Source-to-sea and landscape approaches

Integrating water quality and biodiversity conservation toward the restoration of the Rio Doce watershed

M.C.W. Brito, F.A.R. Barbosa, P. May, C. Maroun, J. Renshaw, L.E. Sánchez, Y. Kakabadse

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The economic, environmental and social context of the Rio Doce Basin is dynamic and rapidly changing. The Rio Doce Panel has prepared this report with the best publicly available information at the time of its writing, and acknowledges that new studies and information are emerging that will shed further light on the restoration effort.

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List of acronyms

APP	Área de Preservação Permanente (Permanent Preservation Area)
CIF	Comitê Interfederativo (Inter-Federative Committee)
CIF-CTBIO	CIF Technical Chamber for Biodiversity Conservation
ES	Espirito Santo
FLR	Forest Landscape Restoration
ICZM	Integrated Coastal Zone Management
IUCN	International Union for Conservation of Nature
MG	Minas Gerais
PES	Pagamento por Serviços Ambientais (Payment for Environmental Services)
PIRH	Plano Integrado de Recursos Hídricos (Integrated Water Resources Plan)
PMBA	Programa de Monitoramento da Biodiversidade Aquática (Aquatic Biodiversity Monitoring Programme for Environmental Area 1)
PMQQS	Programa de Monitoramento Quali-Quantitativo Sistemático de água e sedimentos da bacia do Rio Doce (Systematic Quali-Quantitative Monitoring Program of Water and Sediment for the Rio Doce watershed)
PNGC	Plano Nacional de Gerenciamento Costeiro (National Coastal Management Plan)
PNRH	Plano Nacional de Recursos Hídricos (National Water Resources Plan)
ROAM	Restoration Opportunities Assessment Methodology
RRDM	Rede Rio Doce Mar (Rio Doce Mar Network)
TTAC	Termo de Transação e de Ajustamento de Conduta (Terms of Transaction and Conduct Adjustment)
WRI	World Resource Institute
WWF	World Wide Fund for Nature

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- Members of the Technical Committee and Advisory Board of Renova Foundation;
- Representatives of Affected People Commissions in Minas Gerais and Espírito Santo;
- Representatives of the States of Minas Gerais and Espírito Santo;
- Representatives of socio-environmental non-governmental organisations working in the watershed; and
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Foreword

As the UN Decade on Ecosystem Restoration begins, we must scale up our efforts to breathe new life into degraded ecosystems. Such restoration takes time and investment but brings enormous benefits. These include improving communities' food and water security, alleviating poverty, protecting biodiversity, and helping to mitigate climate change.

Brazil's Rio Doce watershed is an example of ecosystem restoration in action. Home to around 3.6 million people who depend on the river for their health, food and livelihoods, restoration has been underway since the collapse of the Fundão tailings dam badly polluted more than 650 kilometres of the once rich landscape.

In this report, published more than five years after the disaster, the independent Rio Doce Panel looks to the future of this critical watershed and the ongoing work to restore it. The Panel recommends that the restoration programme in addition to re-establishing the river watershed's ecological integrity, consider the full landscape from source to sea. This would help protect the services that the ecosystem provides to the local people, and the region.

As the river watershed crosses state boundaries, the governance of the restoration programme is complex. Among the report's primary recommendations is the adoption of a source-to-sea and integrated landscape approach, which would help identify and prioritise the most critical issues. The Panel also calls for basic sanitation measures to be put in place throughout the watershed and an expanded research programme to monitor the ecosystem's health. This overarching and public monitoring plan should include improved water and sediment sampling, and more terrestrial, marine and freshwater biodiversity surveys.

Alongside the huge benefits to nature, implementing a source-to-sea programme of restoration for the Rio Doce watershed will support the regional and local economy: farmers, fishers, traditional communities and artisanal miners. A robust and healthy ecosystem will also help protect these communities from future disasters. The river does not exist in isolation, so restoration should not end at its mouth but include the adjacent coastal waters. To be successful in the long term, the programme must reflect the social, economic, cultural and environmental features of the entire watershed.

Conservation on this scale allows us to innovate, to pilot new solutions and gather further knowledge that will inspire and guide ecosystem restoration elsewhere. Perhaps, with time and investment, we can build a more biodiverse and sustainable landscape than that which existed before the disaster. A thriving ecosystem, restored from source to sea, will help ensure a healthier future for the people of the Rio Doce region and set a powerful example for other watersheds.

Dr Bruno Oberle
Director General
IUCN, International Union for Conservation of Nature

Preface

In the course of the last five years, since the Fundão tailings dam failure in 2015 communities in the Rio Doce watershed have sought to restore their lives and their natural environment, both of which centre around the Rio Doce itself. This river is a vital artery for the basin not only for its rich biodiversity but also for the diverse stakeholders who depend on it for their livelihoods. Efforts to restore and strengthen this natural lifeline must therefore obviate a piecemeal approach, but rather one that is innovative and broadens the perspective of the restoration, such as adopting a landscape perspective from source-to-sea. This implies a more integrated approach that takes into consideration the environmental, social, financial, economic and cultural aspects of this unique region.

In this report, we analysed data from water quality, further incorporating other elements still not tackled, such as the possibility of chronic metal pollution in particularly in the estuary, and studies on other distinct components of the biota, to show the interconnection between water quality and biodiversity conservation. Based on our analyses, we propose recommendations to enhance and prioritise efforts related to water monitoring and sewage, riparian vegetation restoration, and biodiversity monitoring associated with the development of a data bank.

Most of the efforts undertaken by the Renova Foundation and other stakeholders, including the local communities themselves, have produced visible results that can and should be recognised and expanded to other areas designated for restoration. Increasing and replicating these activities throughout the region will help ensure greater opportunities for a more resilient and sustainable recovery in the long term.

One of the most difficult challenges exacerbated by the disaster is to improve the water quality and biodiversity recovery, which provide essential ecosystem services. While the report recognises the advances that have been made by the 42 programmes, there are still many opportunities to act upon bringing back the health and abundance of the river watershed.

Seeking and building synergies to make the efforts underway to last is the common goal to be achieved by those involved directly and indirectly in the restoration of the Rio Doce watershed. Ultimately, this report is an invitation to identify common paths that can conserve the region’s rich biodiversity and restore the ecosystems services improving the quality of the environment, but mainly providing security for the population in the coming years.

Rio Doce Panel

Executive summary

Renova Foundation has been investing considerable technical-scientific knowledge and financial resources to mitigate the impacts of the Fundão Dam rupture through the implementation of actions for the mitigation of the socio-economic and environmental impacts resultant from this disaster. In this Technical Report, the Rio Doce Panel proposes that Renova Foundation, stakeholder organisations and decision makers operating in the Rio Doce watershed adopt and integrate the source-to-sea and landscape approaches to better evaluate the interactions between water quality and biodiversity conservation at the watershed level and under a long-term perspective.

The Report contextualises the current status of water quality and biodiversity in the Rio Doce watershed, providing selected data and information on the physical, chemical and biological quality of the water and an overview of the terrestrial, freshwater and marine biodiversity since the dam rupture. A review of the integrated approaches already adopted in the Rio Doce restoration actions is also provided, focusing mainly on the TTAC programmes that in some respect embody the source-to-sea and landscape approaches in their conception. The Technical Report suggests pathways toward building a combined approach to restore water quality and biodiversity in the Rio Doce watershed, taking advantage of such actions already implemented by Renova Foundation and its partners.

The Rio Doce Panel understands that the implementation of a combined vision of integrated landscape and source-to-sea framework by the Rio Doce watershed stakeholders is key to restoring the Rio Doce watershed to a healthier and more sustainable state than that which prevailed before the disaster. Moreover, the adoption of a landscape approach for the restoration of the Rio Doce watershed areas affected by the Fundão Dam disaster can also help address the need for long-term planning and effective engagement of affected parties. It calls attention to the need to integrate distinct actions within the watershed, emphasising not only the essential flow of water but also a flow of actions starting from the headwaters and continuing along the Rio Doce channel, with a focus on riparian vegetation restoration. These actions should not end at the river's mouth but expand to the adjacent coastal waters and include not only processes that occur within the river channel but also reflect the social, economic, cultural and environmental features of the entire watershed.

Finally, with the aim of contributing to ensure an effective restoration process for the watershed as a whole, the Rio Doce Panel proposes five recommendations for consideration by Renova Foundation, Inter-Federative Committee (Comitê Interfederativo, or CIF), Federal, State and Municipal governments, and its partners:

Recommendation 1 – Adopt a source-to-sea framework and an integrated landscape approach in the Rio Doce watershed restoration efforts.

Recommendation 2 – Ensure a long-term comprehensive evaluation of the systematic Quali-Quantitative Monitoring Programme of Water and Sediment of the Rio Doce watershed (PMQQS) data to prioritise actions for the continual improvement of Rio Doce's environmental conditions.

Recommendation 3 – Use the existing water monitoring programme to build the capacity in the region to monitor potential impacts on water quality and biota associated with the emergence of synergistic pollutant compounds.

Recommendation 4 – Strengthen technical support to municipalities for the implementation of a comprehensive, innovative and modular basic sanitation programme for the watershed.

Recommendation 5 – Expand the existing monitoring plan in order to inform and prioritise biodiversity restoration activities.

1 Introduction

With an area of 86,715 km^2 the Rio Doce watershed represents the most important hydrographic watershed in the Brazilian southeast region (ANA, 2015). Shared between two states, Espírito Santo and Minas Gerais, Rio Doce is considered as a federal domain.[1] Along with federal government agencies, the state governments and 228 municipalities, whose areas are totally or partially situated within the boundaries of the watershed, are involved in the management of the watershed (28 in Espírito Santo; 200 in Minas Gerais[2]).

Over the years, the watershed has been characterised by poor water quality, sparse remnants of natural vegetation, soil erosion with the exhaustion of fertility and gullying, and river channel siltation due to non-compliance with the Native Vegetation Protection Law.[3] Moreover, invasive species (on land and in freshwater systems) were introduced and chemical pollutants were deposited in the delta and adjacent marine areas (ANA, 2013; ANA, 2015; Consórcio Ecoplan/Lume, 2010; Fragoso-Moura et al., 2016; Hatje et al., 2017).

In response to the National Water Resources Policy, which established the watershed as the management unit for water resources and proposed a system of participatory decision-making for integrated water resources management, an Integrated Water Resources Plan (*Plano Integrado de Recursos Hídricos*, or PIRH) was drawn up for the Rio Doce watershed. The PIRH is designed to integrate the plans, programmes, projects and other sectoral studies that relate to the use of water resources. The PIRH, ratified in 2013 and currently under revision, "defines the measures necessary to protect, restore and promote water resource quality for human health, aquatic life and environmental quality" (ANA, 2013, p. 19).[4] The plan details the actions and investments needed to meet its objectives in each of the nine sub-watersheds that form the Rio Doce watershed, including the creation of additional protected areas and programmes of basic sanitation and emergency preparedness.

The Rio Doce watershed has been exposed for more than a century to mining activities, as the principal Brazilian iron and steel producing region. As a result, additional pressures were placed on the river and its tributaries, that provide water for industrial complexas well as urban areas and rural production activities. Mining also engenders serious environmental risks associated with mine tailings' storage facilities, which have been repeatedly cited as posing serious risks to downstream communities (Espindola, 2019; ICMM, 2020).

In 2015, the collapse of the Fundão tailings dam, a storage facility built as part of the 'Germano complex' iron ore mining site owned by Samarco mining company in Minas Gerais state, led to the ratification

1 The National Water Resources Policy (Law No. 9.433/97) established instruments for the management of water resources in the federal domain (those that cross more than one state or border) and created the National Water Resources Management System (SINGREH). The law determines the installation of river watershed committees that unite public authorities at all three hierarchical levels, as well as water users and civil society, in the management of water resources. For further information, please see: https://www.ana.gov.br/gestao-da-agua/sistema-de-gerenciamento-de-recursos-hidricos

2 For further information, please see http://www.cbhdoce.org.br/institucional/a-bacia

3 The Forest Code (Law No. 4.471/65) of Brazil, which was substituted by the Natural Vegetation Protection Law (Law No. 12.651/12), has historically not been enforced, particularly with regard to its provisions establishing the permitted use and non-use rules governing the areas defined as Legal Reserves (LR) and Permanent Preservation Areas (APPs).

4 The existing PIRH for Rio Doce watershed has overarching targets addressing seven areas: water quality; water quantity, water-balance; susceptibility to floods; universalisation of sanitation; increase in legally protected areas; implementation of water resources management instruments; and implementation of PIRH Rio Doce actions (Consórcio Ecoplan/Lume, 2010).

