan, 1889)	Per	ZB	NV	LC	NE
Stellifer stellifer (Bloch, 1790)	Per	ZB	NV	LC	NE
LUTJANIFORMES					
Haemulidae					
Conodon nobilis (Linnaeus, 1758)*	Per	ZB	NV	LC	NE
Haemulopsis corvinaeformis (Steindachner, 1868)	Per	ZB	NV	LC	NE
Pomadasys ramosus (Poey, 1860)	Per	ZB	NV	LC	NE
Rhonciscus cf. *crocro* (Cuvier, 1830)	Per	ZB	NV	LC	NE
Lutjanidae					
Lutjanus cyanopterus (Cuvier, 1828)	Per	GC	NV	VU	NE
Lutjanus jocu (Bloch & Schneider, 1801)	Per	GC	NV	NT	NE
Lutjanus synagris (Linnaeus, 1758)	Per	GC	NV	NT	NE
CENTRARCHIFORMES					
Kyphosidae					
Kyphosus sectatrix (Linnaeus, 1758)	Per	HB	NV	LC	NE
SPARIFORMES					
Sparidae					
Archosargus probatocephalus (Walbaum, 1792)*	Per	OV	NV	DD	NE
TETRAODONTIFORMES					
Tetraodontidae					
Lagocephalus laevigatus (Linnaeus, 1766)	Per	GC	NV	LC	NE
Sphoeroides greeleyi Gilbert, 1900*	Per	OV	NV	LC	NE
Sphoeroides testudineus (Linnaeus, 1758)	Per	ZB	NV	DD	NE

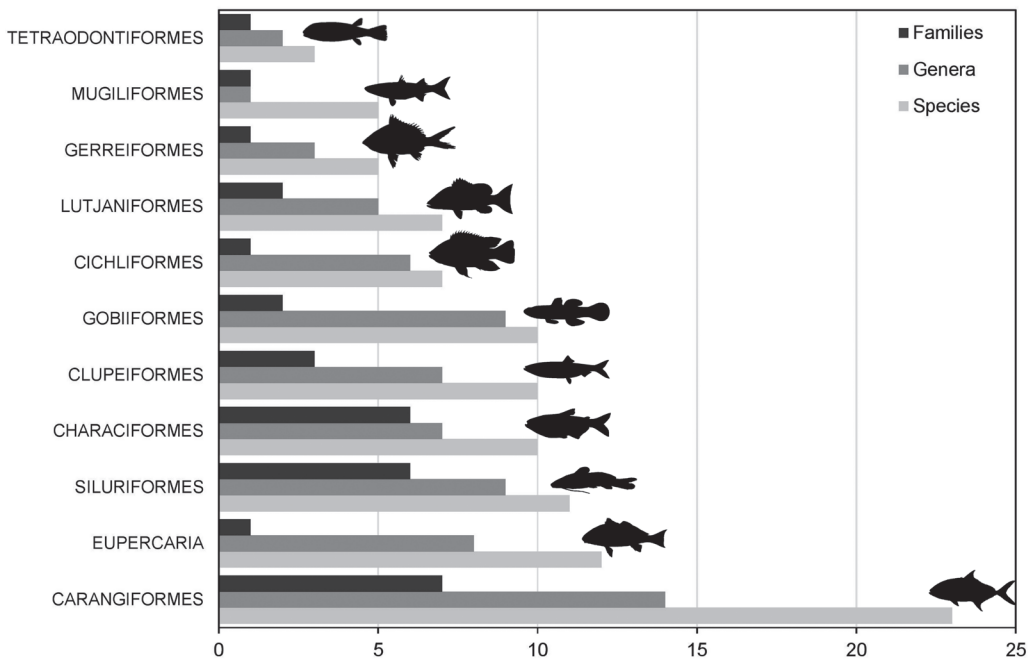

FIGURE 2 | Number of species, genera and families for fish orders in the Doce River estuary. The following orders were represented by a single species and were omitted in the figure: Anguilliformes, Atheriniformes, Aulopiformes, Beloniformes, Blenniiformes, Centrarchiformes, Cyprinodontiformes, Elopiformes, Scombriformes, Spariformes, Symbranchiformes and Syngnathiformes (illustrative taxa images from Phylopic.org).

