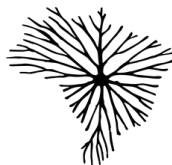


Photo: Robson Santos/Sisema

Foto: Eunice Zimbres

# SCIENTIFIC MANIFESTO FOR THE RECOVERY OF THE RIO DOCE BASIN:

BIODIVERSITY, ECOSYSTEM SERVICES, AND  
EVIDENCE-BASED ENVIRONMENTAL RESTORATION



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Ten years after the collapse of the Fundão dam in Mariana, the Rio Doce basin remains in a chronic state of environmental degradation. A body of independent scientific studies shows that the damage to the basin is far from resolved and that the reparative measures adopted are insufficient to contain and reverse the situation. The tailings not only remain in the environment but are also periodically remobilized, increasing contamination of water, soil, and aquatic and terrestrial organisms.



Mouth of the Rio Doce, in Linhares (ES), photographed in 2019. Photo: Tânia Régio/Agência Brasil

The combination of persistent contamination and the absence of coordinated, long-term actions undermines the basin's natural capacity for regeneration. As a consequence, ecosystem services such as water provision, flood regulation, erosion control, fisheries, and food production are severely threatened, directly affecting the quality of life of the populations that depend on the Rio Doce.

This document synthesizes evidence produced by one of the largest independent research programs on the Rio Doce disaster, as well as other important initiatives on the topic, and demonstrates that several stretches of the basin remain extremely vulnerable to new contamination events and a worsening of the socio-environmental crisis.

## The Basin's Critical Condition and Required Actions

Research shows a direct causal link between the release of tailings and profound transformations in the terrestrial and aquatic ecosystems of the Rio Doce basin. The impacts affect all levels of life — from microbiota, fish, and forests to marine environments — compromising vital ecosystem services such as clean water provision, food production, erosion control, and climate regulation. The main scientific findings are summarized below:

- **Water and sediments remain a major environmental challenge:** The tailings deposited along the riverbed are constantly remobilized during rainfall, causing recurrent contamination, increased turbidity, and elevated metal concentrations. This problem is exacerbated by bank erosion, lack of basic sanitation, and the use of agrochemicals. In the marine portion, remobilization events are associated with the passage of winter cold fronts, worsening environmental indicators to levels similar to those observed immediately after the collapse.
- **Terrestrial biodiversity is under stress:** Impacted areas have less diverse forests, often dominated by invasive species. Native plants are more fragile, with reduced capacity to respond to environmental stress and climate change. Soil fauna (such as earthworms and arthropods) has been profoundly altered, disrupting ecological interactions and key processes like decomposition.
- **Aquatic life is deformed and diseased:** Fish diversity has declined while the abundance and richness of invasive species have increased, leading to a homogenization of the fish fauna along the Rio Doce channel. Fish, tadpoles, and aquatic insects exposed to heavy metals exhibit body deformities, damage to vital organs (liver, kidneys, gills), and impaired reproduction. There is also strong evidence of bioaccumulation and trophic biomagnification of metals such as zinc, aluminum, cadmium, iron, and manganese, among others.



Rio Doce State Park. Photo: Evandro Rodney

- **Contamination is systemic:** Metals such as iron and manganese still appear in quantities above safe limits in water and sediments. They enter the food chain and can accumulate in organisms over time, posing an underrecognized risk to the population — especially because humans sit at the top of this chain.
- **In a future climate-change scenario:** Several modeling studies indicate a worsening of post-disaster impacts on fauna and flora, cutting in half the areas of suitable habitat for species compared to the pre-disaster period. Even invasive species will lose habitat suitability, although some stretches of the Rio Doce basin will remain favorable for a few of them. Native species, however, are expected to be even more severely affected, threatening biodiversity conservation and multiple ecosystem services.

To change this trajectory, urgent, coordinated, and long-term actions are needed, including:

- **Stop ongoing contamination:** Control erosion and sediment remobilization, especially in stretches already identified as major tailings-deposition zones, including hydroelectric reservoirs. In parallel, urgently expand basic sanitation throughout the Rio Doce basin.
- **Regulate mining activities:** Strengthen regulation and oversight of sand and gold extraction in the upper portions of the basin — particularly in the Rio do Carmo and headwaters of the Rio Doce — which are major contributors to sediment suspension during the dry season. It is also necessary to rigorously regulate and inspect ongoing iron mining activities in the headwaters of the Rio Santo Antônio, as this microbasin maintains the best environmental quality and greatest potential to support the physical and biological restoration of the Rio Doce.
- **Implement ecological restoration based on consolidated scientific knowledge:** Prioritize riparian forest restoration, using native species from reference communities specific to each stretch of the basin. In aquatic environments, apply direct recovery mechanisms to the most degraded river and lagoon sections. Similar procedures should be adopted for coastal ecosystems, including restinga and mangroves.
- **Control invasive species:** Implement effective enforcement measures to prevent new invasions and control invasive species already established in the basin — particularly non-native fish and plants that have benefited from environmental degradation after the Fundão dam collapse.
- **Promote long-term monitoring:** Monitor riparian and coastal ecosystems using modern technologies and detailed tracking of native species to understand the persistent effects of the Fundão disaster and to guide effective mitigation, restoration, and conservation actions. Human biomonitoring should also be conducted among populations that consume water and/or fish from the Rio Doce daily, enabling risk assessment of exposure to toxic metals in partnership with academic and research institutions.



- **Promote conservation and improve environmental conditions in tributaries not directly affected by tailings:** Expand and strengthen the protection of preserved environments in unaffected tributaries, as they represent the last refuges for native fish and other aquatic organisms. These areas hold significant potential for natural recolonization of the main river channel and other impacted stretches. In this context, the Rio Santo Antônio basin stands out as one of the most preserved remnants of the system — a biodiversity refuge and potential source for recolonization in scenarios of functional restoration of currently degraded habitats in the Rio Doce.
- **Establish a transparent data-access system:** Digitally publish monitoring data through an online platform in an accessible format to guide actions and evaluate results.
- **Strengthen governance and social participation:** Create mechanisms to integrate local, Indigenous, and quilombola communities into scientific knowledge production, ensuring their effective involvement in decision-making processes.
- **Create spaces and ensure participation for young leaders:** Encourage the formation of youth groups and associations focused on leadership development and income generation.
- **Build a One Health approach:** Adopt the One Health principle as an integrated pathway to restore ecosystems, protect public health, ensure water security, reduce sanitary risks, and rebuild the social-ecological resilience of the basin.
- **Innovation, immediate action, and future building:** Develop and apply remediation technologies capable of mitigating impacts and improving community well-being. This requires transforming years of accumulated scientific evidence into effective public policies, supported by structured and continuous monitoring.

- **Scientific communication and feedback to affected populations:** Strengthen scientific communication with all basin communities, ensuring that residents of affected territories receive clear, continuous, and accessible updates on research progress, monitoring results, and environmental risks or improvements. Science cannot remain restricted to technical reports and closed meetings; it must reach those who live the disaster's consequences every day. This includes producing accessible educational materials, holding periodic community meetings, promoting citizen science, and establishing direct communication channels that enable people to understand, question, participate in, and contribute to the process. Just reparations require transparency, active listening, and recognition of residents as protagonists, not bystanders.

The future of the Rio Doce Basin depends on the ability to act now based on existing knowledge; however, new studies are still needed to fill critical information gaps.

## 1. A Decade of Science and a Warning

Ten years after the collapse of the Fundão dam, the scientific community gathered at the Restaura+ Congress in Belo Horizonte (4–7 November 2025) consolidated the results of initiatives dedicated to monitoring, socio-biodiversity assessment, and restoration in the Rio Doce basin. This unprecedented multidisciplinary effort — accompanied by public agencies, environmental managers, the academic community, and civil society — had as its central goal to understand the impacts of the disaster and to identify pathways for a more effective and sustainable recovery.

Scientists presented a clear and alarming diagnosis of the effects of the tailings. They are deep, persistent, and ecosystem-wide, keeping

the basin in a state of chronic vulnerability even after ten years. This letter synthesizes this body of evidence and, based on it, calls for an immediate shift in mitigation and recovery strategies — strategies that must be guided by scientific data rather than by isolated, assumption-driven interventions. Despite this unprecedented scientific effort, the public response remains fragmented, hindered by weak coordination across levels of government and fragile mechanisms of accountability and oversight. Without a structural reform of governance, even the most robust technical-scientific solutions will have limited potential and be unable to promote recovery at a scale compatible with the magnitude of the impacts.

Furthermore, the Rio Doce disaster was not only an ecological collapse; it was also an expression of socio-environmental inequality. Riverside, Indigenous, quilombola, and traditional communities were especially affected by the cumulative impacts on water, soil, health, and livelihoods. Recovery strategies that fail to consider these inequalities risk reinforcing the historical vulnerabilities faced by these populations.