The Piranga and do Carmo Rivers meet to form the Rio Doce
Photo: NITRO (2018)

of an out-of-court settlement. The agreement, known as the Terms of Transaction and of Conduct Adjustment (*Termo de Transação e de Ajustamento de Conduta*, or TTAC),[5] was signed by Samarco and its parent companies, Vale and BHP, the federal government, the governments of Minas Gerais and Espírito Santo states in response to the emergency situation. The TTAC defines Samarco's and later Renova Foundation's obligations to restore the affected areas and livelihoods in the Rio Doce watershed. Forty-two programmes were established and are being implemented in an impacted area of 670 km along the Rio Doce and its tributaries, as well as the adjacent coastal zone.[6] It also led to the creation of Inter-Federative Committee (*Comitê Interfederativo*, or CIF) composed of environmental agencies and other public agencies who were signatories of the TTAC. The CIF is responsible for orienting and validating the activities of the Renova Foundation, created to manage and execute the recovery measures caused by the tragedy.[7]

The 42 programmes cover an array of environmental, social, cultural and economic aspects of the disaster,

5 For further information, please visit: https://www.samarco.com/reparacao/

6 The Renova Foundation is the entity responsible for the mobilisation of the reparation of the damages caused by the collapse of the Fundão tailings dam. For more information about the Foundation and the 42 programmes, please see: https://www.fundacaorenova.org/en/

7 For further information, please see: http://www.ibama.gov.br/cif

and were designed in a compartmentalised manner, leaving gaps and overlaps, and without paying proper consideration to the participation of the affected population during its initial implementation stages (Sánchez et al., 2018).[8] The situation adds to the current scenario of complex governance and continuous delays in implementation. One possible solution that would further integrate the existing restoration programmes and strengthen their implementation throughout the watershed is the adoption of an integrated landscape approach within a source-to-sea framework. The Rio Doce Panel believes that this approach would help to restore the landscape and livelihoods to a healthier, more sustainable and resilient state of the Rio Doce watershed than that which existed before the disaster.

This thematic report thus aims to present the potential benefits and opportunities of adopting the source-to-sea framework and implementing a landscape approach to the restoration process of the Rio Doce. Some of the benefits that could arise from the use and integration of these approaches are: improved implementation; better integration, efficacy and resilience of the TTAC programmes; enhanced engagement with the affected parties and other stakeholders; better mitigation and adaptation to the likely impacts of climate change (May et al., 2020); and long-term planning to ensure the sustainability of the restoration efforts once Renova's activities are eventually phased out. In particular, a joint consideration of the source-to-sea framework and landscape approach could facilitate comprehension and design ways to tackle the issues related to Rio Doce sub-watersheds, including solutions proposed in the Rio Doce PIRH (ANA, 2013). These include actions, such as the protection and restoration of riverine Permanent Protection Areas (*Área de Preservação Permanente*, or APP), the protection and restoration of degraded and eroded sites, solid waste management and sewage treatment.

The paper is organised into six sections, including the Introduction. Section 2 presents the background and an overview of the current status of the water quality and biodiversity of Rio Doce. The integrated approaches that have the potential to strengthen current TTAC programmes are presented in section 3. Section 4 summarises the ways for setting up a combined approach to restore water quality and biodiversity in the Rio Doce watershed, pointing out the need for further actions to enhance these assets. Finally, the conclusions are given in section 5 followed by the Panel's recommendations to Renova Foundation and other stakeholders, describing practical actions that can be adopted to successfully integrate source-to-sea and landscape approaches in drawing attention to biodiversity restoration and water quality improvement.

8 In 2018, a second Term of Conduct Adjustment (TAC-GOV in its Portuguese acronym), concerned with altering the governance arrangements and providing for greater representation of the affected parties was signed by Renova Foundation, its parent companies, the Public Prosecutors' (Federal and States) and the Public Defender's Offices. Later, in 2019 the parties responsible for reparations in the Fundão Dam disaster were obliged to present to the Federal Court the priority emergency thematic axes considered essential to speed up the implementation and make the execution of the established reparation and compensation programmes concrete (Decision of the 12th Federal Civil and Agrarian Court, 19 December 2019).

2 Background and context of the water quality and biodiversity in the Rio Doce watershed

2.1 Physical, chemical and biological quality of the water

With a view to gain a better understanding of the current situation and how the water quality was affected by the Fundão Dam failure, it is essential to describe the previous impacts of human occupation of the watershed. The Rio Doce has endured over two centuries of human impact, starting with increasing siltation in the hilly upper and middle stretches as well as deforestation caused by gold mining, clearing for agriculture and plantations of Eucalyptus (*Eucalyptus spp.*) to supply the iron and steel plants with charcoal (Espindola et al., 2011). Soil erosion is widespread throughout the watershed, where the soils are highly erodible: 58% of the basin area is characterised as having a high erosion potential and 30% with moderate erosion potential (ANA, 2013).

Moreover, since the main tributaries – the Piranga and do Carmo Rivers – receive considerable amounts of untreated sewage (see photo page 2) and high levels of suspended matter, the quality of the water has deteriorated over time. Out of the 228 municipalities in the Rio Doce watershed, only 132 (58%) have some level of sewage collection (most of which is only with primary treatment) and the remaining 96 municipalities discharge their sewage directly into the river without any treatment (Consórcio Ecoplan/Lume, 2010). As a consequence of all these factors, the freshwater ecosystems have become severely degraded, and human health affected.

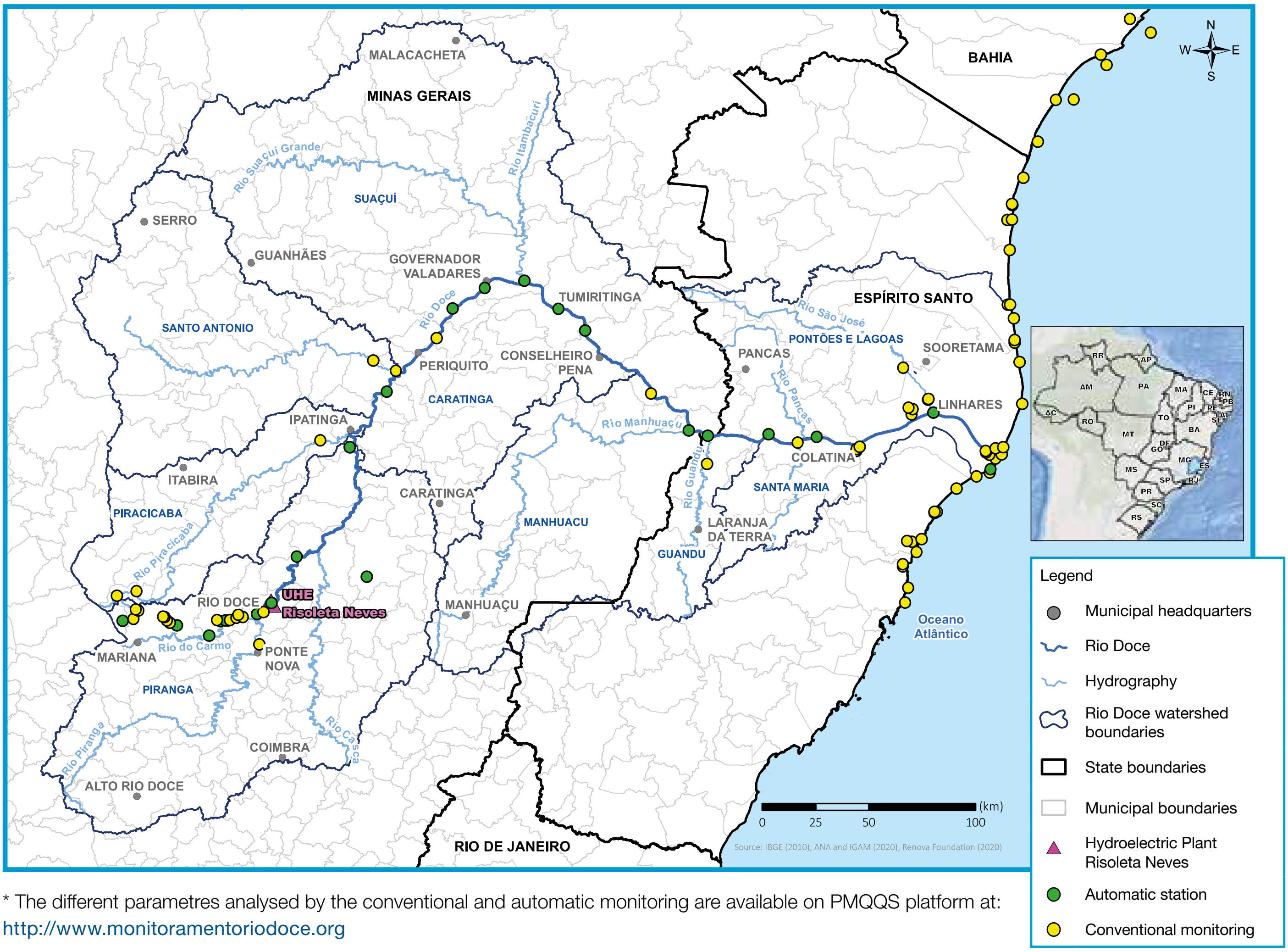
In addition, the hydropower dams that have been built along the Rio Doce and its tributaries have altered its natural flow regime. According to a Consórcio Ecoplan-Lume (2010) report, there were nine large hydroelectric dams and 21 small hydroelectric facilities in operation in the watershed and another two large hydrodams and 33 small hydroelectric plants were projected at the time of the study.

Since the Fundão Dam failure in 2015, an emergency monitoring programme has been implemented in the impacted rivers. Analyses of water and sediment samples along the Rio Doce watershed have been conducted under the TTAC Programme **38** (Systematic Quali-Quantitative Monitoring Program for Water and Sediment for the Rio Doce, or PMQQS). The PMQQS monitors several important physico-chemical[9] and some biotic parametres related to water quality (Figure 1). The results obtained up to 2018 show that some of the conditions detectable during the rainy period within the Rio Doce watershed can be summarised as showing high turbidity, with concentrations of metals and total suspended solids, and occasional peaks above the legal limits recorded in 2018 (Fundação Renova, 2018). Likewise, few values of dissolved oxygen below 5 mgL^{1}, which is the minimum concentration allowable in accordance with Brazilian regulations, were recorded.

In May 2019, the partial report of PMQQS (CIF, 2019) recorded levels for metals above the legal limits for metals in Juparanã, Areão and Monsarás lakes (Espírito Santo); and for manganese (Mn) and dissolved iron (Fe^{2+}) in the Gualaxo do Norte, do Carmo and Doce rivers (MG). Legal limits were also exceeded for the number of *E. coli*, a bacteria whose presence could indicate risk to health (water and food quality aspects), in the three rivers as well as in Lake Juparanã. Low concentrations of dissolved oxygen were also detected in the Juparanã, Limão, Nova and Monsarás lakes, while total nitrogen (N) was also above legal limits in Lake Nova.

9 Physical-chemical characteristics are used to indicate the quality of water, with the determination of several parameters that represent, for example, the existence of impurities when they reach values above those established for a given use.

Figure 1 PMQQS water monitoring stations*



* The different parametres analysed by the conventional and automatic monitoring are available on PMQQS platform at: http://www.monitoramentoriodoce.org

Source: © Renova Foundation (2020).

The assessment of water and sediment conditions throughout the watershed suggest that the parametres analysed were similar to those recorded before the collapse of the Fundão Dam (Fundação Renova, 2018; de Carvalho et al., 2018). However, this does not necessarily mean that the water exhibits good quality, since they have been affected by non-point sources, including areas for agriculture, livestock and commercial forestry, as well as sewage that goes mainly untreated.[10] Furthermore, although some biological indicators are monitored,[11] other distinct components of the biota, whose assessment is not included in the PMQQS, would also need to be investigated for its possible synergistic effects and in conjunction with individual physiochemical parametres analysed by Renova Foundation. This would represent a significant

10 The Integrated Water Resources Plan for the Rio Doce watershed (ANA, 2013) describes the trend and situation of the watershed in 2010: "Water quality falls outside the expected classification. This situation will likely remain unchanged in the absence of integrated water management". The same document expressed that a Class 2 rating for Rio Doce was targeted to be achieved by 2030. The report is available at: http://arquivos.ana.gov.br/institucional/sge/CEDOC/Catalogo/2013/planoIntegradoDeRecursosHidricosDaBaciaHidrograficaDoRioDoce.pdf

11 Renova's PMQQS monitors the following bioindicators: phytoplankton, periphyton and benthic macroinvertebrates. In addition, the PMQQS also includes toxicity texts such as: chronic ecotoxicity tests in water (using *Ceriodaphnia dubia* and *Pseudokirchneriella subcapitata*); acute ecotoxicity in water (using *Danio rerio* and *Daphnia similis*); and chronic ecotoxicity tests on sediment samples (using *Ceriodaphnia dubia*). Available at: https://gis.fundacaorenova.org/portal/sharing/rest/content/items/efbce5674fbb44f894db9849067d0b32/data

progress in water quality monitoring programmes and a legacy for the Rio Doce and Brazil.

Other scientific studies have focused on the biota and physicochemical parametres, which represent further assessed the conditions of the affected areas of the disaster, leading to conclusions that the environmental health of the watershed is still threatened. The findings, as well as the different periods and methodologies presented in these studies are important to consider. A summary of the findings of a selection of these studies are listed below:

1) **Microbial diversity and increase of bacteria populations.** Studies on the effects of the iron ore tailings released by the Fundão Dam collapse indicate that the sediments could be a source of chronic contamination on microbial diversity and activity in distinct ecosystems, showing that as long as the tailings remain within the river and deposited on its adjacent lands, it is an issued that need to be addressed by the restoration process (Cordeiro et al., 2019).

2) **Enhanced frequency of chromosomal aberrations and alterations in mitotic and phase indices.** Studies on concentrations of trace elements and cytogenotoxic effects (that could damage genetic material, including DNA) concluded that the environmental impacts of the dam's failure may not only be far-reaching but are also likely to be long-lasting, persisting in the Rio Doce's sediment (Quadra et al., 2019).

