ARTIGO CIENTÍFICO

Endemism and extinction risk in one of the last refuges of the Doce River: mining, hydroelectric dams, and ecological collapse in the Santo Antônio River Basin, southeastern Brazil

Rainieli Nascimento [1], Frederico Fernandes Ferreira [1], Carlos Frankl Sperber [1], Jorge Abdala Dergam [2], Thadeu Sobral-Souza [3], Paulo dos Santos Pompeu [4], Lorena Torres Oporto [5], Hatus Siqueira [6], Elisabeth Henschel [2]*
**Contato principal*

[1] *Universidade Federal de Viçosa/UFV, Departamento de Biologia Geral/DBG, Viçosa/MG, Brasil. < ictiologiaraineli@gmail.com, frederico.bio@gmail.com, sperber@ufv.br >.*
[2] *Universidade Federal de Viçosa/UFV, Departamento de Biologia Animal/DBA, Viçosa/MG, Brasil. < jdergam@gmail.com, elisabeth.henschel@ufv.br >.*
[3] *Universidade Federal de Mato Grosso/UFMT, Instituto de Biociências/IB, Departamento de Botânica e Ecologia, Cuiabá/MT, Brasil. < thadeusobral@gmail.com >.*
[4] *Universidade Federal de Lavras/UFLA, Departamento de Ecologia e Conservação/DEC, Lavras/MG, Brasil. < pompeu@ufla.br >.*
[5] *Universidade Federal de Minas Gerais/UFMG, Instituto de Ciências Biológicas/ICB, Belo Horizonte/MG, Brasil. < lorenatoporto@gmail.com >.*
[6] *Instituto Chico Mendes de Conservação da Biodiversidade/ICMBIO, Centro Nacional de Pesquisa e Conservação da Biodiversidade Aquática Continental/CEPTA, Pirassununga/SP, Brasil. < hatus.siqueira@gmail.com >.*

Como citar:
Nascimento R, Ferreira FF, Sperber CF, Dergam JA, Sobral-Souza T, Pompeu PS, et al. Endemism and extinction risk in one of the last refuges of the Doce River: mining, hydroelectric dams, and ecological collapse in the Santo Antônio River Basin, southeastern Brazil. Biodivers. Bras. [Internet]. 2026; 16(2): e2909. doi:10.37002/biodiversidadebrasileira.v16i2.2909

Recebido em 21/02/2026 – Aceito em 09/07/2026

ABSTRACT – The Santo Antônio River, a major tributary of the Doce River (site of the 2015 Fundão Dam disaster), is a critical biodiversity hotspot. It harbors approximately 90% of the fish species recorded in the entire Doce River basin, including four endangered species (*Steindachneridion doceanum*, *Hypomasticus thayeri*, *Henochilus wheatlandii*, and *Brycon dulcis*). Despite its importance, the region faces intense human-induced pressures from mining, agriculture, non-native species, and landscape fragmentation caused by hydropower dams. This threat is compounded by the prospect of new projects and legislative deregulation (Bill PL 2159/2021). Although the basin contains 53 protected areas and benefits from ecological payments (ICMS-e), strategic areas within this basin, such as the main Doce River channel at the municipality of Ferros, where four endangered fish species occur, remain unprotected. We propose the urgent inclusion of the Santo Antônio River in the category of permanent preservation river (State Law No. 15,082/2004) as a priority measure to ensure ecological connectivity and the survival of the ichthyofauna and ecosystem services. While this measure could reduce exploitable hydropower potential by up to 277 MW, the economic impacts can be mitigated by strengthening the ICMS-e program and promoting sustainable development practices. The upcoming 25th anniversary of the National System of Conservation Units (SNUC) and the 10th anniversary of Brazil's worst socio-environmental disaster offer a crucial opportunity to redefine governance in the Doce River Basin, integrating conservation, socio-environmental justice, and sustainable use of its natural heritage.

Keywords: Conservation units; Doce River; ecological payment; endangered species; permanent preservation rivers.

Endemismo e risco de extinção em um dos últimos refúgios do Rio Doce: mineração, usinas hidrelétricas e colapso ecológico na Bacia do Rio Santo Antônio, sudeste do Brasil

RESUMO – O Rio Santo Antônio é um importante afluente do Rio Doce, além de ser um hotspot crítico de biodiversidade por abrigar aproximadamente 90% das espécies de peixes registradas em toda a bacia, incluindo quatro espécies ameaçadas de extinção (*Steindachneridion doceanum*, *Hypomasticus thayeri*, *Henochilus wheatlandii* e *Brycon dulcis*). Apesar de sua importância, a região enfrenta intensas pressões antrópicas decorrentes da mineração, agricultura, espécies não nativas e fragmentação da paisagem causada por barragens hidrelétricas. Essa ameaça é agravada pela perspectiva de novos projetos e pela desregulamentação legislativa (Projeto de Lei PL 2159/2021). Embora a bacia contenha 53 áreas protegidas e se beneficie de pagamentos ecológicos (ICMS Ecológico), áreas estratégicas dentro dessa bacia, como o canal principal do Rio Doce no município de Ferros, onde ocorrem as quatro espécies de peixes ameaçadas, permanecem desprotegidas. Propomos a inclusão urgente do Rio Santo Antônio na categoria de rio de preservação permanente (Lei Estadual nº 15.082/2004) como medida prioritária para garantir a conectividade ecológica e a sobrevivência da ictiofauna e dos serviços ecossistêmicos. Embora essa medida possa reduzir o potencial hidrelétrico explorável em até 277 MW, os impactos econômicos podem ser mitigados pelo fortalecimento do programa de ICMS Ecológico e pela promoção de práticas de desenvolvimento sustentável. O próximo aniversário de 25 anos do Sistema Nacional de Unidades de Conservação (SNUC) e o de 10 anos do pior desastre socioambiental do Brasil oferecem uma oportunidade crucial para redefinir a governança na Bacia do Rio Doce, integrando conservação, justiça socioambiental e uso sustentável de seu patrimônio natural.
Palavras-chave: Unidades de conservação; Rio Doce; ICMS Ecológico; espécies ameaçadas; rios de preservação permanente.