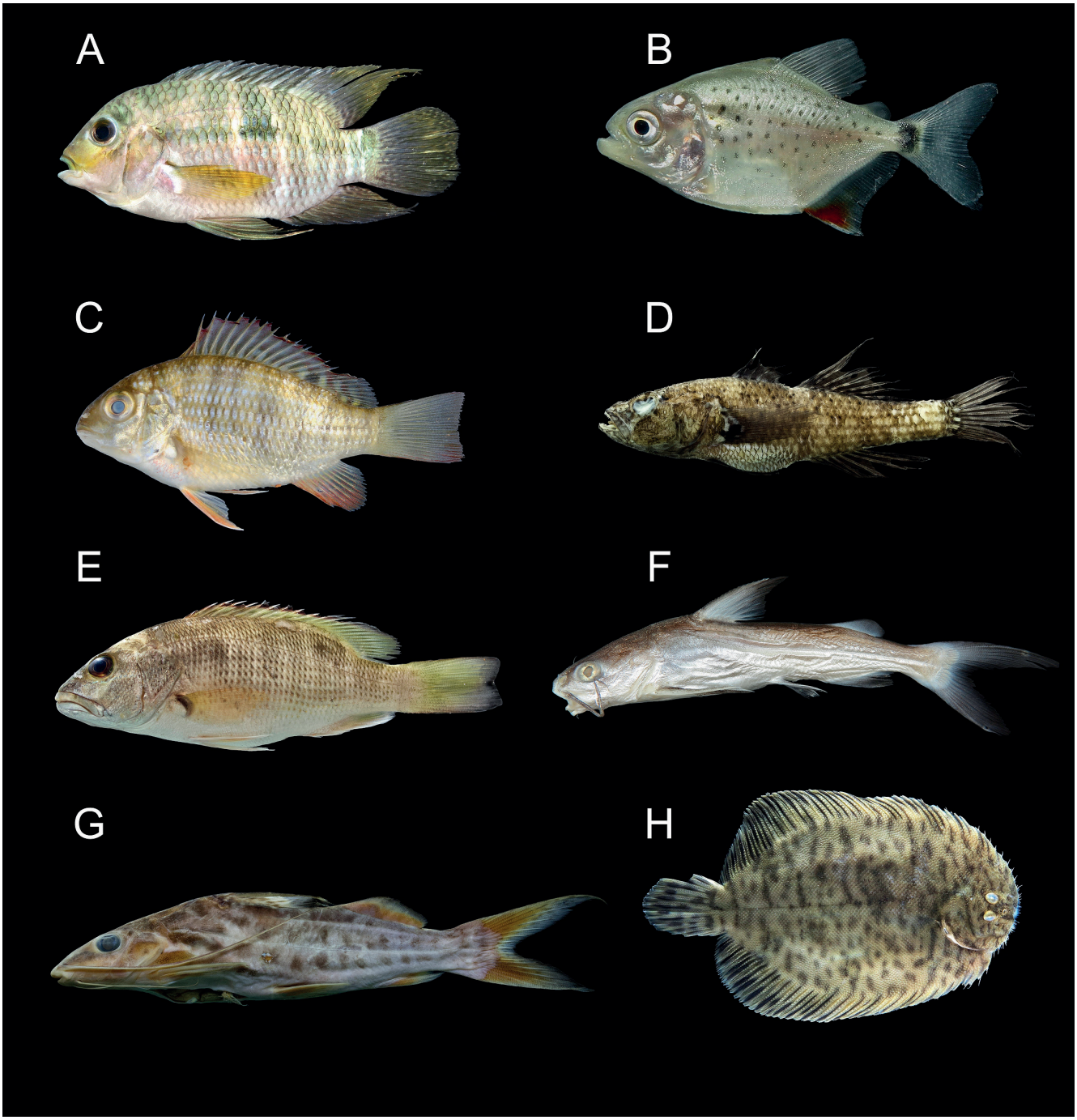

FIGURE 3 | Examples of fishes recorded for the first time in the Doce River estuary. **A.** *Cichlasoma dimerus*; **B.** *Pygocentrus nattereri*; **C.** *Coptodon rendalli*; **D.** *Butis koilomatodon*; **E.** *Lutjanus cyanopterus*; **F.** *Genidens barbus*; **G.** *Pimelodus maculatus*; **H.** *Catathyridium garmani*. Photos: Helder C. Guabiroba (**A**, **B**, **C**, **E**, **H**), Flávio T. Szablak (**D**, **F**, **G**).

(Steindachner, 1877) (Critically Endangered), *Pristis pristis* (Critically Endangered and locally extinct), *Genidens barbus (Lacepède*, 1803) (Endangered) and *Lutjanus cyanopterus* (Cuvier, 1828) (Vulnerable; Fig. 3E). Among non-threatened species, 94 (81.7%) are considered as Least Concern, seven (6.1%) as Data Deficient, and five (4.3%) are Near Threatened: *Cynoscion acoupa* (Lacepède, 1801), *Dormitator maculatus* (Bloch, 1792), *Lutjanus jocu* (Bloch & Schneider, 1801), *Lutjanus synagris* (Linnaeus, 1758), and *Mugil liza* Valenciennes, 1836.

DISCUSSION

This is the first comprehensive fish inventory of the Doce River estuary, with 115 recorded species being Carangiformes, Eupercaria *incertae sedis* and Siluriformes the most speciose orders. Here, we followed the most recent classification of the Carangiformes (Girard *et al*, 2020), that nests a series of subclades with many estuarine representants. Among the recorded Carangiformes species are the snooks (Centropomidae), the flatfishes (*e.g*., Paralichthyidae and Achiridae), and the jacks (Carangidae). The Eupercaria *incertae sedis* order was only represented by the croakers (Sciaenidae) that, like the catfishes (Siluriformes), usually occur in high abundance and richness in tropical estuaries (*e.g*., Catelani *et al*., 2014; Vilar *et al*., 2022). Among the diverse adaptative processes that favor the success of these two last groups in turbid brackish waters are the Weberian apparatus (Siluriformes), mechanosensory barbels and sound-producing mechanisms (Alexander, 1966; Kaatz, 2002).

The DRE fish fauna is dominated by zoobenthivores in both richness and biomass (Vilar *et al*., 2022) and the rarity of piscivores may reflect ill-suited water characteristics for this group (*e.g*., shallow and turbid). The low depth, high turbidity and frequent floods in the low reaches of the Doce River are known since the 19th century expeditions (Saint-Hilaire, 1938). However, with the rapid expansion of agriculture, industry, urbanization and the construction of hydropower and mining dams, sedimentation and hydrological processes have been severely affected (Coelho, 2006; Aprile *et al*., 2016; Rudorff *et al*., 2018). The 19th and 20th centuries were also marked by the decline or extirpation of apex-predators in the lower (or the entirety of the) Doce River such as the largetooth sawfish *Pristis pristis*, the giant endemic catfish *Steindachneridion doceanum* (Eigenmann & Eigenmann, 1889), an endemic lineage of broad-snouted alligator *Caiman latirostris* (Daudin, 1802) and the giant otter *Pteronura brasiliensis* (Gmelin, 1788) (Vieira, Gasparini, 2007; Keesen *et al*., 2016; Swarça *et al*., 2018; Roberto *et al*., 2020). Beyond the immeasurable value of biodiversity loss, ecological consequences related to habitat homogenization are plentiful (Layman *et al*., 2007; Andrades *et al*., 2021).