3) **Potability of the Rio Doce waters.** The chemical concentrations of the water taken from 48 points, including wells, the river itself and the public water supply for three cities (Belo Oriente, Governador Valadares and Colatina) were examined (de Carvalho et al., 2018). The findings indicate that the water at the time of the study was unfit for agriculture or human consumption (de Carvalho et al., 2018), if not subjected at a minimal to conventional treatment.

4) **Potential toxicity of manganese (Mn) for cyanobacteria.** Under laboratory conditions, the toxic effects of this element in high concentration leads to a reduction in chlorophyll *a* content and growth rates coupled with ultrastructural changes (Moura et al., 2019).

5) **Histological and molecular changes in gill and liver of *Astianax lacustris* (tetra).** The water from the Rio Doce watershed can promote histological alterations in the liver and gills of fish, as well as modulation of disruption of ionic balance, cellular responses to stress and cell detoxification pathways (Macedo et al., 2020).

6) **Changes in the structure of aquatic and sediment microbiomes structure.** By deep sequencing the 16S rRNA gene[12] from samples from two impacted rivers and one reference river as a control measure, 7.30 and 150 days after the disaster, the findings revealed that the structure of the impacted community changed greatly over spatio-temporal scales, being less diverse and more uneven, particularly on day seven for the do Carmo River situated closest to the collapsed tailings dam (Reis et al., 2020).

7) **Trace metals contamination and sediments quality.** Measures of the sediments from 17 points within the estuarine areas report that they had been contaminated by cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As), copper (Cu) and zinc (Zn) in all 17 points within estuarine areas, with potential harmful effects to estuarine organisms of commercial importance, such as crabs, shrimps and fishes (Gabriel et al., 2020). Furthermore, the findings called attention to the possibility that chronic sediment contamination and pollution could be an additional ecological risk due to sub-lethal effects from the slow release of nutrients

12 The use of 16S rRNA gene sequences to study bacterial phylogeny and taxonomy has been the most common housekeeping genetic marker used for a number of reasons, which include: (i) its presence in almost all bacteria, often existing as a multigene family, or operons; (ii) the function of the 16S rRNA gene over time has not changed, suggesting that random sequence changes are a more accurate measure of time (evolution); and (iii) the 16S rRNA gene (1,500 bp) is large enough for informatics purposes (Janda et al., 2007).

and potentially toxic elements into the water column as reported previously for other areas (Gati et al., 2016) and for the Rio Doce watershed (Queiroz et al., 2018).

In particular, in relation to the estuary and reinforcing the findings described above, one of the studies (Gabriel et al., 2020) concludes that the Rio Doce estuary exhibited an overall high to moderate contamination up to 2.9 years after the Fundão Dam disaster with current chronic metal pollution, and moderate to high risk of adverse biological effects to its biota. Moreover, the study's results showed that the impacts on communities were caused mostly by Fe (II) oxidizers and Fe (III) reducers, aromatic compound degraders and predator bacteria. Analyses showed a highly interconnected microbiome, whose interactions switched from positive to negative, or vice versa, between the impacted and reference communities.

The study also revealed potential molecular signatures associated with the rivers heavily impacted by metals that might be useful sentinels for predicting riverine health (Gabriel et al., 2020).

In summary, the studies cited find that despite the recorded improvements, the water quality in distinct portions of the Rio Doce watershed, as well as the sediments in estuarine areas, still raise concerns particularly in relation to the potential harm to different groups of organisms, such as microorganisms, crabs, shrimps and fishes.[13] Moreover, the studies demonstrate that the current conditions are still capable of affecting the richness and diversity of aquatic organisms when compared to the areas that were not impacted by the tailings.

In particular, two studies (de Carvalho et al., 2018; Cordeiro et al., 2019) have also suggested that the quality of the river waters could represent a chronic risk to human health over the long term. It is important to highlight that the results can be variable depending on the stretch of the watershed under analysis, even in the affected areas. In addition, different studies are being conducted by Renova Foundation, consultants and the mining companies and should be used for comparison once the results are publicly available.

2.2 Overview of the terrestrial, freshwater and marine biodiversity

River biodiversity reflects the diversity of the environments through which a river flows, including both aquatic and terrestrial areas, varying in different sectors due to their dynamic nature. In the Rio Doce, the deforestation of the watershed has increased siltation of the river channel, reducing its depth and speed of the flows. Hydrological and morphological changes in the river have led to changes in biodiversity, and consequently to changes in the location and abundance of some endemic fish species.

One of the major impacts brought about by the failure of the Fundão Dam in November 2015 is the loss of terrestrial and aquatic biodiversity. Given the diverse types of habitats found throughout the watershed, the impacts on flora and aquatic habitats differed in specific areas of the affected river segment. The analysis of surface reflectance data in Landsat-8 images from the days following the disaster have made it possible to measure the extent and intensity of the damage caused by the released tailings (Hatje et al., 2017).

Prior to the 2015 disaster, a number of comprehensive studies have been undertaken over 20 years to support the management of the Rio Doce watershed (ANA, 2013). However, information other than those that are focused on specific sites and/or groups of fauna and flora is lacking. Most were environmental impact studies and hydrological assessments (Sunaga & Verani, 1987; Vieira, 1994; Barbosa et al.,

13 These findings were reinforced by the Aquatic Biodiversity Monitoring Programme for Environmental Area 1 implemented by Fundação Espirito-Santense de Tecnologia/Rede Rio Doce Mar, coordinated by Renova's Programme 28 (*Biodiversity conservation*) (MMA, 2020).

1997; Barbosa et al., 2013a and 2013b; Barros et al., 2013; Maia-Barbosa et al., 2014; Reis et al., 2014; Fragoso-Moura et al., 2016). For example, when one study identified 71 native fish species in the Rio Doce (Sales et al., 2018), it called attention to the fact that the majority of the available studies have focused on the middle portion of the river, notably within the lake system of the Rio Doce State Park and its surroundings.

Yet, knowledge about the Rio Doce watershed's biodiversity is incomplete and more research efforts are needed (Hatje et al., 2017). While some studies consider that the freshwater fish species inhabiting the Rio Doce are widespread in the adjacent watersheds, recent molecular evidence has revealed taxonomic uncertainties regarding the degree of similarity among freshwater species (Hatje et al., 2017). Because of the high frequency of cryptic species[14] in the Rio Doce, the impact of the disaster on freshwater biodiversity is still unknown and undescribed endemic species may have become extinct (Fernandes et al., 2016).

From the perspective of marine biodiversity conservation, concern has been raised about the impact of the plume on the Rio Doce estuary and the adjacent marine area, particularly on the protected areas. A short-term impact assessment[15] was carried out to understand the effects of the tailing plume and associated sediments in the Rio Doce estuary (Gomes et al., 2017). The authors described significant changes in the estuarine benthic and macro-faunal assemblages just after the arrival of the tailings and pointed out the need to develop further analysis of the effects of sediment toxicity and geochemical interactions.

Similar analyses have been undertaken since 2018 by the Rio Doce Mar Network (*Rede Rio Doce Mar*, or RRDM)[16] that reinforce such findings. The RRDM implements the Aquatic Biodiversity Monitoring Programme for Environmental Area 1 (PMBA),[17] which is coordinated by TTAC Programme 28 (*Biodiversity conservation*) and analysed by CIF-CTBIO (CIF Technical Chamber for Biodiversity Conservation). PMBA's Annual Report 2018–2019 provides information regarding physical, chemical and biotic characteristics of the studied environments. According to CIF-CTBIO Internal Technical Note (15/2020) (MMA, 2020), PMBA's Annual Report noted significant negative changes in all freshwater, coastal and marine environments, including sediments, water and biota compartmentes studied in relation to the pre-existing conditions before the Fundão Dam rupture.

After the Fundão Dam failure, these studies showed environmental stress in the three analysed compartments, changes in their composition and prevalence of opportunistic species. For example, the report described important changes in the structure of the benthic communities in most of the sampled points, a phenomenon that occurred with greater intensity in the river's mouth and in the sampling

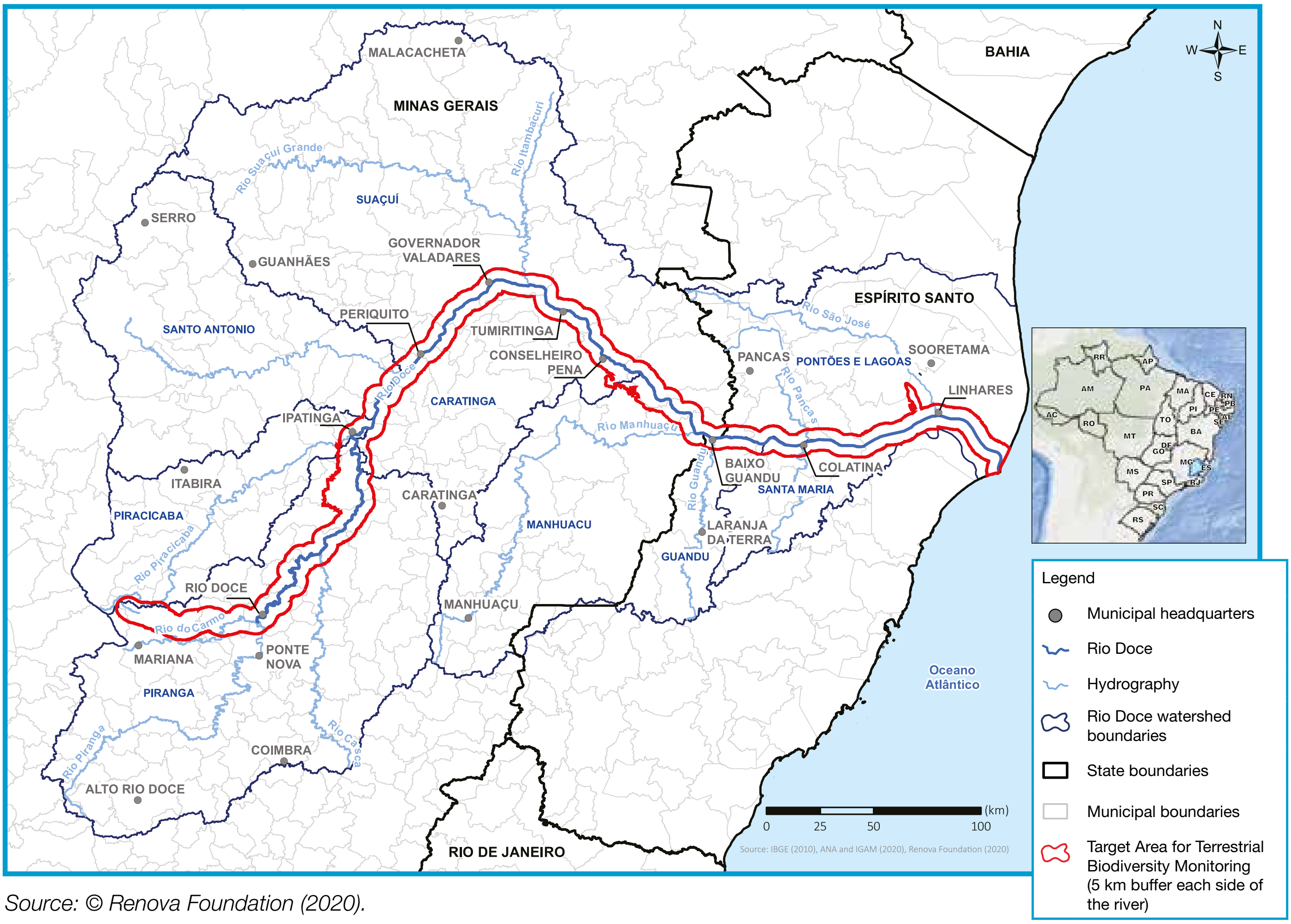
14 Individuals that appear identical but are genetically quite distinct. These findings could have major implications in areas ranging from biodiversity estimates and wildlife management, to our understanding of infectious diseases and evolution. According to Markus Pfenninger and Klaus Schwenk, of the Goethe-Universität in Frankfurt am Main, Germany, who analysed all known data on cryptic animal species, cryptic species are found in equal proportions throughout all major branches of the animal kingdom and occur in equal numbers in all biogeographical regions (Mckenna, 2007).

15 The authors adopted a limited BACI (before and after control impact) study design. "Ten sites were randomly distributed along the estuarine region and sampled 11 days prior to the arrival of the tailing plume in the estuary, and then subsequently sampled until two days after the short-term impact" (Gomes et al., 2017, p. 29).

16 This network of universities and researchers was implemented by the Technical-Scientific Cooperation Agreement signed by Espirito Santo Technology Foundation (*Fundação Espírito Santense de Tecnologia*, or FEST) and Renova Foundation. The Rede Rio Doce Mar (RRDM) was created in July 2018, with the purpose of supporting remedial actions of public interest related to the impact caused on aquatic biodiversity in continental (rivers, estuaries, lakes) and marine environments (beaches, coast and sea), due to the rupture of the Fundão Dam in Mariana (MG). For more information, please visit: http://rrdm.net.br/.RRDM biannual and annual reports are available at CIF's website: https://www.ibama.gov.br/cif/notas-tecnicas/ct-bio/relatorios-da-rede-rio-doce-mar

17 The Environmental Area 1 comprises the Rio Doce area at the Espírito Santo state, and the adjacent marine and coastal region impacted by the Fundão Dam rupture.

Figure 2 Terrestrial biodiversity monitoring area undertaken by Renova and partners



Source: © Renova Foundation (2020).