## **2. The Path to Reparation: A Science-Based Action Plan**

Given this scenario, socio-environmental restoration requires an integrated, long-term strategy focused on solving key problems. Isolated, non-technical actions are ineffective and can accelerate degradation. This plan must incorporate the source-to-sea approach, which proposes integrated management of resources across the entire aquatic system — from headwaters to ocean — recognizing that all parts of the system are interconnected. This approach enables the effective integration of social, economic, and ecological dimensions, from the epicenter of the disaster to the river's mouth.



Moreover, repairing the Rio Doce basin requires hybrid, multiscale governance that is capable of coordinating different management levels and social actors, with clearly defined responsibilities, verifiable targets, and independent oversight mechanisms. Such a structure is essential to ensuring coherent decision-making, continuity of actions, and the effective use of the best available scientific evidence.

## **Strategic and Urgent Actions:**

### **3.1. Transparent and Long-Term Monitoring**

- Establish a public network of monitoring stations for water, soil, climate, and biodiversity, with open-access data.
- Use bioindicators (fish, insects, arachnids, earthworms, etc.) and modern technologies (eDNA, remote sensing, stable isotopes) to assess ecosystem health and the effectiveness of restoration actions.
- Create reference collections of native fauna and flora from the Rio Doce basin to document regional biodiversity, support taxonomic studies, and provide a strong scientific baseline for assessing long-term environmental changes.
- Advance studies on species biology, deepening the understanding of links between environmental degradation, biodiversity loss, and the collapse of ecosystem services.
- Continuously monitor metal bioaccumulation in the food chain.
- Prioritize filling knowledge gaps on the impacts of tailings on understudied groups of organisms.

### **3.2. Ecological Restoration**

Prioritize erosion control and the restoration of riverbanks and headwaters using native species from each region to enhance ecosystem connectivity and biodiversity, while counteracting landscape homogenization.

- Implement strict control of invasive non-native species, both aquatic and terrestrial.
- Protect and connect forest fragments and riparian ecosystems by creating ecological corridors, conserving natural regeneration processes, and actively restoring strategic sites.
- Implement habitat and shelter restoration programs in aquatic and riparian ecosystems.
- Critically assess whether already restored areas meet the minimum criteria established for ecological restoration in the basin and propose corrective measures when necessary.
- Establish fully protected conservation units in critical and still-preserved areas, such as the Piranga, Santo Antônio, and Manhuaçu rivers. Likewise, increasing the rigor in licensing potentially impactful developments is essential in priority conservation areas, such as the Rio Santo Antônio basin, recognized for its high ecological relevance and vulnerability.
- Prevent the fragmentation of aquatic environments in the basin through the construction of new dams.
- Reduce and eliminate conflicts of interest in restoration areas to prevent their continued use for cattle grazing or burning practices.

### 3.3. Control of Pollutants and Pressure Sources

- Expand basic sanitation throughout the basin to reduce diffuse pollution. Special attention is needed in the most polluting regions to identify and control different types of pollution along the basin — from mining impacts in upstream areas to urban and industrial pollution predominant in the middle and lower Rio Doce.
- Stabilize or remove contaminated sediments in critical areas.
- Control active sources of contamination, such as gold extraction, iron mining, sand extraction, and urban and industrial pollution that contribute to turbidity and metal contamination.

### 3.4. Governance, Social Participation, and Education

- Treat the recovery/restoration of the Rio Doce basin as a permanent State agenda, transcending governments and political cycles. Create intersectoral, intermunicipal, and interstate policies to avoid fragmented and disconnected actions.
- Ensure the effective participation of local communities — including Indigenous peoples, quilombola communities, fishers, and farmers — in project co-production and decision-making. Special attention should be given to directly affected communities, such as the Gesteira quilombo (Barra Longa) and the Krenak territory.
- Implement robust environmental education and citizen science programs that empower the population to monitor and protect the river, while promoting community mobilization campaigns that honor the memory of the disaster and engage new generations in continuous monitoring and active restoration.
- Create mechanisms for coordinated action with gold mining and sand extraction activities along the upper course of the river, where such activities are intense.
- Create an independent environmental monitoring network, linking universities, research institutes, community organizations, and environmental journalists to act as a permanent observatory of the Rio Doce — documenting ecological indicators, reporting violations, and tracking progress in the restoration of the basin's socio-biodiversity.
- Integrate the One Health perspective into public policies, connecting environment, health, and social justice to strengthen the basin's socio-ecological resilience.
- Strengthen the role of the Public Prosecutor's Office and the Judiciary in overseeing and contesting legal setbacks, ensuring that environmental licensing and recovery processes are grounded in current scientific knowledge — for example, in ecological restoration strategies that prevent biotic homogenization of the Rio Doce basin.