Changes in richness and composition of basal organisms communities after the arriving of the tailing mud in the estuarine and coastal areas of Doce River have been reported (Gomes *et al*., 2017; Fernandes *et al*., 2022; Rocha *et al*., 2022). As shown by Andrades *et al*. (2020) the ecological niches of some estuarine fishes of the Doce River were also affected by the pollution caused by ore tailings. Here we warns for risks that chronic contamination in the DRE poses to the ichthyofauna given the high number of bottom-feeding species that occurs in this ecosystem (Tab. **S1**).

Human-induced changes along the whole Doce River length have been severe (Espindola, 2015; Aprile *et al*., 2016; Fragoso-Moura *et al*., 2016). However, the DRE fish biodiversity is surprisingly higher than in geographically close estuaries, including one wave-dominated delta (Neto, 2009; Hostim-Silva *et al*., 2013; Vilar *et al*., 2013, Catelani *et al*., 2014). This finding should, however, be parsimoniously interpreted due to distinct sampling effort, catch methods, and the uniqueness of each estuary.

Some records deserve special attention as the Ariidae *Cathorops* cf. *arenatus* and *Paragenidens grandoculis* that were not expected to occur in the DRE. The former is described from the northern Brazilian coast (Marceniuk, 2007) while the latter was considered restricted to deep lakes adjacent to the lower Doce River (Marceniuk *et al*., 2019). The occurrence of the critically endangered *P. grandoculis* in DRE should be monitored given the threats of chronic exposure to toxic ore tailings (Gabriel *et al*., 2020; Andrades *et al*., 2021; Costa *et al*., 2021) and the lack of information on its population status.

Some unexpected records for estuaries, such as *Scomberomorus brasiliensis* Collette, Russo & Zavala-Camin, 1978, *Kyphosus sectatrix* (Linnaeus, 1758) and *Echeneis naucrates* Linnaeus, 1758, clearly refer to vagrant marine individuals that occasionally enter these ecosystems. Another noteworthy record is that of the cryptic blenny *Lupinoblennius paivai* (Pinto, 1958), a species that tolerates low salinity and is usually found in mangroves branches cavities or other submerged vegetation (Machado *et al*., 2017). Despite the multiple fishing gears and the high effort employed in this study, we have captured only one specimen in 2015 (*i.e*., before the ore tailings reached the estuary). Sazima, Carvalho-Filho (2003) warned about the extinction risks for this species due to increasing human pressure over coastal ecosystems.

The presence of exotic fishes in the DRE is another relevant issue (see Bueno *et al*., 2021 for non-estuarine environments). Some of those species have been widely spread for aquaculture purposes (*e.g*., *Oreochromis niloticus*) and the risks they present for the native fish community structure and the supporting trophic web are well known (Zambrano *et al*., 2010; Jere *et al*., 2021). We are also concerned about native Brazilian species exotic to the Doce River basin (*e.g*., *Pygocentrus nattereri*, *Salminus brasiliensis*, and *Cichla* spp.). Studies conducted in Doce River lakes show evidence of loss in native species richness and changes in the structure of basal resources after the introduction of exotic predatory species such as the red-piranha *P. nattereri* and Peacock bass *Cichla* spp., among others (Latini, Petrere, 2004; Pinto-Coelho *et al*., 2008).

The Doce River and its estuary have been affected by multiple human-induced stressors during the 20th and 21st centuries (Fig. 4; Tab. **S2**). In this context, the present study serves as a valuable baseline of the local ichthyofauna –even though the system is far from pristine. We emphasize the importance of long-term monitoring of fishery target resources, vulnerable species (*e.g*., endangered and rheophilic fishes) and high-level consumers (generalist carnivores and piscivores) for a better understanding of the consequences of human impacts on the local ichthyofauna and its social-economic unfoldings.