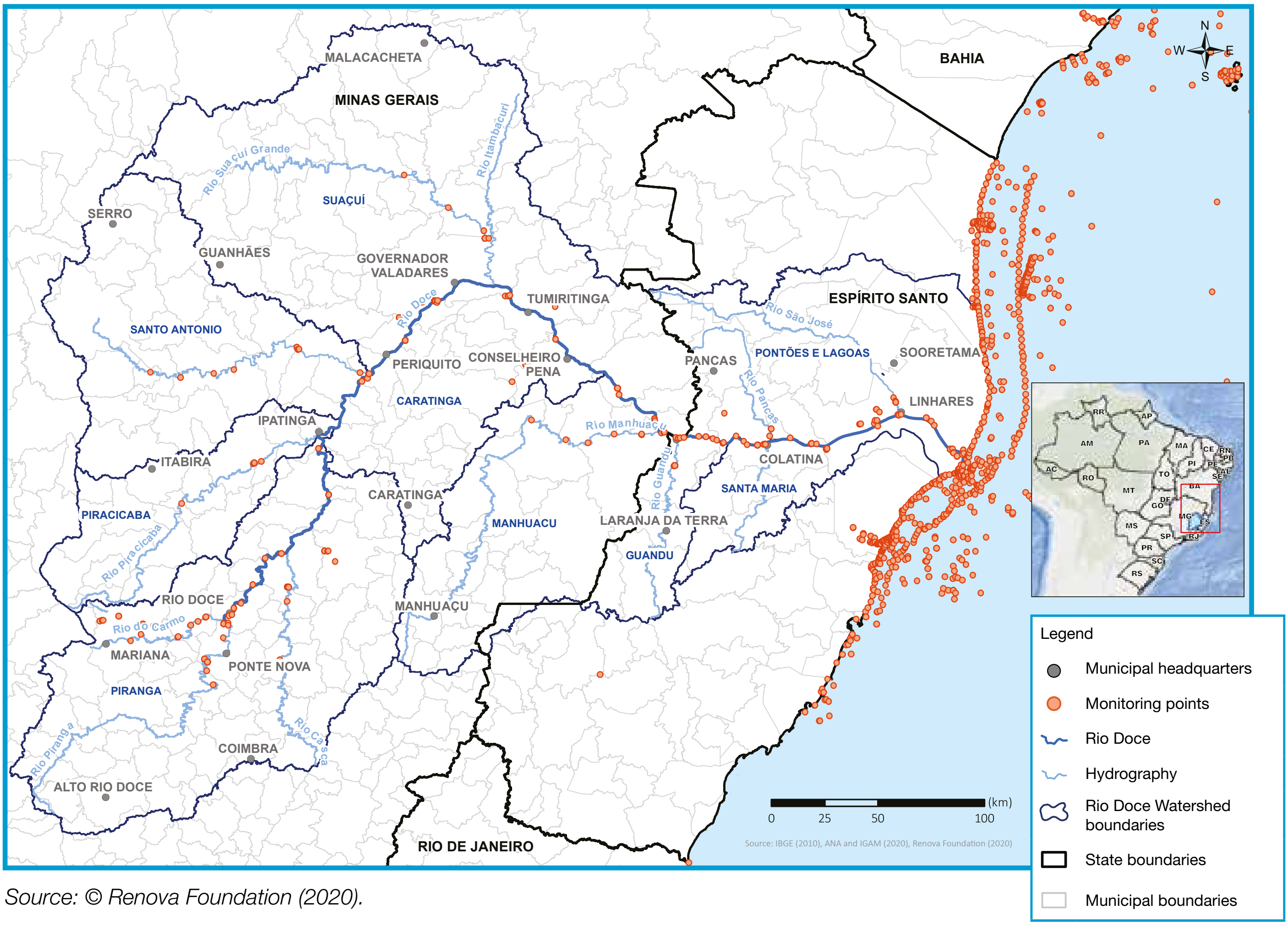
stations closer to the coast that are in the areas with greater influence of the river plume (MMA, 2020).

The CIF-CTBIO Internal Technical Note (15/2020) acknowledges that the lack of previous data for many studied parametres does not allow a series of comparative analyses between the pre- and post-disaster (present) situation. However, the report raises relevant conclusions for each of the environments studied and their compartments, showing important and lasting impacts which need to be further mitigated and continually monitored.

Another study focused on the oceanic time and spatial patterns of river discharge dispersion (Marta-Almeida et al., 2016). The river plume was monitored for two months after the arrival of the tailings to the ocean. The study finds that the “observed and modelled dispersion pattern of the plume showed that the inner shelf between the river mouth and the city of Vitória was the region most often in contact with the riverine waters (…), were the Comboios Biological Reserve (*Reserva Biológica*, or REBIO), at the river mouth, the Costa das Algas Environmental Protection Area (*Área de Proteção Ambiental*, or APA) and Santa Cruz Wildlife Refuge (RVS), occupying the shelf 26 km to the south were right in the core of the most affected region” (Marta-Almeida et al., 2016, pp. 362–363). These findings were confirmed by the PMBA Annual Report (2018-2019) earlier. Other protected coastal zones further south were not touched as the plume in the southward path deviated from the coastal area near Vitória city (Marta-Almeida et al., 2016).

Although the full impact of the Fundão Dam disaster on biodiversity has yet to be fully established, the

Figure 3 Water biodiversity monitoring areas undertaken by Renova and partners



Source: © Renova Foundation (2020).

monitoring actions undertaken by Renova Foundation to identify impacts and measures to restore the affected ecosystems should therefore develop actions to continue the mitigation of the chronic impacts and include concrete actions to widely disseminate information about biodiversity restoration (Figures 2 and 3). In addition to TTAC Programmes 28 (*Biodiversity Conservation*), 30 (*Terrestrial Fauna and Flora*), 38 (*Rio Doce watershed monitoring*) and 39 (*Conservation Units*), are of particular importance to the monitoring activities.

Biodiversity underpins the stability of an ecosystem and offers a potential starting point for the application of integrated landscape management (IUCN-Netherlands, n.d.). As an important indicator of water quality, an overarching systematic and long-term biodiversity monitoring programme would provide more strategic information for the measurement of restoration results.

While acknowledging the efforts made by Renova Foundation in the five years since the disaster, as well as the difficulties of assessing the impacts of the Fundão Dam rupture on terrestrial and aquatic biodiversity, the time is ripe to strategically move from assessing the impacts of the dam's rupture to monitoring the efficient implementation of the biodiversity-focused programmes.[18]

18 In addition to Programmes 28, 30 and 38, other TTAC programmes related to biodiversity restoration, conservation and monitoring are: 25 (Environmental Area 1 in Minais Gerais' municipalities of Mariana, Barra Longa, Rio Doce and Santa Cruz do Escalvado (MG)); 26 (*Degraded Permanent Protection Areas and Recharge Areas Recuperation*); 27 (*Springs Recuperation*); 39 (*Protected Areas Consolidation*); 40 (*Promotion of the Environmental Rural Register (CAR)* and *Degraded Areas Restoration Programme* (*DARP*)).

3 Integrated approaches that have the potential to strengthen current TTAC programmes

3.1 The source-to-sea framework

Source-to-sea is a comprehensive approach used to analyse a watershed at its highest level of interdependence and ecological influence (Granit et al., 2017). A source-to-sea system includes all the land area that is drained by a river system, its lakes and tributaries (the river's watershed), connected aquifers and downstream recipients, including deltas and estuaries, coastal areas and inshore waters, the adjoining sea and continental shelf, as well as the open ocean. Key flows in the form of water, sediment, pollutants, biota, materials and ecosystem services connect the sub-systems in the source-to-sea continuum at different scales (Figure 4). Furthermore, the source-to-sea framework expresses the scale and the elements needed to deal with complex systems of governance and vast territories (Granit et al., 2017).[19]

River ecosystems in the source-to-sea continuum are being progressively and intensely degraded throughout the world, mainly by the intensification of human activities and climate change. This comes about due in part to a lack of understanding of how these ecosystems are linked by the nexus water flows, biota and ecosystem processes (Palmer & Ruhi, 2019). Furthermore, current governance and management arrangements are not well suited to address these flows and ensure sustainability and resilience of the combined source-to-sea systems (Granit et al., 2017).

Figure 4 Illustration of a source-to-sea system

Source: © Rio Doce Panel (2021).

19 The source-to-sea framework used in this document has been originally proposed by the Global Environmental Facility (GEF) for use in its Integrated Water Management projects as a way to consolidate the analysis, planning, policy making and decision making across sectors and scales (Granit et al., 2017).

In the context of the Rio Doce watershed, the failure of the Fundão Dam has made it clear that it will be necessary to deal with land and sea together in order to address the magnitude and long-term consequences of the disaster.

The application of the source-to-sea framework offers an alternative for integrating the different issues affecting the quality of the watershed as well as its adjacent coastal and marine areas. As a means to counteract the fragmented approach of the 42 programmes, the source-to-sea framework would bring a more integrated perspective, including:

- a characterisation of the source-to-sea system, showing the interconnection between key flows along the continuum and highlighting segment-specific and source-to-sea systemic issues;
- a more comprehensive analysis of governance issues (particularly the capacity of the past and existing systems of governance to address the issues identified);
- a definition of the appropriate scales for different levels of analysis (the scale can vary from one or more closely connected segments to an entire river watershed and downstream recipients);
- facilitating the engagement of key stakeholders from different sectors and domains; and
- applying a theory of change to guide governance and management responses over the long-term and tracking progress towards achieving agreed goals and positive changes in societal, economic and environmental conditions in the continuum (Granit et al., 2017).[20]

Box 1 shows an example of how the approach was applied to strengthen cooperation and coordination between upstream and downstream stakeholders in central Viet Nam in order to deal with the challenge of plastic waste.

3.2 Landscape approach

Integrated approaches to managing landscapes are not new. The need for integration stems from the acknowledgement that conventional sectoral approaches do not yield satisfactory results when seeking to address complex and interconnected social, environmental, economic and cultural issues within a spatial context (Reed, et al., 2016; Arts et al., 2017). Yet, the definition of the proper scale and the source-to-sea elements[21] are of particular importance to achieve the intended results of such approaches.

Global commitments, like the Brisbane Declaration,[22] that recognises the connection between terrestrial water resource flows and their downstream environments are being increasingly applied (Granit et al., 2017). Similar commitments underscore the important links between upstream and downstream systems from different perspectives, such as the UN Environment Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA, 2012),[23] and the ecosystem approach[24] definition

20 The forthcoming Thematic Report No. 4 of the Rio Doce Panel will focus on the long-term governance of the Rio Doce watershed, and consider how the restoration efforts can help solve some of the systemic problems that have existed in the watershed prior to Fundão Dam failure.

21 Elements: flows of water, sediments, pollutants, biota, material and ecosystem services.

22 According to the Brisbane Declaration (2007), environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. The Brisbane Declaration was released during the 10th International River*symposium* and International Environmental Flows Conference held in Brisbane, Australia. An updated version is available here.

23 The objectives of the GPA are to: identify the sources of and impacts of marine pollution from the land surface; identify priority problems to carry out actions; establish managerial objectives for priority problems; identify, evaluate and select strategies and measures to achieve the objectives; and assess the impacts of these strategies. For further information, please see: https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/governing-global-programme

24 “Many practitioners use the terms ‘landscape approach’ and ‘ecosystem approach’ interchangeably to broadly describe any spatially explicit attempt to simultaneously address conservation and development objectives” (Sayer et al., 2013, p. 8).

BOX 1

The Vu Gia-Thu Bon River watershed (Viet Nam) – Foundations for source-to-sea management

Vu Gia-Thu Bon River watershed is one of the nine largest watersheds in Viet Nam, with a coastline of over 200 km and covering an area of 10,350 km^2.

Due to its geomorphological and hydrological characteristics – short, steep watersheds with highly variable seasonal flow – the watershed presents rapid runoff events that can quickly carry the solid waste from land areas to water bodies, from the upper to lower watershed. Among these pollutants, the plastic leakage has been identified as a critical challenge in this watershed. In 2019 the estimated amount of uncollected plastic waste was 13,524 tonnes (SIWI, 2020).

The "Foundations for Source-to-Sea Management" project, developed by the Stockholm International Water Institute (SIWI), with support from IUCN Viet Nam, applied the initial steps of the source-to-sea approach at the watershed, as follows:

i) Identify land-based sources of plastic pollution and understand their impacts from source-to-sea;

ii) Engage local to global stakeholders to gain control of plastic waste; and

iii) Develop coherent governance, finance and management across sectors and scales.

Step 1 was helpful in defining and prioritising the investments which will solve the greatest impacts of the pollutant. Step 2 allowed to draw a better picture of the strengths and weaknesses of the different stakeholders related to solid waste management, a common understanding of the sources of the pollution and a shared desire for finding solutions, including by highlighting the importance of the informal sector which is critical for waste collection and recycling. Step 3 enabled to identify different government bodies that have responsibilities over the issue, showing the existence of management overlaps and gaps. By improving a governance baseline a source-to-sea framework makes it possible to develop strategies and solve the gaps, as well as create a set of instruments at all levels to deliver the needed changes in behaviour.

The initial phase of the application of the source-to-sea approach in the Vu Gia-Thu Bon River watershed reinforces the need for cooperation between upstream and downstream stakeholders, and the importance of strengthening coordination across all sectors.