Endemismo y riesgo de extinción en uno de los últimos refugios del Río Doce: minería, centrales hidroeléctricas y colapso ecológico en la Cuenca del Río Santo Antônio, sureste de Brasil

RESUMEN – El Río Santo Antônio es un importante afluente del Río Doce, además de ser un punto crítico (hotspot) de biodiversidad al albergar aproximadamente el 90% de las especies de peces registradas en toda la cuenca, incluidas cuatro especies en peligro de extinción (Steindachneridion doceanum, Hypomasticus thayeri, Henochilus wheatlandii y Brycon dulcis). A pesar de su importancia, la región enfrenta intensas presiones antrópicas derivadas de la minería, la agricultura, las especies no nativas y la fragmentación del paisaje causada por represas hidroeléctricas. Esta amenaza se ve agravada por la perspectiva de nuevos proyectos y la desregulación legislativa (Proyecto de Ley PL 2159/2021). Aunque la cuenca cuenta con 53 áreas protegidas y se beneficia de pagos ecológicos (ICMS Ecológico), áreas estratégicas dentro de esta cuenca, como el cauce principal del Río Doce en el municipio de Ferros, donde habitan las cuatro especies de peces amenazadas, siguen sin protección. Proponemos la inclusión urgente del Río Santo Antônio en la categoría de río de preservación permanente (Ley Estatal N° 15.082/2004) como una medida prioritaria para asegurar la conectividad ecológica y la supervivencia de la ictiofauna y los servicios ecosistémicos. Si bien esta medida podría reducir el potencial hidroeléctrico explotable hasta en 277 MW, los impactos económicos pueden mitigarse mediante el fortalecimiento del programa de ICMS Ecológico y la promoción de prácticas de desarrollo sostenible. El próximo 25º aniversario del Sistema Nacional de Unidades de Conservación (SNUC) y el 10º aniversario del peor desastre socioambiental de Brasil ofrecen una oportunidad

crucial para redefinir la gobernanza en la Cuenca del Río Doce, integrando la conservación, la justicia socioambiental y el uso sostenible de su patrimonio natural.
Palabras clave: Unidades de conservación; Río Doce; ICMS Ecológico; especies amenazadas; ríos de preservación permanente.

Introduction

The Doce River Basin

The Doce River Basin, located in the Atlantic Forest domain in southeastern Brazil, encompasses two economically relevant states (Minas Gerais and Espírito Santo) and has been historically overexploited since the colonial period [1]. Initially driven by gold mining and, more recently, by iron extraction, silviculture, pulp and paper mill, installation of large hydroelectric power plants, and the proliferation of sand extraction dredges, this process of intensive human occupation has generated profound environmental changes in landscapes and ecosystems [2].

Ten years have passed since Brazil's most significant socio-environmental disaster: the rupture of the Fundão Dam in Mariana, Minas Gerais, which occurred on November 5, 2015. The burst of the Fundão ore-tailing reservoir, which was operated by the mining company Samarco (a joint venture of Vale and BHP Billiton), released over 40 million cubic meters of mining waste, devastating the district of Bento Rodrigues and contaminating the entire main channel of the Doce River, from its headwaters, formed by the union of the Piranga and Carmo Rivers, to its mouth in the Espírito Santo State, spreading over a large span into the Atlantic Ocean [3]. This environmental setback was not isolated, but a result of a complex historical process of extractive capitalism, with poor risk assessment and low concerns for ecological degradation [2].

Recently, silviculture was exempted from environmental licensing by Law No. 14,876/2024 [4]. In addition, data from the Secretariat of the Minas Gerais State for Environment and Development indicate that new projects continue to be licensed, increasing the cumulative effects of human-induced pressure on the Doce River Basin [5]. The dire condition of illegal mining activities and the involvement of politicians in Minas Gerais is currently being addressed by a major Federal Police operation, with an estimated US$3.4 billion corruption scheme [6].

Despite the environmental setback, the region retains a unique ecological relevance. The basin encompasses biodiverse areas that harbor endemic and rare species of birds [7], anurans [8], and a remarkably diverse flora, including species under varying degrees of threat [9] such as *Comanthera brasiliana*, *Cuphea rubrovirens*, *Lavoisiera angustifolia*, *Lavoisiera tetragona*, *Minaria bifurcata*, *Minaria diamantinensis*, *Orthophytum humile*, and *Panicum brachystachyum*, which are listed among the conservation target species of the Espinhaço Mineiro [10]. Moreover, new fish taxa are continuously being described for the Doce River Basin [11-13], revealing its potential for biodiversity studies and the need for more intensive taxonomic research. The middle portion of the Doce River is characterized by specific geological formations that have favored unique evolutionary processes, such as high levels of endemism [14, 15] and a mosaic of environments that includes lowland areas and one of the largest lacustrine systems in South America, represented by Rio Doce State Park [16, 17]. These characteristics support a wide range of essential benefits for the populations living around the basin by providing fundamental ecosystem services such as water regulation, maintenance of water quality, climate stabilization, and support for small-scale fisheries, in addition to contributing directly to the region's water and food security [18]. The conflict between biological relevance and environmental degradation highlights the

challenges of territorial management and the urgent challenge of reconciling conservation and environmental justice in a context marked by political corruption and strong mining and energy interests.

