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

Vitor L. A. Rodrigues1, Helder C. Guabiroba1, Ciro C. Vilar1, Ryan Andrades1, Alexandre Villela2, Maurício Hostim-Silva3 and Jean-Christophe Joyeux1

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.

1 Laboratório de Ictiologia, Departamento de Oceanografia, Universidade Federal do Espírito Santo, 29075-910 Vitória, ES, Brazil. (VLR) vitor_leo@hotmail.com (corresponding author), (HCG) helder.oceano@yahoo.com.br; (CCV) cirovilar@hotmail.com, (RA) ryanandrades@gmail.com, (CJ) 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.vrribeiro@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.
Fish biodiversity of the Doce River estuary

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 m³/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 (Domínguez, 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, totaling 23 days of sampling in the marginal creeks and adjacencies of the sandbanks.
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 pandemic. 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 & Chamom, 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: *Paragenidens 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 |
| *Anchovia cayennensis* (Puyo, 1946) | Per | ZP | NV | LC | NE |
| *Anchovia leptidentostole* (Fowler, 1911) | Per | ZP | NV | LC | NE |
| *Cetengraulis edentulus* (Cuvier, 1829) | Per | ZP | NV | LC | NE |
| *Lycengraulis grossidens* (Spix & Agassiz, 1829) | Per | ZP | NV | LC | NE |
| *Odontognathus mucronatus* Lacepède, 1800 | Per | ZP | NV | LC | NE |
| **SILURIFORMES**  |               |        |                     |          |
| Callichthyidae     |               |        |                     |          |
| *Callichthys callichthys* (Linnaeus, 1758) | 1st | ZB | NV | LC | NE |
| Loricariidae       |               |        |                     |          |
| *Hyphostomus sabriceps* (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 |
| *Sciaedes 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  |               |        |                     |          |
| *Microglaucis patasso* 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 comorosiris* (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 | | | | | |
| *Batiz koiolmatodon* (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 |
| *Euvorthodus 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 | | | | | |
| *Symbranchus 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 |
| Polygordidae | | | | | |
| *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 chrysorhynchos* (Linnaeus, 1766)* | Per | OV | | NV | LC | NE |
| *Eoligopliotes 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 | | | | | |
| *Echeńaeus 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 salmonopterus* Günther, 1862 | Per | ZB | | NV | LC | NE |
| *Eutropus crosstos* (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. brasilienensis* (Quoy & Gaimard, 1824) | 2nd | OV | NV | LC | NE |
| *Oreochromis niloticus* (Linnaeus, 1758) | 2nd | HB | EX-C | NA | NE |
| BELONIFORMES | | | | | |
| Belonidae | | | | | |
| *Strongyloglena 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 |
| *Magil incisus* Hancock, 1830 | Per | DT | NV | LC | NE |
| *Magil liza* Valenciennes, 1836 | Per | DT | NV | NT | NE |
| BLENNIIFORMES | | | | | |
| Blenniidae | | | | | |
| *Lupinoblennius paivai* (Pinto, 1958) | Per | ZB | NV | LC | ED |
| GERREIFORMES | | | | | |
| Gerreidae | | | | | |
| *Diapterus auratus* Ranzi, 1842 | Per | ZB | NV | LC | NE |
| *Diapterus rhombes* (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 brasiliensis* (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* (Lacépède, 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 |
| *Microprogonias furnieri* (Desmarest, 1823) | Per | ZB | NV | LC | NE |
| *Pachyurus adsorsus* Steinbachner, 1879 | Per | ZB | NV | DD | ED |
| *Stellifer brasiliensis* (Schultz, 1845) | 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

| Taxa | Euryhalinity | Trophic group | Origin | Brazilian Red List | Endemism |
|------|--------------|---------------|--------|--------------------|----------|
| Conodon nobilis (Linnaeus, 1758)* | Per | ZB | NV | LC | NE |
| Haemulopsidae corvinaeformis (Steindachner, 1868) | Per | ZB | NV | LC | NE |
| Pomadaeus ramosus (Poey, 1860) | Per | ZB | NV | LC | NE |
| Rhinocricus cf. croco (Cuvier, 1830) | Per | ZB | NV | LC | NE |

Lutjanidae

| Taxa | Euryhalinity | Trophic group | Origin | Brazilian Red List | Endemism |
|------|--------------|---------------|--------|--------------------|----------|
| 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

| Taxa | Euryhalinity | Trophic group | Origin | Brazilian Red List | Endemism |
|------|--------------|---------------|--------|--------------------|----------|
| Kyphus sectatrix (Linnaeus, 1758) | Per | HB | NV | LC | NE |

SPARIFORMES

Sparidae

| Taxa | Euryhalinity | Trophic group | Origin | Brazilian Red List | Endemism |
|------|--------------|---------------|--------|--------------------|----------|
| Archosargus probatocephalus (Walbaum, 1792)* | Per | OV | NV | DD | NE |

TETRAODONTIFORMES

Tetraodontidae

| Taxa | Euryhalinity | Trophic group | Origin | Brazilian Red List | Endemism |
|------|--------------|---------------|--------|--------------------|----------|
| Lagocephalus laevisatus (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 koilomatox; 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; Keessen *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 Lupinoblebnius 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).

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

**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**

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**COMPETING INTERESTS**

The authors declare no competing interests.

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