- Mobilize public civil actions to secure full reparation for the remaining environmental and social damages, holding companies and institutions accountable for losses in biodiversity, ecosystem services, and livelihoods.
- Bring environmental justice into research, monitoring, and reparation actions, including issues of environmental racism and gender. Special attention should be given to the impacts on Black and Indigenous women living in the basin, recognizing their specific vulnerabilities, central roles in sustaining local ways of life, and the disproportionate socio-environmental burdens they face.
- Create a permanent restoration fund for the Rio Doce basin, managed transparently and with participatory governance, dedicated to long-term projects in ecological restoration, headwater revegetation, and the strengthening of traditional and rural communities.
- Promote the recognition of the Rio Doce and its ecosystems as subjects of rights, drawing inspiration from international and national precedents that expand legal protection of nature and reinforce an ethic of ecological care.
- Bring the Rio Doce into multilateral and international cooperation agendas, seeking technical and financial support from international organizations to ensure that basin recovery is recognized globally as a case of socio-environmental justice and ecological reconstruction.
- Create a real-time situation room for monitoring the condition of the Rio Doce across multiple dimensions, integrating abiotic (climate, soil, water) and biotic (biodiversity, zoonoses) aspects.

### 3.5. Alignment with the Sustainable Development Goals (SDGs)

This document is directly aligned with the UN 2030 Agenda and its Sustainable Development Goals (SDGs), underscoring that the recovery of the Rio Doce basin is a strategic priority for national development. The proposed actions directly address SDGs 6 (Clean Water and Sanitation), 14 (Life Below Water), and 15 (Life on Land) by demanding pollution control, ecological restoration, and biodiversity conservation.

They also relate to SDGs 3 (Good Health and Well-Being) and 13 (Climate Action), by acknowledging risks to human health and the urgent need to strengthen the basin's climate resilience; and to SDG 10 (Reduced Inequalities), by highlighting the disproportionate impacts on Indigenous, quilombola, and traditional communities.

The document further contributes to SDG 16 (Peace, Justice, and Strong Institutions), by advocating for transparency, multilevel governance, and accountability, and to SDG 17 (Partnerships for the Goals), by promoting cooperation among universities, civil society, public managers, and international organizations.

Thus, the recovery of the Rio Doce basin transcends the environmental dimension and represents an integrated commitment to socio-environmental justice, One Health, and long-term sustainability.

## 4. Conclusion and Final Call to Action

The Rio Doce basin endures, harboring unique biodiversity essential to its natural regeneration processes. However, in the face of disturbances caused by tailings deposition, combined with long-standing degradation, its response capacity and resilience have been severely compromised. Brazilian science has fulfilled its role — diagnosing the problems and presenting evidence-based solutions.

At this moment, the direction and future of the basin lie in the hands of public authorities, the companies responsible for the disaster, and society. It is imperative that the knowledge generated becomes the central foundation of all future actions. Political commitment, institutional continuity, and adequate funding are essential to implement a robust plan capable of restoring the basin's functionality and sustainability.

The restoration of the Rio Doce basin can, and should, become a national and international reference for the recovery of degraded watershed systems. How Brazil conducts this repair process will have implications far beyond the basin's boundaries. It stands as a global test case of the capacity to respond to large-scale disasters through scientific knowledge, social participation, and corporate responsibility.

The Rio Doce may become a laboratory for innovative solutions in watershed restoration, environmental justice, and One Health — or remain a symbol of neglect and impunity. At this moment, the choice is fundamentally political.

We call upon all involved actors — society, institutions, and public authorities — to act with urgency and responsibility. Only by transforming scientific evidence into effective public policies will it be possible to honor the victims of the disaster and ensure a future of socio-environmental justice for the Rio Doce basin.

It is time to break the cycle of degradation, overcome simplistic and fragmented decisions, and rebuild based on knowledge, cooperation, and a commitment to life.



This letter is signed by environmental science researchers gathered at the “Restaura+ Mariana 10 Years” event on the Rio Doce basin, held at UFMG from November 4 to 7, 2025, together with several other specialists in Brazilian biodiversity. On behalf of the scientific community committed to sustainability, socio-environmental justice, and the integrity of Brazilian ecosystems, we reaffirm our responsibility and our commitment to the conservation and restoration of this region.

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