Santo Antônio River Basin: fish diversity and anthropogenic pressures

The Doce River is conventionally divided into three sections: the Upper, Middle, and Lower Doce River. The middle portion of the basin is characterized by specific geological formations that have favored distinctive evolutionary processes, as observed in the evolutionary history and close phylogenetic relationship between *Brycon* and *Henochilus* [14, 15, 19, 20]. This region also comprises a mosaic of environments, including floodplain areas and the lacustrine system associated with Rio Doce State Park, one of the largest lake systems in South America [21-23].One of the main tributaries of the middle Doce River is the Santo Antônio River, located in the Serra do Espinhaço, a region widely recognized as a center of endemism [24, 25, 12] and situated between two threatened biodiversity hotspots, the Cerrado and the Atlantic Forest [26, 27]. In addition, the Santo Antônio River is included in two areas of fish endemism defined by Sarmento-Soares et al. (2022): the Santo Antônio unit of analysis (UA) and the Western endemism pattern [28]. Although it occupies approximately 13% of the Doce River Basin, the Santo Antônio River harbors about 90% of the fish species recorded for the region [29]. Therefore, this river represents an important genetic reservoir for the conservation of aquatic biodiversity in the Doce River Basin [30]. Even before the Fundão dam collapse, the Santo Antônio River already required special conservation attention. However, after the disaster, it became evident that this river may play a central role as a source of native species for basin recolonization in a potential restoration process.

The diversity of endemic fish in the Santo Antônio River Basin, coupled with various habitat degradation processes, represents a true environmental emergency, as several species inhabiting it face a serious risk of extinction [31]. Currently, the basin is home to four fish threatened species [32, 33]: the Surubim-do-Doce *Steindachneridion doceanum* (Eigenmann & Eigenmann, 1889), the Timburé *Hypomasticus thayeri* (Borodin, 1929), the Piabanha *Brycon dulcis* (Lima & Vieira, 2017), and the Andirá *Henochilus wheatlandii* (Garman, 1890). Moreover, the latter is endemic to the Santo Antônio River Basin and, together with *S. doceanum*, has been designated as a target species in the Territorial Action Plan for the conservation of endemic and threatened species of the Espinhaço region [34]. All of these species share common threats, mainly the installation of hydroelectric dams, mining activities, pollution, and the reduction of riparian forests [31]. The introduction of non-native freshwater species also represents a threat to the conservation of local ichthyofauna, contributing to the loss of native species and the reduction of aquatic heterogeneity [35, 36]. This threat is exemplified and intensified in the remaining portions of the Doce River Basin, where the invasion scenario is particularly severe [37].

The expansion of hydroelectric power production can irreversibly damage biodiversity and ecosystem functioning [38] and, in the case of the Santo Antônio River, may impose additional barriers to the dispersal of species throughout the Doce Basin. Currently, three hydroelectric power plants (HPPs) are operating in this basin: Salto Grande, Porto Estrela, and Dona Rita, in addition to several small hydropower plants (SHPs) [5]. Although these projects represent a source of income for the municipalities where they are installed, they have caused significant environmental impacts, such as the transformation of lotic environments into lentic ones, the fragmentation of aquatic habitats, and the increased risk to the local biota especially the ichthyofauna leading to the loss of ecosystem services, including reduced fish resources and diminished water security [39].

Approximately 16 new projects for the installation of hydroelectric power plants (HPPs) and small hydropower plants (SHPs) are currently undergoing licensing processes along the Santo Antônio River Basin (Figure 1) [30]. This scenario is particularly concerning when compared to 2010, when only two HPPs were in

operation, two SHPs were active, and eight others were at some stage of the licensing process [40]. Furthermore, extensive debates have arisen regarding the Environmental Licensing Law Proposal (PL 2.159/2021)[41], which foresees the flexibilization of evaluation criteria and procedures for such enterprises. The approval of this measure will weaken environmental control mechanisms, reducing the rigor of cumulative impact assessments associated with any project [42]. In this context, aquatic fauna, especially threatened fish species, become even more vulnerable to the loss of habitat connectivity and the degradation of critical areas for reproduction and survival. Thus, this legislative proposal accelerates the implementation of hydroelectric projects, representing a setback for biodiversity conservation.