To date, the project was able to: increase knowledge of priority local challenges that constrain sustainable development; strengthen awareness of the linkages between upstream and downstream activities and their impacts; highlight the opportunities and challenges associated with implementing source-to-sea approach to management; and build local capacity for taking a holistic approach to natural resource and economic development.

Source: Rio Doce Panel (2020).

adopted in the Convention on Biological Diversity (SCBD, 2004), among others.

The landscape approach is one way to integrate the different elements. It has emerged and has been applied to explore the inter-relationship between the ecological, economic and developmental, socio-cultural, and political dimensions in a range of scientific fields. Landscape approaches have evolved from a primary focus on land use planning in Central and Eastern Europe based on geoecological and landscape ecology perspectives. In North America, it emerged with a stronger orientation toward landscape ecology and wildlife conservation and management, emphasising the connectivity among protected areas and other areas of natural forest (Klink et al, 2002; Naveh & Lieberman, 1994). From this direction, the approach took on a more integrated perspective for the restoration of degraded lands and water resources (Arts et al., 2017).

Global concern about such issues has led to international pledges, such as the Bonn Challenge and the New York Declaration on Forests[25] (Erbaugh & Agrawal, 2017; Arts et al., 2017). These pledges reflect integrated perspectives by promoting a “landscape approach to restoration” that aim to restore degraded landscapes through equitable and sustainable land use that enhances climate change mitigation and adaptation. The application of landscape approaches implies shifting from project-oriented actions to more process-oriented activities (Sayer et al., 2013).

Contemporary landscape approaches have been primarily associated with nature conservation, conservation and development, sustainable development, integrated natural resource management, land-use planning, socio-ecological systems and climate change. In this context, “a landscape approach can be defined as a framework to integrate policy and practice for multiple competing land uses through the implementation of adaptive and integrated management systems involving stakeholder engagement” (Reed et al., 2016, p. 2544). Hence, a landscape approach can also help understand the relationships between people and space, and how these have been developed from a historical perspective, offering a better basis for environmental management and governance. Such an approach seeks to minimise trade-offs and maximise synergies through participatory negotiations and planning to achieve better use and management of a specific territory.

Landscape can refer to various aspects, such as: geomorphology (landforms), biophysical components (e.g. species, habitats and ecosystems), production and consumption (e.g. agriculture, mines, industries and shops), and meaningful places (e.g. villages and neighbourhoods). Landscape can also be defined as a socio-ecological system consisting of a mosaic of natural and/or human-modified ecosystems, with a particular configuration of topography, vegetation, land use and settlements, all of which have been influenced by the ecological, historical, economic and cultural processes and activities of the area (Scherr et al., 2013).

Although all aspects that define landscape can be relevant, not all landscape approaches involve all aspects. Moreover, the different approaches pursue coordination across sectors, meaning that in each case one sector acts as the focal point, typically within a defined spatial unit, while not necessarily addressing all the larger system linkages (Arts et al., 2017). Likewise, due to the dynamic nature of landscapes, the approach does not follow the traditional unidirectional project cycle approach, but rather requires an iterative process of negotiation, trial and adaptation (Sayer et al., 2013 and 2014).

A landscape approach can be described as “a multifaceted integrated strategy that aims to bring together multiple stakeholders from multiple sectors to provide solutions at multiple scales and to address

25 For further information, please see: https://forestdeclaration.org/

increasingly widespread and complex environmental, economic, social and political challenges" (Reed et al., 2016, p. 2551). Likewise, due to the dynamic nature of landscapes, the approach does not follow the traditional unidirectional project cycle approach but rather requires an iterative process of negotiation, trial and adaptation (Sayer et al., 2013 and 2014).

In Brazil, the importance of a landscape approach to restoration is clearly present in the country's National Water Resources Policy (*Plano Nacional de Recursos Hídricos*, or PNRH). One of the most important aspects of this policy is the adoption of the watershed as a territorial planning and management unit, where PNRH mentions the need for systemic studies linking water management with environmental management, and the need to develop and implement an integrated water resources plan for each watershed. Similarly, PNRH should induce and/or restrict land use, leading to the implementation of sustainable economic development plans in their territories. Thus, the management of water and watersheds requires consideration of several interconnected natural and social processes, taking a holistic and systemic approach, and aiming to ensure land use in the watershed is compatible with the availability of sufficient water for all needs in order to ensure sustainable economic and social development.

3.3 Applying landscape approaches in the Rio Doce restoration efforts

Renova Foundation, as it leads the Rio Doce restoration efforts, has applied a landscape analysis focused primarily on terrestrial resources, which have been designed and applied through agreements, partnerships and the commissioning of studies and instruments. Box 2 briefly describes Renova's landscape analysis initiative, and Box 3 summarises the activities of the landscape approach aimed at the restoration of rural areas.

The other examples of Renova's initiatives that have been inspired by a landscape approach are those undertaken by the Sustainable Land Use Team in applying the Restoration Opportunities Assessment Methodology (ROAM) and the initial experiences with Payment for Environmental Services (PES) (see Box 3). Piloted by Renova in different parts of the Rio Doce watershed, both initiatives are aimed at integrating environmental conservation and improvement of livelihoods by adopting a territorial strategy and working closely with stakeholders. The results and learnings could be replicated for the restoration processes throughout the Rio Doce watershed.

3.4 Other integrated approaches

Other integrated approaches applicable to the restoration processes in the Rio Doce watershed include Forest Landscape Restoration (FLR) and Integrated Coastal Zone Management (ICZM). These approaches recognise the connection between terrestrial-water resources flows and downstream environments and address the need to recover biodiversity.

As an ongoing process to regain ecological functionality, FLR enhances the well-being of people living in deforested or degraded forestlands (IUCN-The Netherlands, n.d.). FLR encompasses processes that include: planting new trees, natural regeneration, agroforestry, or improved land management to accommodate a mosaic of land uses, including agriculture, protected areas, managed plantations and forest planting on streambanks, among others. The guiding principles of FLR focus on entire landscapes, the maintenance and enhancement of natural ecosystems within landscapes, engagement with stakeholders and support for participatory governance, adaptation to the local context using a variety of approaches, and the restoration of multi-functionality to achieve multiple benefits.

BOX 2

Applying the landscape analysis in the Rio Doce*

The analysis undertaken by Renova Foundation considered landscape as an interface between "time, space and people", with an emphasis on peoples' perceptions and representations of their physical environment and its significance to their lives, i. e. their "sense of place" (Tuan, 1977). This landscape analysis is presented as an integrated means for understanding the relationship between people and space, and how these have been formed from a historical perspective (see Figure 5).

The methodology has three phases:

i) Landscape Pre-Inventory (collection and analysis of secondary data of the municipalities where Renova works);

ii) Landscape Inventory (landscape characterisation through field work and interviews; and

iii) Landscape Analysis (analysis of and integration of information, description of landscape types)".

The landscape approach was initially applied as a methodological test in the areas surrounding Lake Juparanã in the state of Espírito Santo and featured a typology of 19 distinct landscape features identified by residents themselves. The types ranged from a continuum of natural features (e.g. waters, inundated areas, fishing points, etc.) to man-made features, such as farms, urban areas and fish tanks. The current and past uses were mapped for each landscape type, along with information derived from interviews with users. The result was a dossier of historical and current maps and images that describe the landscape and the users' perceptions of the conflicts and interfaces between land use types.

Another methodological test was applied in the municipality of Mutum, in the Manhuaçu watershed, a sub-watershed of the Rio Doce in the state of Minas Gerais. The information was organised into maps, descriptions and images (photos and works of art) that show how people's interaction with space (biological, physical and cultural) has evolved over time.

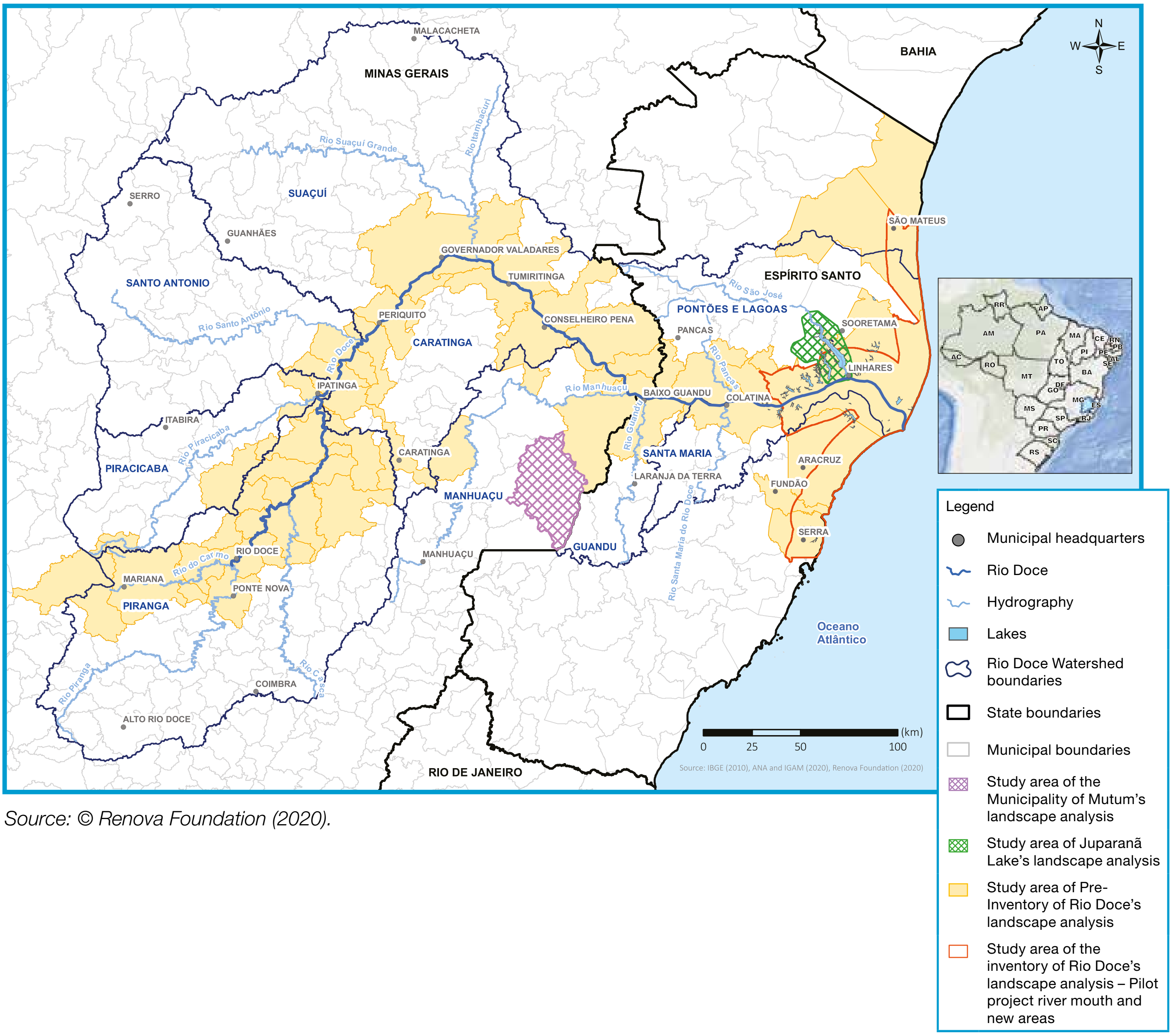
In January 2020, the landscape inventory phase was applied in the area 15 km from Rio Doce riverbed and coastline through to the Rio Doce's mouth region.

The areas where the pre-inventory, methodological tests and landscape inventory were implemented so far are presented in Figure 5.

* The information reported in this box was provided by Renova technical teams during technical meetings held in 2020. The results of the landscape analysis are planned to be launched and available at Renova's website in 2021.

Source: Rio Doce Panel (2020).

Figure 5 Areas where Renova Foundation's landscape analysis was applied



Source: © Renova Foundation (2020).

BOX 3

Restoration Opportunities Assessment Methodology (ROAM) and Payment for Environmental Services (PES)

Renova Foundation has tested two parallel strategies to restore degraded slopes and streambanks and to promote agricultural recovery. Based on the results, it is envisaged that the learnings can be replicated in the 40,000 hectares in properties located in the watershed water recharging areas and the areas around 5,000 springs that are to be recovered under TTAC.

One strategy has been promoted by the World Resources Institute (WRI), based on ROAM, which is an approach that seeks to empower local communities to address practical needs for landscape restoration (**Figure 6**). The methodology assesses how the most substantial economic benefits can be attained, including the return to productive activities, local water recharge and the potential for global carbon sequestration. Starting in 2018, the methodology was undertaken in the Gualaxo do Norte sub-watershed through 25 demonstration farm units and included reforestation, agroforestry and regenerative pasture management practices, depending on the decision of each property owner. The economic analysis of the proposed options showed that farmers could obtain rates of return as high as 20% on these investments, ranging from Net Present Values from BRL 313 to BRL 912 per hectare per year, among the different opportunities. The carbon sequestration potential of these land use options would total 281,000 tCO2eq, if the entire sub-watershed was restored using ROAM methodology (IUCN & WRI, 2014; WRI & Fundação Renova, 2020) (**Figure 6**).