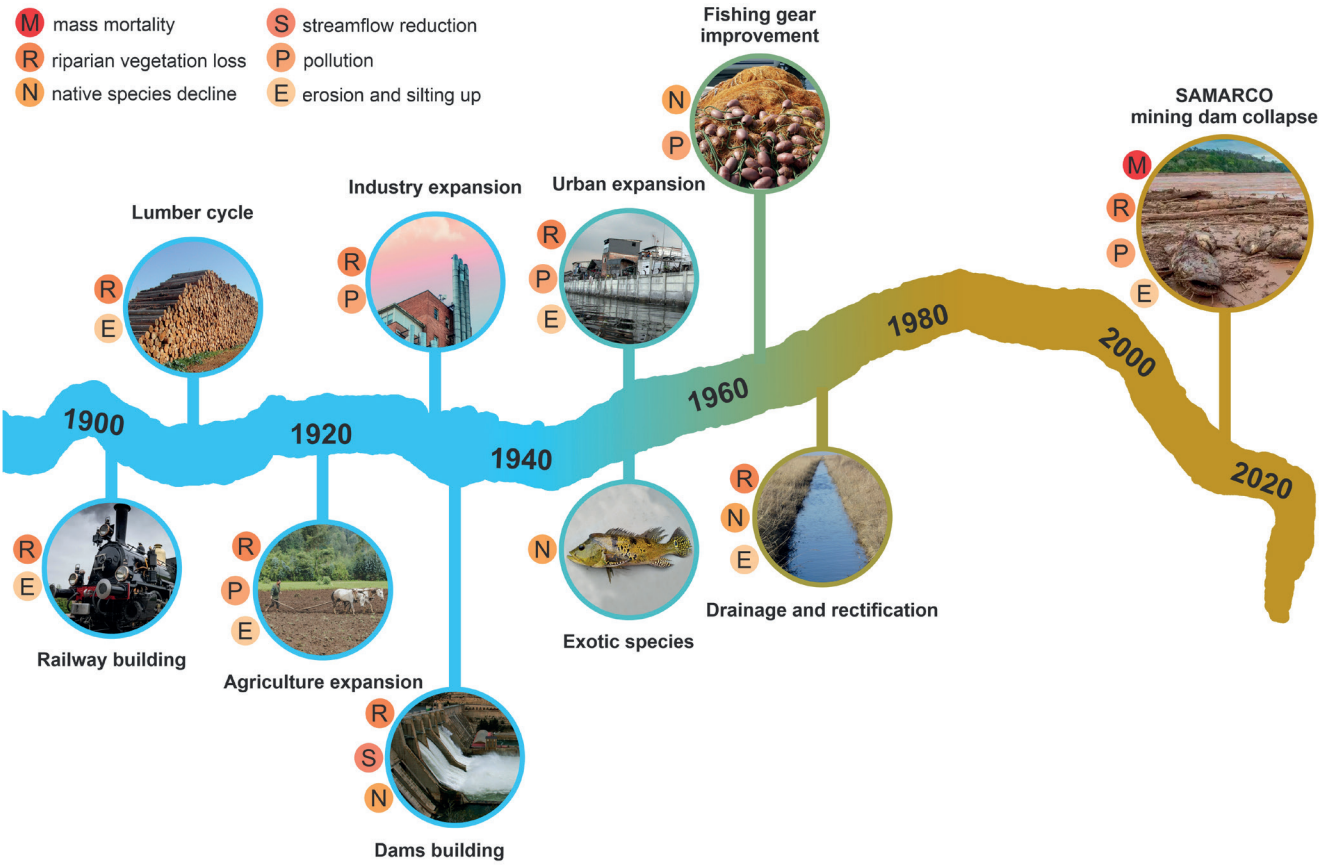

FIGURE 4 | Main human-driven impacts after the 19th century and their consequences on the Doce River basin. Photos by A. Villela (Exotic species) and E. Nascimento (Mining dam collapse); the other pictures belong to the public domain (Tab. **S2**).

ACKNOWLEDGMENTS

The present work would not have been possible without the immense help of Flávio Szablak, Rebeka Martins, Kathiani Bastos, Layza de Lima and Pedro Bastos in field and laboratory activities. We also thank Luiza Sarmento-Soares and João Luiz Gasparini for helping with the taxonomic identification of some freshwater fishes and Alexandre Marceniuk for catfish species.We are indebted with Felipe Buloto, Maik Da Hora, Nelson Barcelos, Jonathas Barreto, Cristielli Rotta, Miguel Saldanha, Lucas Caliman, Fernanda Guimarães, Bianca Cruz, Nefertiti Rojas and all the fishermen of Regência village for their help in sampling and for sharing their knowledge about the fish community of the Doce River; special thanks are due to Arnoilto Alcântara, Josenildo "Frango", Clavelanio "Preto" and Leônidas. We also would like to thank TAMAR/ICMBio and Associação de Pescadores de Regência for logistic support for field activities. Data acquisition for this research was partially done in the scope of the Aquatic Biodiversity Monitoring Program, Environmental Area I, established by the Technical-Scientific Cooperation Agreement nº 30/2018 between Fundação Espírito-Santense de Tecnologia (FEST) and Fundação Renova, published in Brazil's Official Gazette (Diário Oficial da União). Neither agency played any role in result interpretation or manuscript preparation.

REFERENCES

- **Agostinho AA, Thomaz SM, Gomes LC.** Conservation of the biodiversity of Brazil's inland waters. Conserv Biol. 2005; 19(3):646–52. https://doi.org/10.1111/j.1523-1739.2005.00701.x
- **Alexander RMcN.** Structure and function in the catfish. J Zool. 1966; 148(1):88–152. https://doi.org/10.1111/j.1469-7998.1966.tb02943.x
- **Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G.** Köppen's climate classification map for Brazil. Meteorol Zeitschrift. 2013; 22(6):711–28. https://doi.org/10.1127/0941-2948/2013/0507
- **Andrades R, Guabiroba HC, Hora MSC, Martins RF, Rodrigues VLA, Vilar CC *et al*.** Early evidences of niche shifts in estuarine fishes following one of the world's largest mining dam disasters. Mar Pollut Bull. 2020; 154:111073. https://doi.org/10.1016/j.marpolbul.2020.111073
- **Andrades R, Martins RF, Guabiroba HC, Rodrigues VLA, Szablak FT, Bastos KV *et al*.** Effects of seasonal contaminant remobilization on the community trophic dynamics in a Brazilian tropical estuary. Sci Total Environ. 2021; 801:149670. https://doi.org/10.1016/j.scitotenv.2021.149670
- **Aprile F, Lorandi R, Siqueira G.** Influence of natural and anthropogenic processes in the coastline evolution at the Doce River mouth (Espírito Santo, Brazil). Br J Environ Clim Chang. 2016; 6(1):18–27. https://doi.org/10.9734/bjecc/2016/25454
- **Basset A, Elliott M, West RJ, Wilson JG.** Estuarine and lagoon biodiversity and their natural goods and services. Estuar Coast Shelf Sci. 2013; 132:1–04. https://doi.org/10.1016/j.ecss.2013.05.018
- **Baviera PT.** Viagem pelo Espírito Santo (1888): Viagem pelos trópicos brasileiros. Vitória: Arquivo Público do Estado do Espírito Santo, Brasil; 2013.
- **Berra TM, editor.** Introduction. In: Freshwater Fish Distribution. San Diego: Academic Press; 2001. https://doi.org/https://doi.org/10.1016/B978-012093156-9/50026-3
- **Betancur-R R, Wiley EO, Arratia G, Acero A, Bailly N, Miya M *et al*.** Phylogenetic classification of bony fishes. BMC Evol Biol. 2017; 17(162). https://doi.org/http://doi.org/10.1186/s12862-017-0958-3
- **Bonecker ACT, Castro MS, Costa PG, Bianchini A, Bonecker SLC.** Larval fish assemblages of the coastal area affected by the tailings of the collapsed dam in southeast Brazil. Reg Stud Mar Sci. 2019; 32:100848. https://doi.org/https://doi.org/10.1016/j.rsma.2019.100848
- **Bueno ML, Magalhães ALB, Andrade Neto FR, Alves CBM, Rosa DM, Junqueira NT *et al*.** Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. Biol Invasions. 2021; 23(10):3021–34. https://doi.org/10.1007/s10530-021-02564-x
- **Carvalho-Filho A.** Peixes: Costa brasileira. São Paulo: Melro; 1999.
- **Catelani PA, Petry AC, Di Dario F, Santos VLM, Mincarone MM.** Fish composition (Teleostei) of the estuarine region of the Macaé River, southeastern Brazil. Check List. 2014; 10(4):927–35. https://doi.org/10.15560/10.4.927
- **Coelho ALN.** Situação hídrico-geomorfológica da bacia do rio doce com base nos dados da série histórica de vazões da estação de colatina - ES. Caminhos Geogr. 2006; 6(19):56–79.
- **Condini MV, Pichler HA, Oliveira-Filho RR, Cattani AP, Andrades R, Vilar CC *et al*.** Marine fish assemblages of Eastern Brazil: An update after the world's largest mining disaster and suggestions of functional groups for biomonitoring long-lasting effects. Sci Total Environ. 2022; 807(2):150987. https://doi.org/10.1016/j.scitotenv.2021.150987
- **Cordeiro MC, Garcia GD, Rocha AM, Tschoeke DA, Campeão ME, Appolinario LR *et al*.** Insights on the freshwater microbiomes metabolic changes associated with the world's largest mining disaster. Sci Total Environ. 2019; 654:1209–17. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.11.112
- **Costa ES, Cagnin RC, Silva CA, Longhini CM, Sá F, Lima AT *et al*.** Iron ore tailings as a source of nutrients to the coastal zone. Mar Pollut Bull. 2021; 171:112725. https://doi.org/10.1016/j.marpolbul.2021.112725