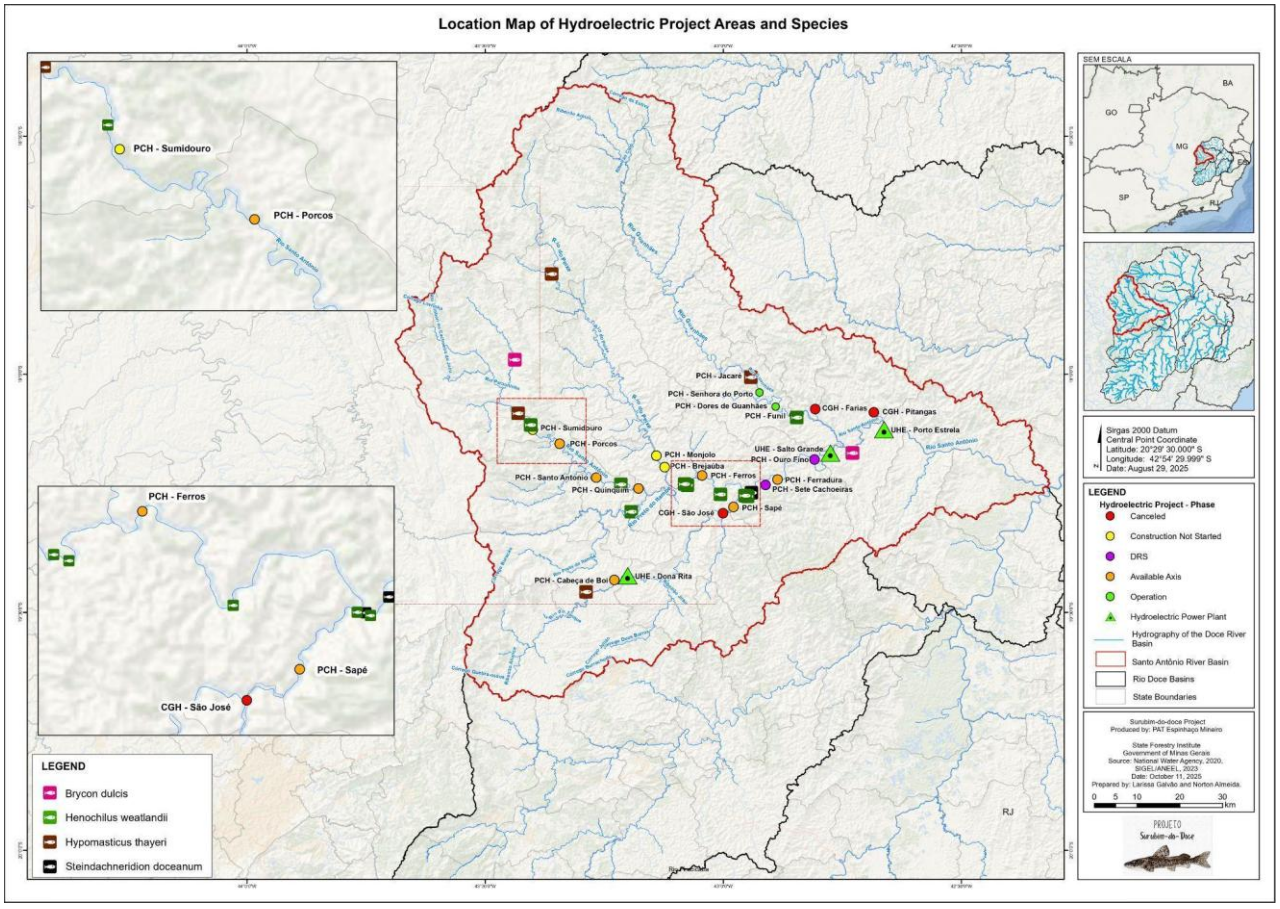

Figure 1 – Hydroelectric and small hydropower plants in the Santo Antônio River Basin: current operations and projects under licensing, with the distribution of threatened species. Source: Authors' own elaboration.

Protected areas and the conservation of freshwater biodiversity in Brazil

Protected areas play a crucial role in biodiversity conservation, particularly in Brazil, by directly protecting representative territories of various ecosystems. In Brazil, Law No. 9,985/2000 established the National System of Conservation Units (SNUC), which provides the norms and guidelines for creating and managing conservation units throughout the country [43]. Despite significant progress over the 25 years since its enactment, many protected areas remain primarily focused on terrestrial biodiversity conservation or are limited to protecting

regions located at rivers' headwaters, covering only their sources [30, 38]. Consequently, extensive stretches of river courses remain unprotected, compromising the ecological integrity of aquatic ecosystems and limiting the effectiveness of conservation strategies for water resources and associated biodiversity.

Legal framework: Law No. 15.082/2004 and the proposal for the Santo Antônio River

In Minas Gerais, Law No. 15,082/2004 stands out for categorizing watercourses as "permanent preservation rivers" (RPPs) [31]. This law aims to complement the protection of specific rivers considered priorities for conserving water resources and associated biodiversity. The law stipulates complete protection to marginal strips of permanent preservation rivers regardless of other uses and interests, considering their ecological, hydrological, and socio-environmental particularities. This category of conservation unit aims to: (i) maintain an "ecological balance" (sic) between the biodiversity of aquatic and marginal ecosystems; (ii) protect natural landscapes of scenic beauty; (iii) promote environmental education and "recreation in contact with nature"; (iv) provide conditions for nautical practices "in balance with nature" (sic); (v) favor conditions for amateur fishing and the development of sport fishing [25]. The legislation also establishes specific land use and occupation guidelines in these areas, restricting activities that could compromise their ecological integrity and water quality. Therefore, this category prohibits: (i) modification of the riverbed and banks, except for the Union's jurisdiction over rivers under its domain; (ii) disturbance of sediments for mineral resource extraction; (iii) exercise of activities that threaten to extinguish aquatic fauna species or that may endanger the "balance of ecosystems" (sic); (iv) the use of water resources or the execution of related works or services that are inconsistent with preservation objectives [31].