Similarly, Renova Foundation and WWF-Brazil are developing a large-scale forest recovery pilot project integrating sustainable rural development and an inclusive approach to communities in the Rio Doce watershed.[a] The pilot project applies forest recovery models aimed at increasing water flows and improving water quality. According to Renova's teams, it is being implemented in an area of 810 hectares (APPs and other areas of water recharge) in the regions of Coimbra (Piranga sub-watershed), Galiléia, Governador Valadares and Periquito (Suaçuí sub-watershed), Pancas, Colatina and Marilândia (Pontões and Lagoas do Doce sub-watersheds).

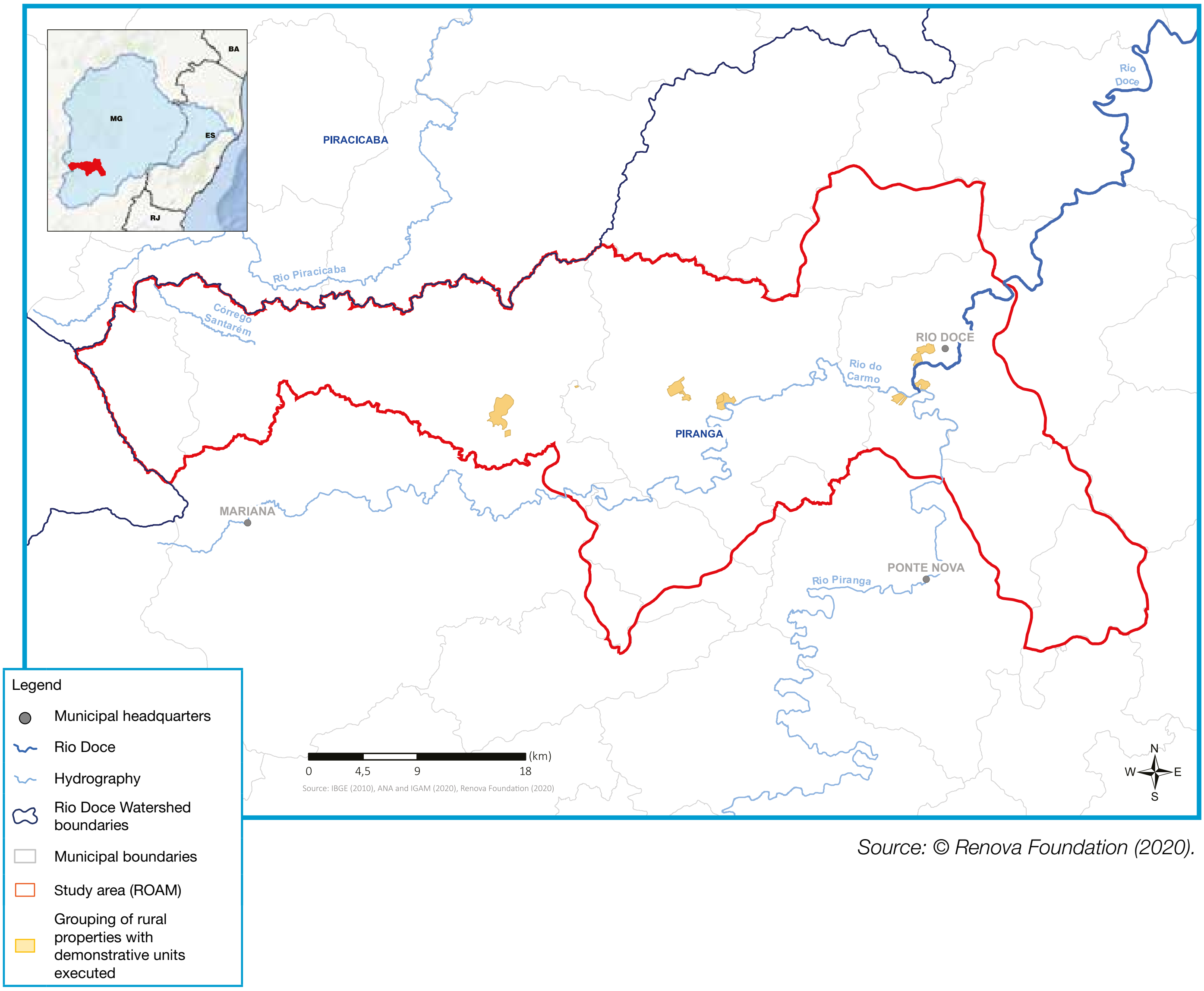
The results of this pilot project and its lessons learnt are expected to be replicated in the 40,000 hectares of APPs that will be recovered in the Rio Doce watershed as defined in the TTAC. In February 2018, Renova asked local landowners to submit proposals for APP and agricultural restoration that could be remunerated by providing environmental services.[b] Landowners were eligible to receive PES funding of up to BRL 252 per hectare per year for areas in aquifer recharge zones restored under the programme, and half that amount for soil conservation practices applied in areas subject to erosion.

The location of Renova's work in springs recovery and water recharge areas and PES initiatives are presented in **Figures 7** and **8**.

a) For further information, please see: https://www.wwf.org.br/?66162/renova-e-wwf-brasil
b) Call for PES Programme. Available at: https://www.fundacaorenova.org/paineis/edital-para-pagamento-por-servicos-ambientais-psa/

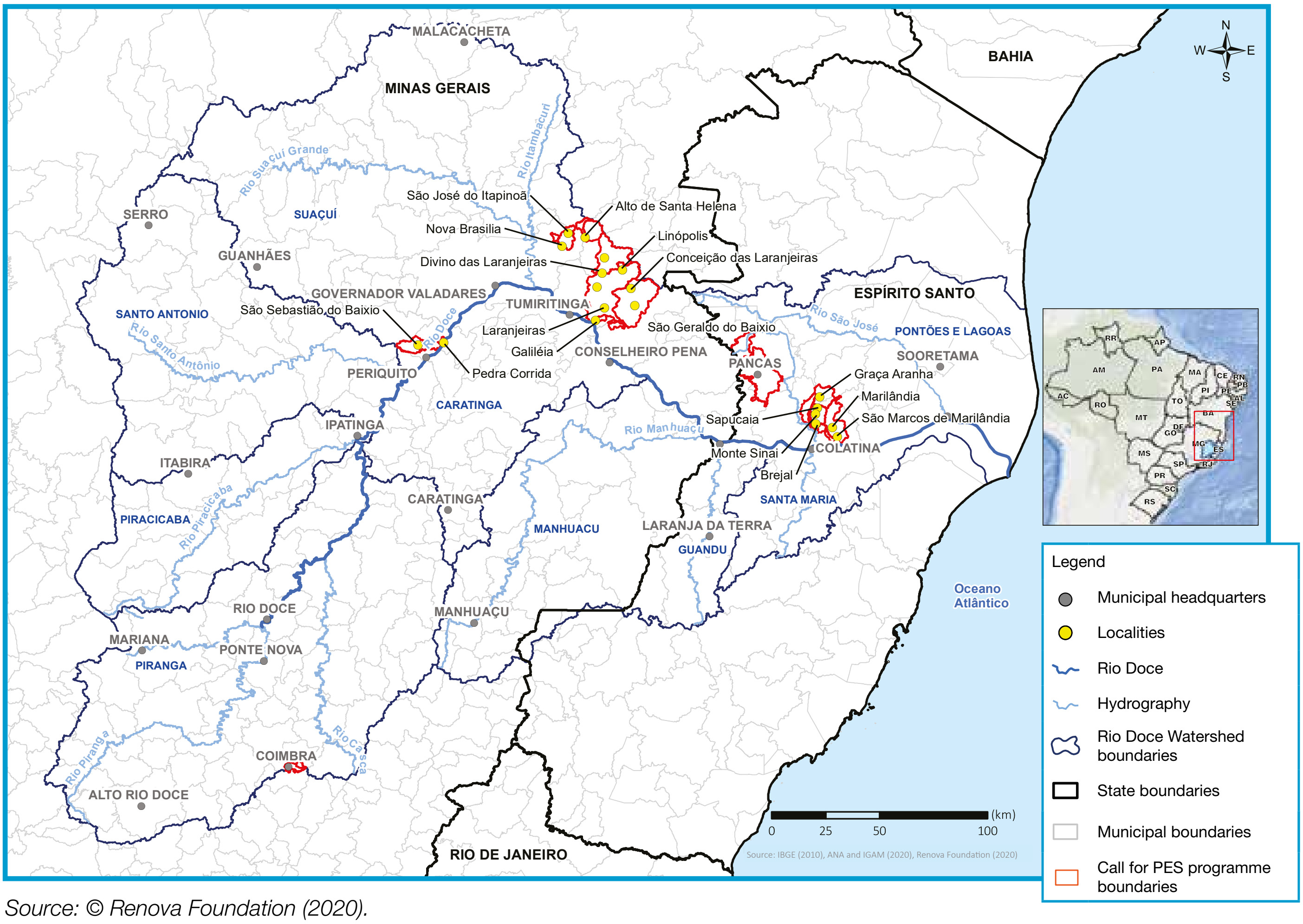
Source: Rio Doce Panel (2020).

Figure 6 Areas where ROAM methodology was applied by Renova Foundation and partners



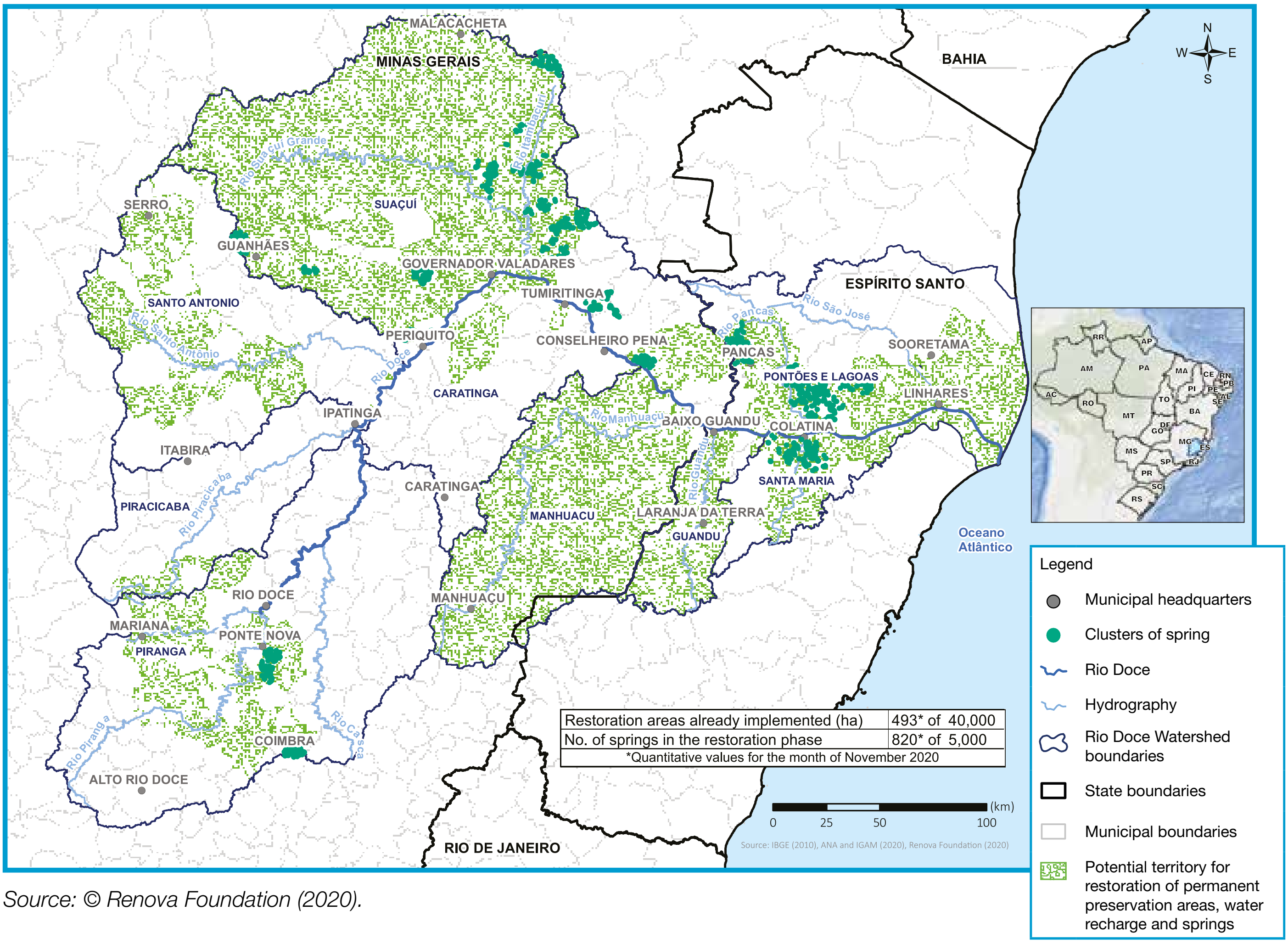
Source: © Renova Foundation (2020).