- **Diniz JMFS, Reis AA, Acerbi Junior FW, Gomide LR.** Detecção da expansão da área minerada no Quadrilátero Ferrífero, Minas Gerais, no período de 1985 a 2011 através de técnicas de sensoriamento remoto. Bol Ciênc Geod. 2014; 20(3):683–700. https://doi.org/http://dx.doi.org/10.1590/S1982-21702014000300039
- **Dominguez JML, Wanless HR.** Facies architecture of a falling sea-level strandplain, Doce River coast, Brazil. In: Swift DJP, Oertel GF, Tillman RW, Thorne JA, editors. Shelf sand and sandstone bodies: Geometry, facies and sequence stratigraphy. Blackwell Publishing Ltd.; 1991. p.257–81. https://doi.org/10.1002/9781444303933.ch7
- **Espindola HS.** Vale do rio Doce: Fronteira, industrialização e colapso socioambiental. Front J Soc Technol Environ Sci. 2015; 4(1):160. https://doi.org/10.21664/2238-8869.2015v4i1.p160-206
- **Espindola HS, Guerra CB.** The ongoing danger of large-scale mining on the rio Doce: An account of Brazil's largest biocultural disaster. In: From Biocultural Homogenization to Biocultural Conservation. Ecology and Ethics, vol 3. Springer, Cham. 2018. p.97–108. https://doi.org/10.1007/978-3-319-99513-7_6
- **Fernandes L, Jesus H, Almeida P, Sandrini J, Bianchini A, Santos H.** The influence of the Doce River mouth on the microbiome of nearby coastal areas three years after the Fundão Dam failure, Brazil. Sci Total Environ. 2022; 807:151777. https://doi.org/10.1016/J.SCITOTENV.2021.151777
- **Figueiredo JL, Menezes NA.** Manual de peixes marinhos do sudeste do Brasil. II. Teleostei (1). São Paulo: Museu de Zoologia: USP; 1978.
- **Fragoso-Moura EN, Oporto LT, Maia-Barbosa PM, Barbosa FAR.** Perda de biodiversidade em uma unidade de conservação da mata atlântica brasileira: Efeitos da introdução de espécies não nativas de peixes. Braz J Biol. 2016; 76(1):18–27. https://doi.org/10.1590/1519-6984.07914
- **França MC, Cohen MCL, Pessenda LCR, Rossetti DF, Lorente FL, Buso Junior AÁ *et al*.** Mangrove vegetation changes on Holocene terraces of the Doce River, southeastern Brazil. Catena. 2013; 110:59–69. https://doi.org/10.1016/j.catena.2013.06.011
- **Fricke R, Eschmeyer WN, van der Laan R.** Eschmeyer's catalog of fishes: Genera, species, references [Internet]. Sna Francisco: California Academy of Sciences; 2022. Available from: http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp
- **Froese R, Pauly D.** FishBase. World Wide Web electronic publication. 2020. Available from: https://www.fishbase.se/search.php
- **Gabriel FÂ, Ferreira AD, Queiroz HM, Vasconcelos ALS, Ferreira TO, Bernardino AF.** Long-term contamination of the rio Doce estuary as a result of Brazil's largest environmental disaster. Perspect Ecol Conserv. 2021; 19(4):417–28. https://doi.org/10.1016/j.pecon.2021.09.001
- **Gabriel FÂ, Silva AG, Queiroz HM, Ferreira TO, Hauser-Davis RA, Bernardino AF.** Ecological risks of metal and metalloid contamination in the Rio Doce estuary. Integr Environ Assess Manag. 2020; 16(5):655–60. https://doi.org/10.1002/ieam.4250
- **GEOBASES.** Sistema Integrado de Bases Geoespaciais do Estado do Espírito Santo. 2015. Available from: https://geobases.es.gov.br/
- **Girard MG, Matthew PD, Smith WL.** The phylogeny of carangiform fishes: Morphological and genomic investigations of a new fish clade. Copeia. 2020; 108(2):265–98. https://doi.org/10.1643/CI-19-320
- **Gomes LEO, Correa LB, Sá F, Neto RR, Bernardino AF.** The impacts of the Samarco mine tailing spill on the Rio Doce estuary, Eastern Brazil. Mar Pollut Bull. 2017; 120(1–2):28–36. https://doi.org/10.1016/j.marpolbul.2017.04.056
- **Hartt CF, Agassiz L.** Scientific results of a journey in Brazil by Louis Agassiz and his travelling companions: Geology and physical geography of Brazil. Boston: Fields, Osgood & Co; 1870. p.620.
- **Hatje V, Pedreira RMA, Rezende CE, Schettini CAF, Souza GC, Marin DC *et al*.** The environmental impacts of one of the largest tailing dam failures worldwide. Sci Rep. 2017; 7:10706. https://doi.org/10.1038/s41598-017-11143-x