Following the rupture of the Fundão Dam in Mariana, Minas Gerais, the Bill No. 3.082/2015 [44], authored by Deputy Dr. Jean Freire/PT, was presented to the Legislative Assembly of Minas Gerais, proposing the inclusion of the Santo Antônio River upstream of the Salto Grande Hydroelectric Power Plant into the RPPs category. For three terms, the proposal never reached the plenary. It was consistently blocked through requests for review in the preliminary evaluation committees, due to pressure from the industrial sector of the state of Minas Gerais. Therefore, its legislative process remains incomplete, leaving the Santo Antônio River unprotected against the growing pressure from hydroelectric and mining projects [45].

Protected areas and the role of the Ecological ICMS

The Santo Antônio River Basin is home to approximately 182,000 people across 28 municipalities, spanning an area of more than 10,000 km2 [35]. Covers 51 protected areas (PAs) (Figure 2), of which 12 are designated for integral protection, 38 for sustainable use, and one for indigenous land, covering approximately 20% of the basin's territory [35]. In addition to their ecological benefits, these protected areas play a strategic role in fostering the local economy through the Ecological Tax on Circulation of Goods and Services (ICMS-e) [38]. This tax mechanism allocates a portion of the Tax on Circulation of Goods and Services (ICMS) revenue to municipalities with protected areas, compensating for land-use limitations and encouraging the creation and maintenance of protected areas. In May 2024, the municipalities within the basin received R$330,000 (approximately US$61,350.00), with amounts ranging from R$120.00 in some protected areas, such as those classified as sustainable use, to R$27,000.00 in Integral Protection categories [46]. These resources, allocated through this mechanism, can contribute to conservation and sustainable local development. However, not all municipalities contain conservation units, resulting in inequalities in the distribution of funds. For example, the

municipality of Ferros, which is home to the four endangered fish species in the basin [32], does not receive ICMS-e resources due to the absence of conservation units within its territory. This institutional gap exposes the fragility of environmental governance and points to the need for new strategies, including creating specific protected areas to protect ichthyofauna.