Figure 7 Areas where payment for environmental services will be applied by Renova Foundation and partners



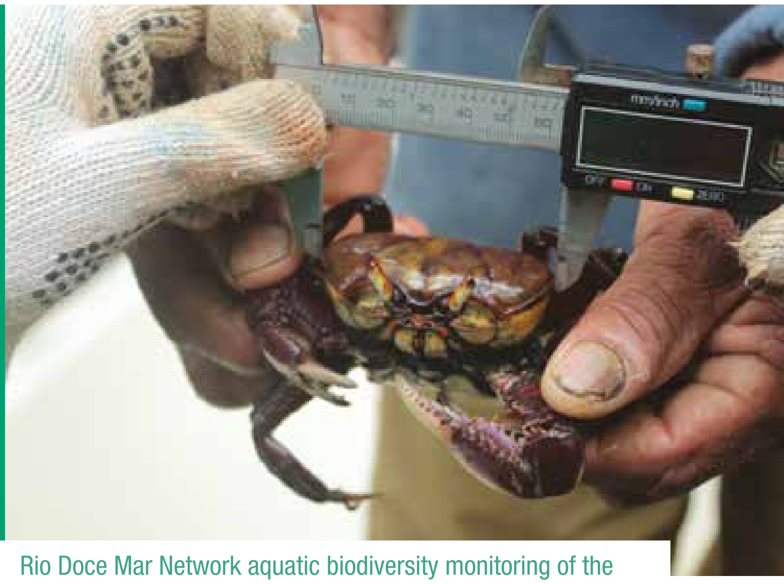
Source: © Renova Foundation (2020).

Figure 8 Areas where springs and water recharge areas recovery actions are put in place by Renova Foundation and partners



Source: © Renova Foundation (2020).

Researchers monitor the fauna and flora in the Rio Doce State Park (September 2018). *Photo: Gustavo Baxter/NITRO*



Rio Doce Mar Network aquatic biodiversity monitoring of the mouth of the Piraquê Açú River, a mangrove area affected by mining tailings resulting from the Fundão Dam failure.
Photo: Saulo Ronconi/Rede Rio Doce Mar (March 2018)

ICZM is a process of governance and consists of establishing the legal and institutional framework necessary to ensure that the development and management plans for coastal zones are integrated with environmental and social goals, and are developed with the participation of the people that will be affected by those plans (Post & Lundin, 1996). An ICZM should maximise the benefits provided by the coastal zone and minimise conflicts and harmful effects of activities upon each other on resources and on the environment. The approach acknowledges that the negative impacts of increased human settlements and industrial development are more acutely felt in the coastal zone since it is at the receiving end of land and water-based pollution.

Besides being the receptacle of land and water flows, the coastal zone has been a focus of attention due to the impacts of climate change that are expected to bring important changes to these areas, e.g. rise in sea level, coastal erosion, etc. Among its characteristics, an ICZM should move beyond traditional sectoral approaches to one that aim at managing the coastal zone as a whole.

In Brazil, the Constitution defines the coastal zone as 'national heritage' (Brasil, 1988a) and looks to the National Coastal Management Plan (*Plano Nacional de Gerenciamento Costeiro*, or PNGC) (Brasil, 1988b) as one way to implement its statutes. PNGC's objectives are to: develop a national strategy for the conservation of the Brazilian coastline, including actions to reduce the risks associated with climate change and the impacts caused by extreme events; maintain environmental quality in the coastal zone in order to reduce risks to health; and combat the disposal of waste at sea and pollution from domestic and industrial sewage. The plan is based on the principle that it will only be possible to resolve the impacts of marine pollution through the integration of watershed and coastal management. It is important to note that the states and municipalities should develop their own coastal management plans, as the state of Espírito Santo has done.

Thus, in the context of the Rio Doce restoration, a landscape approach has to be adapted to the needs and dynamics of the specific processes at hand. Applying the source-to-sea framework, a process that combines FLR and ICZM with the watershed scale, would be valuable for the Rio Doce restoration.

4 Setting up a combined approach to restore water quality and biodiversity in the Rio Doce watershed

Freshwater environments, such as rivers, are globally important for wildlife and essential for all economic activities and for human well-being. The communities of plants and animals associated with rivers are rich and varied, owing to the wide variety of shelter, breeding and feeding opportunities that river habitats provide (Addy et al., 2016).
River ecosystems support a high level of biodiversity and provide environmental services that are essential for human well-being and for all economic activities. As the main sources of organic matter and sediments for estuarine and marine environments, rivers influence water quality in adjacent coastal and oceanic regions.

Like the Rio Doce, the deltas and adjacent marine areas of many river ecosystems have been increasingly degraded by a variety of factors such as: sewage[26] and solid waste discharges; diversion or abstraction of water; the clearing of land; siltation; and climate change, among others. The aim of restoration should be the reinstatement of a river's physical, chemical and ecological characteristics, all of which contribute to human well-being.

Among the rivers' physical aspects, attention should be given for example, to variation in flow (latitudinal and longitudinal), sediment movement, and the size and shape of the river channel. Moreover, "although longitudinal connectivity from source to sea is a defining characteristic of rivers, they have many other intimate hydrological and biological connections such as lateral hydrological connections to floodplain and coastal habitats. In particular, river-floodplain connections are widely recognised as important in sustaining natural functions such as nutrient inputs from the terrestrial environment which many riverine species rely on" (Addy et al., 2016, p. 16).

Equally important are the chemical and ecological characteristics, which include water quality, biodiversity richness and the presence of invasive species (Addy et al., 2016).

Using a hydrological approach, studies have been undertaken about the influence of streamflow on ecosystem processes like nutrient uptake, the transformation of organic matter and ecosystem metabolism (Palmer & Ruhi, 2019). River flows exert direct and indirect control over the composition, structure and dynamics of communities from the local to regional levels. Flow patterns determine the structure and functioning of a river and shape the adaptation of a wide range of aquatic and riparian species.

The flow regime also influences in-stream and floodplain ecosystem processes, including primary production and nutrient cycling, and when flows are altered, a combination of biotic and abiotic pathways are triggered (Granit et al., 2017, Barbosa et al., 2019; Palmer & Ruhi, 2019). Different river flows, such as flash or extreme low flows, can cause significant changes in a river ecosystem, for example by increasing suspended sediments, inhibiting organismal feeding and reproduction, or increasing water temperature and pollutant concentrations to levels that prevent the survival or reproduction of many species (Palmer & Ruhi, 2019).

The studies also indicate that while most restoration practices have focused on improving channel morphology or habitat, the recovery of biodiversity or species of interest has proven more difficult. The authors of the studies call attention to the need to change the focus from the river channel to the

26 According to the World Health Organization (WHO), it is estimated that for every BRL 1 invested in basic sanitation, BRL 4 are saved in health expenditures. The WHO also estimates that 15,000 people die annually and 350,000 are hospitalised in Brazil due to diseases linked to inadequate basic sanitation (Ordem dos Advogados do Brasil, 2020).

watershed, so that a whole or key ecosystem process can be recovered. To achieve this, more attention should be given to the interaction between flow-biota-ecosystem processes as well as the existing land use and major human activities in the watershed.

Aside from the importance of the river flows, another important influence on freshwater quality and biodiversity is the presence of forests or natural vegetation along the river's channels (riparian corridor) and in the wider watershed. A riparian corridor, when well conserved, can act as a protected area in managed landscapes and promote a positive effect on stream conditions, leading to the improvement of watershed resistance and resilience[27] during the rainy and dry seasons, respectively (Pires et al., 2017). Riparian corridors provide shelter and resources that are important for different species that are directly and indirectly dependent on the river. They also influence flow and temperature, the structure of the habitat, fish growth and biodiversity, and serve as stepping-stones for wildlife in fragmented or degraded areas (Addy et al., 2016; Pires et al., 2017).

Forested riparian zones influence water quality, which in turn influence biodiversity. In relation to the Rio Doce watershed, Pires et al. (2017) verified that the improvement in water quality was three-fold faster where the coverage of the riparian areas was in accordance with the Natural Vegetation Protection Law (NVPL),[28] and notes that water quality[29] is one of the best indicators of the effects of forest restoration since it reveals the effects of multiple integrated processes.

In another study, a systematic review of the influence of tropical forests on freshwater fish showed that fish diversity was higher where there was more forest cover, due to the existence of a greater range of resources, which consequently can support a wider range of species (Lo et al., 2020). In contrast, non-forested or deforested streams lack large substrate materials, and present higher levels of sedimentation and siltation. These factors contribute to homogenising the condition of in-stream habitats and, consequently, lead to the homogenisation of freshwater communities (Zeni & Cassati, 2014). While forested riparian zones have a role in reducing siltation and sedimentation, maintaining the complexity and availability of micro-habitats for river biota, pastureland streams are associated with the simplification of the trophic chain (Lo et al., 2020).

Although Renova Foundation's efforts are determined by the programmes set out in the TTAC and focus on the direct impacts of the disaster and affected area, a landscape approach could be applied to better integrate the programmes and incentivise federal and state governments and other stakeholders to prioritise the restoration of the main channel riparian corridors of the Rio Doce, including the estuary, and later expand to cover the restoration of other riparian corridors throughout to the entire watershed. Some of TTAC programmes, such as Programmes 25 (*Revegetation, riprap and other methods*), 26 (*Recovery of Permanent Preservation Areas*), 27 (*Springs recovery*) and 40 (*Rural environmental registry (CAR) and Environmental adjustment programmes (PRA)*), could share their results and bring valuable information and methodology to help stakeholders in the implementation of this important step towards the restoration of Rio Doce watershed.

27 For Pires et al. (2017), watershed resistance is defined as the ability to keep the water quality closer to its average temporal behaviour, and watershed resilience is the ability of the system to return to a hypothetical natural condition of water quality.

28 The Native Vegetation Protection Law (Law No 12561/12) requires that riparian vegetation of water courses and springs on rural properties be fully protected as APPs.

29 To determine water quality, the water quality index (WQI), as suggested by the US National Sanitation Foundation, was used (Pires et al., 2017). The WQI integrates nine limnologic variables – thermotolerant coliforms, dissolved oxygen, turbidity, nitrates, total phosphorus, total suspended solids, biological oxygen demand, temperature variation and pH – to determine a single value for water quality (Pires et al., 2017).

Due to the degraded state of the Rio Doce watershed and the poor quality of its water, compliance with the NVPL through restoration of the riparian corridors will not by itself be sufficient to guarantee a substantial improvement in both water quality and biodiversity status. Renova Foundation is implementing Programme **31** (*Sewage collection and treatment*) that was designed to help affected municipalities with technical assistance to develop and implement projects on sewage and solid waste infrastructure and treatment. The programme works closely with public developing banks, which check the bidding processes and projects from governments and disburse the payments according to the fulfilment of the projects' phases.[30] As of December 2020, Renova has invested BRL 19 million out of BRL 600 million allocated for sanitary sewage and solid waste actions in 18 locations in Minas Gerais and Espírito Santo. This amount is part of the compensatory measures agreed for these activities in the Rio Doce restoration process.[31]

Although work is progressing on Programme **31**, these measures could be reinforced by a complementary programme of sewage treatment to achieve a long-term improvement in water quality. The Brazilian Congress has recently approved the New Legal Framework for Basic Sanitation (Law No. 14.026/2020),[32] which brings innovations to sewage treatment in Brazil, including: the aim of achieving universal service; the regionalisation of the sewage treatment service; and competitive selection among private or public service providers. The new law envisages an increase in the volume of resources that will be invested in sewage treatment in the country, which could offer new opportunities for municipalities in the Rio Doce watershed to increase their investment and attract financial resources from the private sector (along with resources from the public sector) to develop their sewerage network and sewage treatment systems. The Rio Doce Watershed Committee is a key stakeholder to help coordinate efforts to improve sewage treatment in the watershed.

Two of TTAC programmes are focused on the overall course of the Rio Doce channel, its delta and marine adjacent areas: Programmes **28** (*Biodiversity conservation*) and **38** (*Water monitoring of Rio Doce watershed*).[33] These programmes could provide the sectoral focal point for a source-to-sea framework (Granit et al., 2017), which as a first step could involve the implementation of an integrated landscape approach. This would imply considering the flows and morphology of the Rio Doce, as well as its riparian vegetation and biodiversity characteristics. Provided that TTAC programmes were more closely integrated, this would enhance their contribution to improving the river's water quality and the integrity of its habitat and ecosystem – a critical step in achieving the restoration of the Rio Doce watershed and the livelihoods that depend on it.

30 For further information, please see: https://www.fundacaorenova.org/en/program/collection-and-sewage-treatment/

31 For further information and latest news, please see: https://www.fundacaorenova.org/dadosdareparacao/reconstrucao-e-infraestrutura/#saneamento

32 According to this law, basic sanitation comprises the set of public services infrastructure and operational facilities for: drinking water supply; sewage treatment; urban sanitation and solid waste management; and drainage and management of urban rainwater.

33 The objective of Programme 28 (*Biodiversity conservation*) is to identify and measure the acute and chronic impacts on the biota and environments of the Rio Doce, including its mouth, coastal, estuarine and marine areas, and to implement measures for the recovery and conservation of this biota. The overall objective of Programme 38 (*Investigation and monitoring of the Rio Doce watershed*) is to develop and implement a research and monitoring programme in the Rio Doce watershed, impacted estuarine, coastal and marine areas, generating information on water quality and sediments to support decision making in other TTAC programmes, as well as by environmental and water agencies. For more information about the programmes, please visit: https://www.fundacaorenova.org/en/discover-the-programs/environmental/

5 Conclusions

The source-to-sea framework expresses the scale and the elements needed to address complex governance systems and vast territories, which is the case of Rio Doce watershed. It calls attention to the need to integrate distinct actions within the watershed, emphasising not only the essential flow of water but also a flow of actions starting from the headwaters – continuing from the river's mouth and expanding to the adjacent coastal waters. These actions should not only include processes that occur within the river channel but must incorporate the social, economic, cultural and environmental features of the entire watershed. In this sense, an integrated landscape approach can contribute to a better understanding of the relationship between governance, people and space and enable stakeholders to minimise trade-offs.