- **Hostim-Silva M, Lima AC, Spach HL, Passos AC, Souza JD.** Estuarine demersal fish assemblage from a transition region between the tropics and the subtropics of the South Atlantic. Biotemas. 2013; 26(3):153–61. https://doi.org/10.5007/2175-7925.2013v26n3p153
- **Instituto Brasileiro de Geografia e Estatística (IBGE).** Manual técnico da vegetação brasileira. Rio de Janeiro. IBGE - Coordenação de Recursos Naturais e Estudos Ambientais; 2012.
- **Ministério do Meio Ambiente (MMA).** Atualização da lista nacional de espécies ameaçadas de extinção. Portaria nº 148, de 7 de junho de 2022. Diário Oficial da União, seção 1, edição 108 (7 de junho de 2022). Brasília: MMA; 2022.
- **Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio).** Livro vermelho da fauna brasileira ameaçada de extinção: Volume VI - Peixes. 1 ed. Brasília, DF: ICMBio/MMA, 2018.
- **Jankowsky M, Carvalho RM, Gomes VAP, Freitas RR.** Peixes e pesca na bacia do Rio Doce, uma análise bibliométrica. Brazilian J Prod Eng - BJPE. 2021:14–40. https://doi.org/10.47456/bjpe.v6i8.33769
- **Jere A, Jere WWL, Mtethiwa A, Kassam D.** Impact of *Oreochromis niloticus* (Linnaeus, 1758) (Pisces: Cichlidae) invasion on taxonomic and functional diversity of native fish species in the upper Kabompo River, northwest of Zambia. Ecol Evol. 2021; 11(18):12845–57. https://doi.org/10.1002/ECE3.8031
- **Kaatz IM.** Multiple sound-producing mechanisms in teleost fishes and hypotheses regarding their behavioural significance. Bioacoustics. 2002; 12(2–3):230–33. https://doi.org/10.1080/09524622.2002.9753705
- **Keesen F, Nunes AV, Scoss LM.** Updated list of mammals of Rio Doce State Park, Minas Gerais, Brazil. Bol Mus Biol Mello Leitão. 2016; 38(2):139–62. http://boletim.sambio.org.br/pdf/38_2_06.pdf
- **Kullander SO, Ferreira EJG.** A review of the South American cichlid genus *Cichla*, with descriptions of nine new species (Teleostei: Cichlidae). Ichthyol Explor Freshw. 2006; 17(4):289–398.
- **Latini AO, Petrere Jr. M.** Reduction of a native fish fauna by alien species: An example from Brazilian freshwater tropical lakes. Fish Manag Ecol. 2004; 11(2):71–79. https://doi.org/10.1046/J.1365-2400.2003.00372.X
- **Layman CA, Quattrochi JP, Peyer CM, Allgeier JE.** Niche width collapse in a resilient top predator following ecosystem fragmentation. Ecol Lett. 2007; 10(10):937–44. https://doi.org/10.1111/j.1461-0248.2007.01087.x
- **Lins RC, Mendes CAB, Agra SG, Carvalho AE, Fragoso Junior CR.** Integração de um modelo hidrológico a um SIG para avaliação da qualidade da agua na bacia do Rio Doce. Rev Bras Recur Hídricos. 2012; 17(4):171–81. https://doi.org/10.21168/rbrh.v17n4.p171-181
- **Longhini CM, Rodrigues SK, Costa ES, Silva CA, Cagnin RC, Gripp M *et al*.** Environmental quality assessment in a marine coastal area impacted by mining tailing using a geochemical multi-index and physical approach. Sci Total Environ. 2022; 803:149883. https://doi.org/10.1016/j.scitotenv.2021.149883
- **Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC et al.** Depletion, degradation, and recovery potential of estuaries and coastal seas. Science. 2006; 312(5781):1806–09. https://doi.org/10.1126/science.1128035
- **Machado FS, Carvalho-Filho A, Giarrizzo T.** Redescription and range extension of the endangered Paiva's blenny *Lupinoblennius paivai* (Perciformes: Blenniidae). J Fish Biol. 2017; 90(6):2394–401. https://doi.org/10.1111/JFB.13322
- **Marceniuk AP.** Revalidação de *Cathorops arenatus* e *Cathorops agassizii* (Siluriformes, Ariidae), bagres marinhos das regiões norte e nordeste da América do Sul. Iheringia Sér Zool. 2007; 97(4):360–75. https://doi.org/10.1590/S0073-47212007000400002
- **Marceniuk AP.** Chave para identificação das espécies de bagres marinhos (Siluriformes, Ariidae) da costa brasileira. B Inst Pesca. 2005; 31(2):89–101.