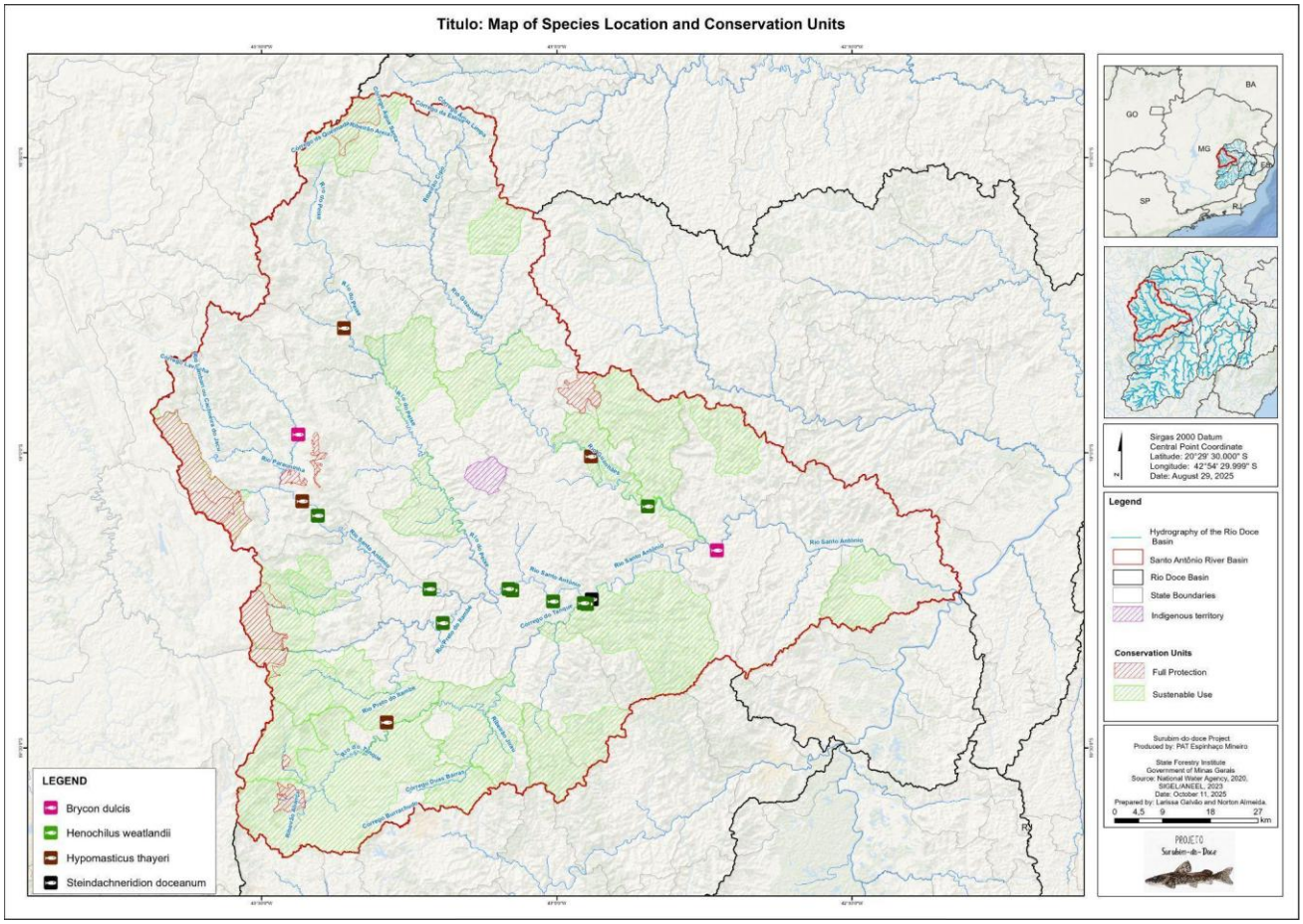

Figure 2 – Protected areas and the distribution of threatened species in the Santo Antônio River Basin. Source: Authors' own elaboration.

Conclusion

The 25th anniversary of the SNUC (National System of Nature Conservation Units) and the 10th anniversary of the Mariana disaster converge in 2025, presenting a unique opportunity to rethink the future of the Doce River Basin and one of its last well-preserved refuges, the Santo Antônio River. Conflicting pressures from mining, hydroelectric dams, pollution, and the introduction of exotic species threaten biodiversity and the livelihoods of riparian communities that depend on the river for survival. Existing protected areas, although relevant, do not have the direct protection of water bodies as their primary objective, since watercourses generally extend beyond the legal boundaries established for these units. Transforming the Santo Antônio River into a 'permanent preservation river' in at least a few key stretches represents a strategic measure to guarantee the persistence of endangered species and ensure the ecological recovery of the basin.

Although this measure could represent an estimated loss of 277 MW in hydroelectric potential, this amount is less than 10% of the current power capacity of the Doce Basin. Moreover, a stronger ICMS-e policy coupled with increasing sustainable development practices may overcome the economic impacts of restricting economic activities in this watercourse. The prevalence of sustainable use categories, such as areas for environmental protection (APAs) and private natural heritage reserves (RPPNs), also reveals opportunities for expanding and strengthening the conservation network through partnerships with municipalities, landowners, and rural communities. Expanding ecological connectivity could generate additional socioeconomic benefits, such as increased ICMS-e transfers, creating a virtuous cycle between conservation and territorial development. Hence, the current challenge lies in transforming historical milestones of tragedy and resistance into a turning point: strengthening the legal framework, expanding the network of protected areas, and ensuring that rivers such as the Santo Antônio River are recognized and protected as natural heritage of national ecological, social, and cultural importance.

Acknowledgments

To the Surubim-do-Doce Project, especially to Letícia Lourenço Ferreira, Ana Clara Pereira, and Vanessa Laiane da Silva, for valuable discussions and inputs on the conservation of fish and freshwaters. We are also thankful to the Laboratory of Biology and Molecular Systematics (BEAGLE), and the Graduate Program in Ecology at the Federal University of Viçosa for providing the necessary infrastructure for research. Thanks are also due to the Minas Gerais State Research Support Foundation (FAPEMIG) for the scholarship granted to Rainieli Aparecida do Nascimento and the Terra-Água Research Network for logistical support and data analysis. PSP (302328/2022-0) acknowledges the support received through a research fellowship from the CNPq. TSS thanks FAPEMAT (0746/2024).

References

1. Espindola HS, Wendling IJ. Elementos biológicos na configuração do território do Rio Doce. Varia Hist. 2008; 24: 177-197.
2. Cruz MA. Fantasmas do rompimento da barragem: impactos na diversidade alfa e beta da ictiofauna na Bacia do Rio Doce Dissertação de Mestrado. Belo Horizonte- Minas Gerais: Universidade Federal de Minas Gerais - UFMG; 2024. Disponível em: https://repositorio.ufmg.br/items/de56a114-5c15-4df2-b94b-0bfcbe5cab6a
3. Dias CA, Costa ASV, Guedes GR, Umbelino GJM, Sousa LG, Alves JH, et al. Impactos do rompimento da barragem de Mariana na qualidade da água do Rio Doce. Rev Espinhaço. 2018; 7(1): 21-35.
4. Brasil. Lei nº 14.876, de 31 de maio de 2024. Altera a descrição do Código 20 do Anexo VIII da Lei nº 6.938, de 31 de agosto de 1981, acrescido pela Lei nº 10.165, de 27 de dezembro de 2000, para excluir a silvicultura do rol de atividades potencialmente poluidoras e utilizadoras de recursos ambientais. Diário Oficial da União: Brasília, DF, 31 maio 2024. Disponível em: Planalto. Acesso em: 14 jun. 2026.
5. Secretaria de Meio Ambiente e Desenvolvimento Sustentável/ SEMAD - Fundação Estadual de Meio Ambiente – FEAM. Relatório de monitoramento. 2020.
6. G1. Entenda esquema de corrupção na ANM [Internet]. 2025 [citado 2025 Set 24]. Disponível em: https://g1.globo.com/mg/minas-gerais/noticia/2025/09/17/entenda-esquema-corrupcao-pf-prisao-diretor-anm-propina-servidores-publicos.ghtml
7. Vasconcelos MF, Lopes LE, Machado CG, Rodrigues M. As aves dos campos rupestres da Cadeia do Espinhaço: diversidade, endemismo e conservação. Megadiversidade. 2008; 4(1-2): 221-241.
8. Leite FSF, Juncá FA, Eterovick PC. Status do conhecimento, endemismo e conservação de anfíbios da Serra do Espinhaço, Brasil. Biota Neotropica. 2008; 8(2): 151-163.

9. Costa FN, Andrino CO, Negrão R. Plantas raras, ameaçadas e endêmicas dos topos de serra do Espinhaço Meridional. Rev Espinhaço. 2023.
10. Instituto Estadual de Florestas; Fundação de Parques Municipais e Zoobotânica; pat espinhaço mineiro. Guia de espécies do Plano de Ação Territorial para conservação de espécies ameaçadas de extinção do Espinhaço Mineiro: ciência cidadã. Organização de Nadja Simbera Hemetrio. Belo Horizonte: Instituto Estadual de Florestas, 2024. 39 p.
11. De Pinna M, Reis V, Britski H. A new species of Trichogenes (Siluriformes, Trichomycteridae), with a discussion on the homologies of the anterior orbital bones in trichomycterids and other loricarioids. American Museum Novitates. 2020; (3951): 1-27.
12. Oliveira-Silva L, Santos SA, Lopes MM, Zanata AM. A new species of Characidium (Characiformes: Crenuchidae) from the rio Doce basin, Brazil. Neotrop Ichthyol. 2022; 20(1): e210125.
13. Costa WJ, Mattos JLO, Barbosa MA, Vilardo PJ, Katz AM. Alto endemismo em um hotspot de biodiversidade ameaçado: Filogenia, taxonomia e padrões de distribuição de bagres do clado alfa de Psammocambeva (Siluriformes: Trichomycteridae) da bacia do Rio Doce, Brasil. Fishes. 2023); 8(10): 474.
14. De Queiroz V, Silva PC, Machado VN, De Assis CE, Barros LC, Dergam JA, et al. Uma nova espécie endêmica de Psalidodon eigenmann (Characiformes: Acestrorhamphidae) da bacia do alto rio Doce, Brasil. Zootaxa. 2025; 5725(2): 231-254.
15. Saadi, A. (1995). A geomorfologia da Serra do Espinhaço em Minas Gerais e de suas margens. Revista Geonomos; 3(1).
16. Freire JP, Costa TR, Alves PL, Machado ELM, Gonzaga APD. Raridade e endemismo da flora em campo rupestre (OCBIL) na Reserva da Biosfera da Serra do Espinhaço. Rev Espinhaço. 2021; 10(2).
17. Maia-Barbosa PM, Barbosa LG, Brito SL, Garcia F, Barros CFA, Souza, MBG, et al. Limnological changes in Dom Helvécio Lake (South-East Brazil): natural and anthropogenic causes. Brazilian Journal of Biology, 70(3 suppl), 795-802.
18. Meis MR, Monteiro AMF. Evolução do sistema de lagos barrados do médio vale do Rio Doce (MG) com base em estudos de sedimentação quaternária e neotectônica. Rev Inst Geol. 1979; 1(1): 1-14.
19. Garman S. On a genus and species of the characines (*Henochilus wheatlandii*, gen. n. et sp. n.). Bulletin of the Essex Institute. 1890; 22: 49-52.
20. Castro RMC, Vari RP, Vieira F, Oliveira C. Phylogenetic analysis and redescription of the genus Henochilus (Characiformes: Characidae). Copeia, v. 2004, n. 3, p. 496–506, 2004. doi: 10.1643/CI-03-202R2.
21. Bezerra MP, Barbosa PM, Barbosa FAR, Bezerra JF. Temporal coherence of physical, chemical and biological variables in four tropical lakes (Minas Gerais, Brazil). Acta Limnologica Brasiliensia, 2017; 29: e12.
22. Fragoso-Moura EN, Oporto LT, Maia-Barbosa PM, Barbosa FA. Loss of biodiversity in a conservation unit of the Brazilian Atlantic Forest: the effect of introducing non-native fish species. Brazilian Journal of Biology, 2016; 76(1): 18-27.
23. Pivari MO, Oliveira VBD, Costa FM, Ferreira RM, Salino A. Macrófitas aquáticas do sistema lacustre do Vale do Rio Doce, Minas Gerais, Brasil. Rodriguésia; 2011. 62(4): 759-770.
24. Assessment ME. Ecosystems and human well-being: wetlands and water. World resources institute; 2005.
25. Giulietti AM, Pirani JR, Harley RM. Espinhaço Range region, eastern Brazil. In: Davis SD, Heywood VH, Herrera-MacBryde O, Villa-Lobos J, Hamilton AC, editors. Centres of Plant Diversity: a guide and strategy for their conservation. Cambridge: IUCN; 1997. p. 397-404.
26. Assunção-Silva CC, Bueno ML, de Souza Assis LC. Centros de riqueza e endemismo de Lauraceae na Serra do Espinhaço, Brasil. Flora. 2021; 285: 151943.
27. Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GA, Kent J. Biodiversity hotspots for conservation priorities. Nature. 2000; 403(6772): 853-858.
28. Mittermeier R. Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions. 2005. (No Title).
29. Vieira-Guimarães F, Sarmento-Soares LM, Marinho Nobre D, Cantarin Neiva D, Paulo da Silva J, Martins-Pinheiro RF. Biogeographic patterns of the freshwater fishes from the state of Espírito Santo, eastern Brazil. Studies on Neotropical Fauna and Environment. 2024; 59(3): 727-746.
30. Siqueira HO. Estudos na conservação de espécies de peixes do Rio Santo Antônio, Bacia do Rio Doce [Dissertação]. Botucatu: Universidade Estadual Paulista; 2019.
31. Pompeu PS. Rios de preservação permanente: uma alternativa para conservação da ictiofauna. Ação Ambiental. 2012; 13(47): 12-14.