- **Marceniuk AP, Ingenito LFS, Lima FCT, Gasparini JLR, Oliveira C.** Systematics, biogeography and conservation of *Paragenidens grandoculis* n. gen. and n. comb. (Siluriformes; Ariidae), a critically endangered species from southeastern Brazil. Zootaxa. 2019; 4586(3):425–44. https://doi.org/10.11646/zootaxa.4586.3.2
- **McLusky DS, Elliott M.** The estuarine ecosystem. 3rd ed. New York: Oxford University Press; 2004. https://doi.org/10.1093/acprof:oso/9780198525080.001.0001
- **Menezes NA.** Manual de peixes marinhos do sudeste do Brasil III Teleostei (2). São Paulo: Museu de Zoologia USP; 1980.
- **Menezes NA, Figueiredo JL.** Manual de peixes marinhos do sudeste do Brasil VI Teleostei (5). São Paulo: Museu de Zoologia USP; 2000.
- **Menezes NA, Figueiredo JL.** Manual de peixes marinhos do sudeste do Brasil V Teleostei (4). São Paulo: Museu de Zoologia USP; 1985.
- **Menezes NA, Figueiredo JL.** Manual de peixes marinhos do Sudeste do Brasil IV Teleostei (3). São Paulo: Museu de Zoologia USP; 1980.
- **Ministério do Meio Ambiente (MMA).** Áreas prioritárias para conservação, uso sustentável e repartição de benefícios da diversidade biológica brasileira. Portaria n°. 9, de 23 de janeiro de 2007. Diário Oficial da União, seção 1, edição 17 (23 de janeiro de 2007). Brasília: 2007.
- **Moura RL, Lindeman KC.** A new species of snapper (Perciformes: Lutjanidae) from Brazil, with comments on the distribution of *Lutjanus griseus* and *L. apodus*. Zootaxa. 2007; 1442(1):31–43. https://doi.org/http://doi.org/10.11646/zootaxa.1422.1.2
- **Munroe TA, Nizinski MS.** Clupeidae. In The living marine resources of the Western Central Atlantic Volume 2: Bony fishes part 1 (Acipenseridae to Grammatidae). In: Carpenter KE, editor. FAO Species Identification Guide for Fishery Purposes, Am Soc Ichthyol Herpetol Spec. Publ. 5.; 2002.
- **Myers GS.** Fresh water fishes and West Indian zoogeography. 1937th ed. Annual Report of the Board of Regents of the Smithsonian Institution; 1938. p.339–64.
- **Neto FR de A.** Estado atual do conhecimento sobre a fauna de peixes da bacia do Jequitinhonha. MGBiota. 2009; 2(5):23–35.
- **Nimer E.** Climatologia do Brasil. Rio de Janeiro: IBGE - Departamento de Recursos Naturais e Estudos Ambientais; 1989.
- **Nizinski MS, Munroe TA.** Engraulidae, in The living marine resources of the Western Central Atlantic Volume 2: Bony fishes part 1 (Acipenseridae to Grammatidae). In: Carpenter KE, editor. FAO Species Identification Guide for Fishery Purposes, Am Soc Ichthyol Herpetol Spec. Publ. 5; 2002.
- **Oliveira KSS, Quaresma VS.** Temporal variability in the suspended sediment load and streamflow of the Doce River. J South Am Earth Sci. 2017; 78:101–15. https://doi.org/10.1016/j.jsames.2017.06.009
- **Pinto-Coelho RM, Bezerra-Neto JF, Miranda F, Mota TG, Resck R, Santos AM *et al*.** The inverted trophic cascade in tropical plankton communities: Impacts of exotic fish in the middle Rio Doce lake district, Minas Gerais, Brazil. Braz J Biol. 2008; 68(4):1025–37. https://doi.org/10.1590/S1519-69842008000500010
- **Ribeiro MC, Martensen AC, Metzger JP, Tabarelli M, Scarano F, Fortin M-J.** The Brazilian Atlantic Forest: A shrinking biodiversity hotspot. Biodiversity Hotspots. Berlin, Heidelberg: Springer Berlin Heidelberg; 2011. p.405–34. https://doi.org/10.1007/978-3-642-20992-5_21
- **Richard EC, Estrada GCD, Bechtold J-P, Duarte Jr. HA, Maioli BG, Freitas AHA et al.** Water and sediment quality in the coastal zone around the mouth of Doce River after the Fundão tailings dam failure. Integr Environ Assess Manag. 2020; 16(5):643–54. https://doi.org/10.1002/ieam.4309
- **Roberto IJ, Bittencourt PS, Muniz FL, Hernández-Rangel SM, Nóbrega YC, Ávila RW *et al*.** Unexpected but unsurprising lineage diversity within the most widespread Neotropical crocodilian genus *Caiman* (Crocodylia, Alligatoridae). Syst Biodivers. 2020; 18(4):377–95. https://doi.org/10.1080/14772000.2020.1769222

- **Rocha GM, Salvador B, Laino PS, Santos GHC, Demoner LE, Conceição LR *et al*.** Responses of marine zooplankton indicators after five years of a dam rupture in the Doce River, Southeastern Brazil. Sci Total Environ. 2022; 806:151249. https://doi.org/10.1016/j.scitotenv.2021.151249
- **Rolim SG, Ivanauskas NM, Rodrigues RR, Nascimento MT, Gomes JML, Folli DA *et al***. Composição florística do estrato arbóreo da floresta estacional semidecidual na planície aluvial do rio Doce, Linhares, ES, Brasil. Acta Bot Bras. 2006; 20(3):549–61. https://doi.org/10.1590/S0102-33062006000300005
- **Rudorff N, Rudorff CM, Kampel M, Ortiz G.** Remote sensing monitoring of the impact of a major mining wastewater disaster on the turbidity of the Doce River plume off the eastern Brazilian coast. ISPRS J Photogramm Remote Sens. 2018; 145:349–61. https://doi.org/10.1016/j.isprsjprs.2018.02.013
- **Ruschi A.** Lista dos tubarões, raias e peixes de água doce e salgada do estado do Espírito Santo e uma observação sobre a introdução do dourado no Rio Doce. Bol do Mus Biol Prof Mello-Leitão. 1965; 25(A):1–24.
- **Saint-Hilaire A.** Viagem pelas províncias de Rio de Janeiro e Minas Gerais. Série V: 1. São Paulo: Companhia Editora Nacional; 1938.
- **Saint-Hilaire A.** Segunda viagem ao interior do Brasil : Espirito Santo. Série V: 7. São Paulo: Companhia Editora Nacional; 1936.
- **Saldanha MC.** Do sistema tripolar GTP – geossistema, território e paisagem à geografia transversal e de travessias: Uma abordagem geográfica do distrito de Regência Augusta – Linhares (ES). Master Thesis in Geography, Universidade Federal do Espírito Santo. 2018. http://repositorio.ufes.br/bitstream/10/10670/1/tese_12667_MIGUEL CHAVES SALDANHA.pdf
- **Sarmento-Soares LM, Pinheiro RM, Rodrigues LN.** Peixes do Rio Doce segundo as coleções. Bol Soc Bras Ictiol. 2017; 123(3):9–25.
- **Sazima I, Carvalho-Filho A.** Natural history of the elusive blenny *Lupinoblennius paivai* (Perciformes: Blenniidae) in coastal streams of southeast Brazil. Ichthyol Explor Freshw. 2003; 14(2):175–84.
- **Su G, Logez M, Xu J, Tao S, Villéger S, Brosse S.** Human impacts on global freshwater fish biodiversity. Science. 2021; 371(6531):835–38. https://doi.org/10.1126/science.abd3369
- **Swarça AC, Orsi ML, Takagui FH, Dias AL, Dergam JA, Fenocchio AS.** First chromosome data on *Steindachneridion doceanum* (Siluriformes: Pimelodidae): A critically endangered catfish endemic of the doce river basin, Brazil. Neotrop Ichthyol. 2018; 16(4):3–07. https://doi.org/10.1590/1982-0224-20180066
- **Vieira F.** Distribuição, impactos ambientais e conservação da fauna de peixes da bacia do rio Doce. MGBiota. 2009; 2(5):5–22.
- **Vieira F, Gasparini JL.** Os peixes ameaçados de extinção no estado do Espírito Santo. In: Passamani M, Mendes SL, editors. Espécies da Fauna Ameaçada Extinção no Estado do Espírito Santo. 1st ed. Vitória: Instituto de Pesquisas da Mata Atlântica; 2007.
- **Vieira F, Gasparini JL, Macieira RM.** Guia ilustrado dos peixes da bacia do rio Benevente - ES. Vitória: ACQUA Consultoria e Recuperação de Ambientes Aquáticos Ltda/São Joaquim Energia S.A.; 2014.
- **Vieira F, Gomes JPC, Maia BP, Silva LGM.** Peixes do Quadrilátero Ferrífero: Guia de identificação (Fish of the Iron Quadrangle: Identification guide). Belo Horizonte: Fundação Biodiversitas; 2015.
- **Vilar CC, Joyeux J-C, Giarrizzo T, Spach HL, Vieira JP, Vaske-Junior T.** Local and regional ecological drivers of fish assemblages in Brazilian estuaries. Mar Ecol Prog Ser. 2013; 485:181–97. https://doi.org/10.3354/meps10343
- **Vilar CC, Andrades R, Szablak FT, Guabiroba HC, Pichler HA, Lima LRS *et al*.** Variability in nearshore fish biodiversity indicators after a mining disaster in eastern Brazil. Mar Environ Res. 2022; 175:105565. https://doi.org/10.1016/j.marenvres.2022.105565

- **Wied-Neuwied M.** Viagem ao Brasil. Série V: 1. São Paulo: Companhia Editora Nacional; 1940.
- **Zambrano L, Valiente E, Zanden MJV.** Food web overlap among native axolotl (*Ambystoma mexicanum*) and two exotic fishes: carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*) in Xochimilco, Mexico City. Biol Invasions. 2010; 12(9):3061–69. https://doi.org/10.1007/S10530-010-9697-8

AUTHORS' CONTRIBUTION

Vitor L. A. Rodrigues: Conceptualization, Formal analysis, Investigation, Software, Validation, Visualization, Writing-original draft, Writing-review and editing.

Helder C. Guabiroba: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing-original draft, Writing-review and editing.

Ciro C. Vilar: Data curation, Formal analysis, Methodology, Validation, Writing-original draft, Writing-review and editing.

Ryan Andrades: Data curation, Formal analysis, Methodology, Validation, Writing-original draft, Writing-review and editing.

Alexandre Villela: Formal analysis, Software, Validation, Visualization.

Maurício Hostim-Silva: Funding acquisition, Project administration, Resources, Validation.

Jean-Christophe Joyeux: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing-original draft, Writing-review and editing.

ETHICAL STATEMENT

Sampling was conducted under the approval of the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio, license #64345–4).

COMPETING INTERESTS

The authors declare no competing interests.

HOW TO CITE THIS ARTICLE

- **Rodrigues VLA, Guabiroba HC, Vilar CC, Andrades R, Villela A, Hostim-Silva M, Joyeux J-C.** Fish biodiversity of a tropical estuary under severe anthropic pressure (Doce River, Brazil). Neotrop Ichthyol. 2022; 20(3):e220022. https://doi.org/10.1590/1982-0224-2022-0022

Neotropical Ichthyology

OPEN ACCESS

Official Journal of the
Sociedade Brasileira de Ictiologia