32. Vieira F. A ictiofauna do rio Santo Antônio, bacia do rio Doce, MG: proposta de conservação [Dissertação/Tese]. Belo Horizonte: Universidade Federal de Minas Gerais; 2006.
33. Alves CBM, Gomes JPC, Pessali TC, Gasparini JL. Peixes ameaçados de extinção na bacia do rio Doce. Livro vermelho da biota aquática do Rio Doce ameaçada de extinção pós rompimento da barragem de Fundão: Mariana, Minas Gerais: crustáceos, efemerópteros, odonatos e peixes. 2021; 205-264.
34. Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio. Lista Nacional de Espécies da Fauna Ameaçadas de Extinção [Internet]. 2022 [citado 2025 Out 16]. Disponível em: https://salve.icmbio.gov.br
35. Instituto Estadual de Florestas. Plano de Ação Territorial para Conservação de Espécies Ameaçadas de Extinção do Território Espinhaço Mineiro: sumário executivo. Belo Horizonte: IEF; 2021.
36. Fragoso-Moura EN, Oporto LT, Maia-Barbosa PM, Barbosa FAR. Loss of biodiversity in a conservation unit of the Brazilian Atlantic Forest: the effect of introducing non-native fish species. Braz J Biol. 2016; 76(1): 18-27.
37. Azevedo-Santos VM, Frederico RG, Fagundes CK, Pompeu PS, Pelicice FM, Padial AA, et al. Protected areas: a focus on Brazilian freshwater biodiversity. Diversity and Distributions. 2019; 25(3): 442-448.
38. da Silva DAR, de Carvalho DR, Ferreira FF, Dergam JA, Moreira MZ, Pompeu PS. Non-native fishes occupy broader isotopic niche than native fishes in an impaired river system. Hydrobiologia. 2025; 852(8): 2149-2169.
39. Linares MS, Callisto M, Marques JC. Conformidade da produção secundária e da eco-exergia como indicadores da resposta das assembleias de macroinvertebrados bentônicos às condições de cobertura do dossel em riachos de cabeceira neotropicais. Science of the Total Environment. 2018; 613: 1543-1550.
40. Agência Nacional de Energia Elétrica – ANEEL. Relatório de segurança e serviços ecossistêmicos. [Internet] 2024 [citado em outubro de 2025].
41. Brasil. Senado Federal. Projeto de Lei nº 2.159, de 2021. Dispõe sobre o licenciamento ambiental; regulamenta o inciso IV do § 1º do art. 225 da Constituição Federal; altera as Leis nº 9.605, de 12 de fevereiro de 1998, e nº 9.985, de 18 de julho de 2000; revoga dispositivo da Lei nº 7.661, de 16 de maio de 1988; e dá outras providências. Brasília, DF: Senado Federal, 2021. Disponível em: https://www25.senado.leg.br/web/atividade/materias/-/materia/148785. Acesso em: 05 jun. 2026.
42. Comitê de Bacias Hidrográficas do Rio Doce - CBH Santo Antônio [Internet]. 2022 [citado em Set de 2025]. Disponível em: https://www.cbhsantoantonio.org.br/a-bacia
43. Brasil. Lei nº 9.985, de 18 de julho de 2000. Regulamenta o art. 225, § 1º, incisos I, II, III e VII da Constituição Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza e dá outras providências. Diário Oficial da União: Brasília, DF, 19 jul. 2000. Disponível em: https://www.planalto.gov.br/ccivil_03/leis/l9985.htm. Acesso em: 06 jun. 2026.
44. Minas Gerais. Assembleia Legislativa do Estado de Minas Gerais. Projeto de Lei nº 3.082/2015. Acrescenta incisos ao art. 5º da Lei nº 15.082, de 27 de abril de 2004, que dispõe sobre rios de preservação permanente e dá outras providências. Belo Horizonte: ALMG, 2015. Disponível em: https://www.almg.gov.br/atividade-parlamentar/projetos-de-lei/texto/?tipo=PL&ano=2015&num=3082. Acesso em: 10 jun. 2026.
45. Frota AM. O papel do PL nº 2.159/2021 no desmonte do licenciamento ambiental [Monografia]. Porto Velho: Universidade Federal de Rondônia; 2024. 83 f.
46. Fundação João Pinheiro. ICMS – Lei Robin Hood. Belo Horizonte: Fundação João Pinheiro, [s.d.]. Disponível em: https://robin-hood.fjp.mg.gov.br/municipios. Acesso em: 10 jun. 2026.

Biodiversidade Brasileira
Fluxo Contínuo
v. 16 n.2, 2026
https://revistaeletronica.icmbio.gov.br/index.php/BioBR/
Biodiversidade Brasileira é uma publicação eletrônica científica do Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) que tem como objetivo fomentar a discussão e a difusão de experiências em conservação e manejo de unidades de conservação, gestão e uso sustentável de recursos naturais renováveis, biodiversidade e espécies ameaçadas, fiscalização e proteção da biodiversidade e patrimônio natural, e educação e formação para a conservação da sociobiodiversidade.
ISSN: 2236-2886