The Rio Doce Panel recognises that the key to restoring the landscape to a healthier and more sustainable state than that which existed before the disaster and to contribute to the resilience of environmental quality and local livelihoods is the implementation of a combined vision to integrate the landscape approach and the source-to-sea framework. In addition, the adoption of a landscape approach for the restoration of the Rio Doce watershed areas affected by the Fundão Dam disaster can also help address the need for long-term planning and effective engagement of affected parties.

The Panel acknowledges that some actions undertaken by Renova Foundation represent important steps towards the application of a landscape approach. Programmes under the heading of 'Sustainable Land Use and the landscape analysis', for example, demonstrate clear linkages among socio-economic and environmental aspects that has the potential to have a positive impact on environmental and livelihood conditions, in combination with the positive effects on water quality and biodiversity within the watershed. These initiatives were launched through a process of consultation at a sub-watershed level between local governments, Renova and affected communities to better respond to local concerns.

To operationalise the combination of an integrated landscape approach and source-to-sea framework for the restoration of the Rio Doce watershed, it is essential to define the sectoral focus. One possibility could be the restoration of the Rio Doce channel as a riparian corridor for water quality improvement and biodiversity conservation. Water quality and biodiversity monitoring render vital information about the restoration process, particularly in how they exert influence on each other. In practical terms, this implies the need to enhance coordination between TTAC programmes in order to achieve a positive impact at the scale of the river's watershed and adjacent coastal and marine areas. For example, springs and forest restoration, water and sewage treatment facilities, terrestrial and aquatic biodiversity conservation, biodiversity monitoring and protected areas reinforcement, streambank restoration, among other TTAC programmatic areas, could only achieve greater synergy among them if they are better linked and strengthened in spatial terms.

Other aspects of such an integrated approach that could be captured in the Rio Doce watershed restoration are related to livelihood enhancement, such as irrigation systems, livestock management, fisheries and pisciculture. The engagement of Rio Doce Watershed and Sub-watershed Committees, as well as stakeholder groups associated with livelihood improvement, should also target the synergies and potential conflicts that might arise, and the need to negotiate complementary water uses.

Renewing Landscapes Project (Renovando Paisagens), Region of Mariana municipality, Minas Gerais, Brazil. 25–27 November 2019.
Photo: Daniel Hunter/WRI Brasil

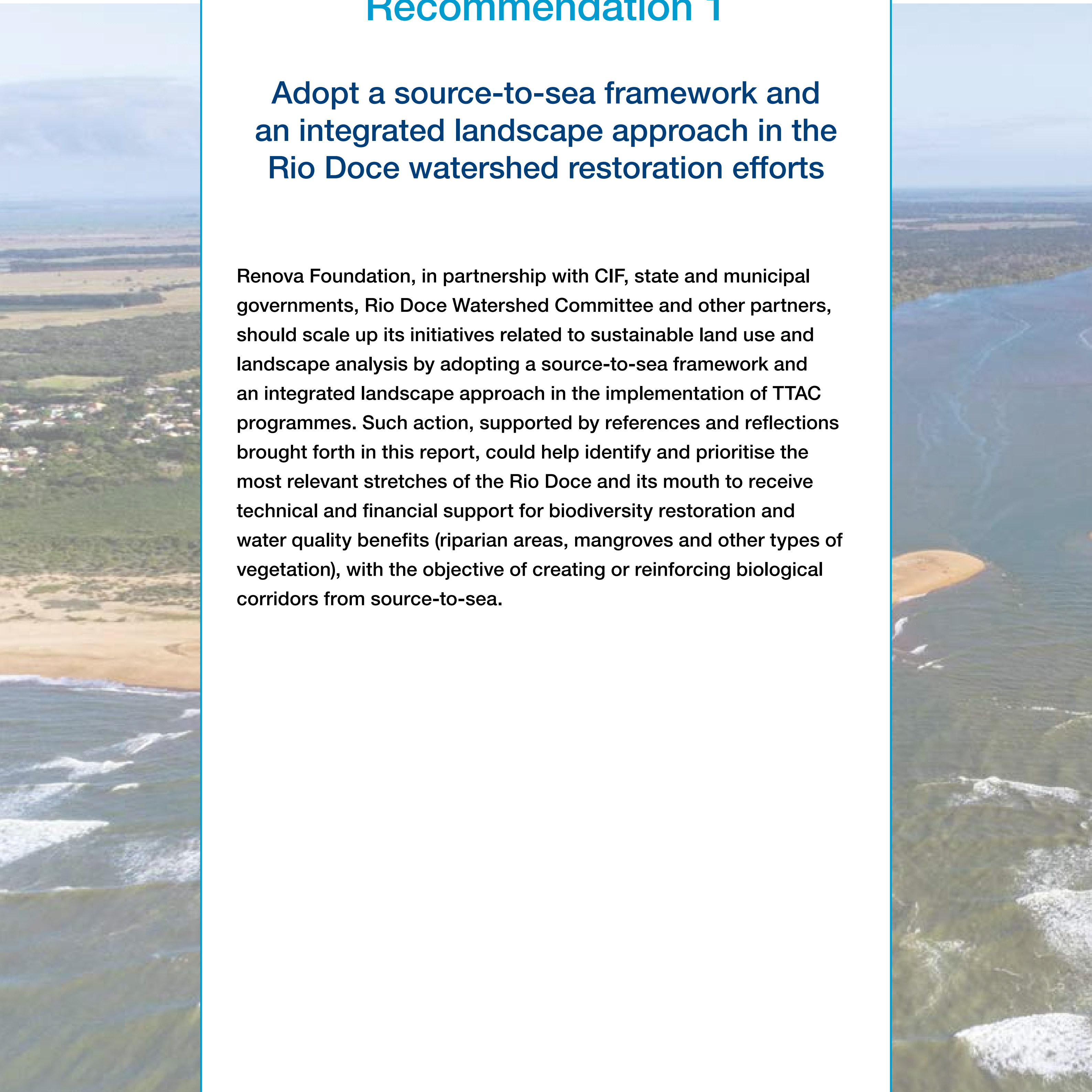
Moving towards the operationalisation of a landscape approach will require attention to the process design and implementation, clear definition of objectives, collaborative participation, transdisciplinary/cross-sectoral approaches, adaptive capacity management, and an iterative process to address the inherent complexity within the system.

Bearing in mind its objectives and building upon previous recommendations,[34] the Rio Doce Panel is seeking to contribute to the restoration of the Rio Doce watershed from an interdisciplinary and integrative perspective.

Recommendations

Aiming to contribute to ensure an effective restoration process for the watershed as a whole, the Rio Doce Panel propose the following recommendations to Renova Foundation, CIF, federal, state and municipal governments, and its partners to:

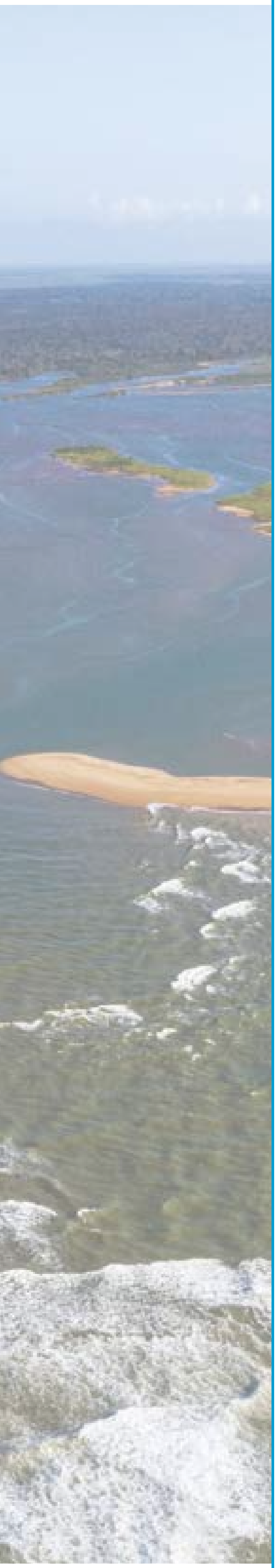
34 Please see Recommendation 6, RDP Thematic Reports No. 1 and No. 2; RDP Issue Papers 1, 2, 3, 4 and 5. Available at: https://www.iucn.org/rio-doce-panel/resources



Recommendation 1

Adopt a source-to-sea framework and an integrated landscape approach in the Rio Doce watershed restoration efforts

Renova Foundation, in partnership with CIF, state and municipal governments, Rio Doce Watershed Committee and other partners, should scale up its initiatives related to sustainable land use and landscape analysis by adopting a source-to-sea framework and an integrated landscape approach in the implementation of TTAC programmes. Such action, supported by references and reflections brought forth in this report, could help identify and prioritise the most relevant stretches of the Rio Doce and its mouth to receive technical and financial support for biodiversity restoration and water quality benefits (riparian areas, mangroves and other types of vegetation), with the objective of creating or reinforcing biological corridors from source-to-sea.



Recommendation 2

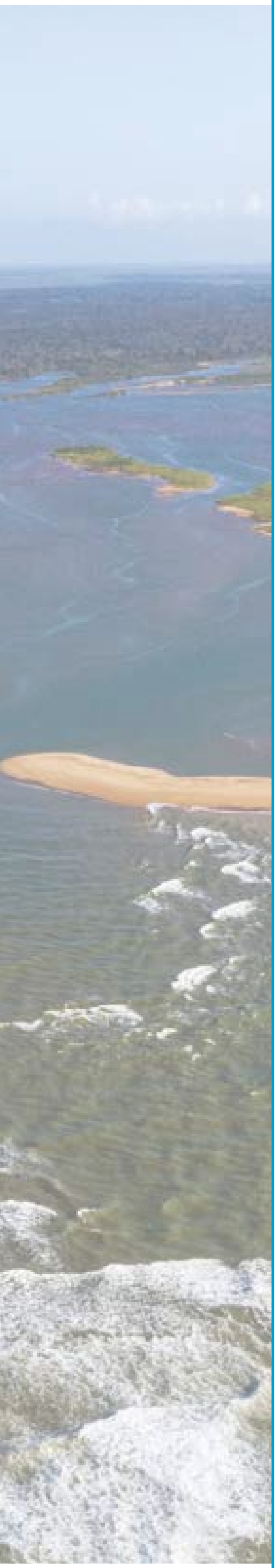
Ensure a long-term comprehensive evaluation of the systematic Quali-Quantitative Monitoring Programme of Water and Sediment of the Rio Doce watershed (PMQQS) data to prioritise actions for the continual improvement of Rio Doce's environmental conditions

The CIF could revisit the PMQQS and include within its scope a long-term comprehensive evaluation of the changes in water quality along the watershed to guide Renova Foundation in its efforts to ensure that the physical, chemical, biological and ecological characteristics of Rio Doce are continually improved. While the PMQQS has ensured regular monitoring of such parametres, there is a need for an integrated perspective on how best to use such data to inform restoration actions.

Recommendation 3

Use the existing water monitoring programme to build the capacity in the region to monitor potential impacts on water quality and biota associated with the emergence of synergistic pollutant compounds

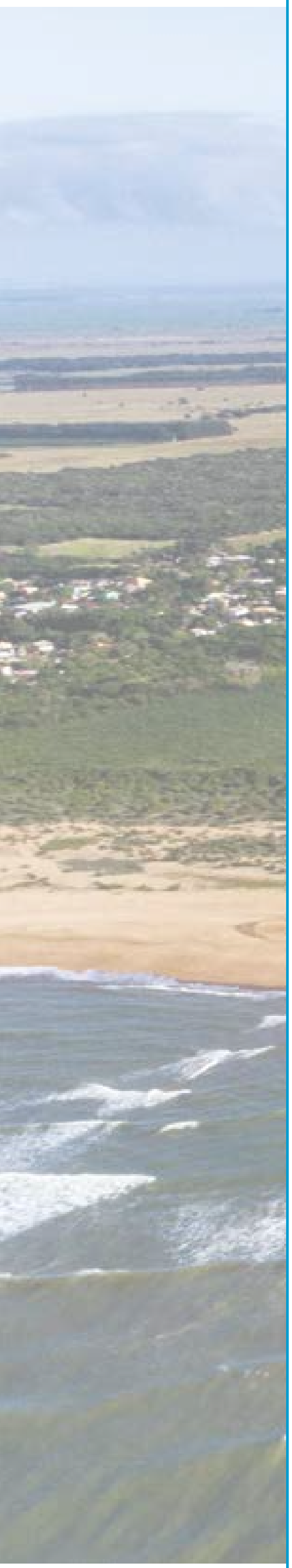
Building on the structure and expertise developed in the implementation of PMQQS, CIF, through its Technical Chambers, and Renova Foundation could support the Federal and State government agencies on the implementation of a specific monitoring programme at the watershed level to examine the potential formation of synergistic effects of the combination of distinct pollutants and their impacts on water quality and the biota of the Rio Doce. Considering that the Rio Doce has become one of the most monitored rivers in Brazil, and given that the methodologies for assessing synergistic effects are not widespread in the country, the implementation of this recommendation could offer a benchmark in water monitoring conditions. It could become a reference for water monitoring programmes in Brazil.



Recommendation 4

Strengthen technical support to municipalities for the implementation of a comprehensive, innovative and modular basic sanitation programme for the watershed

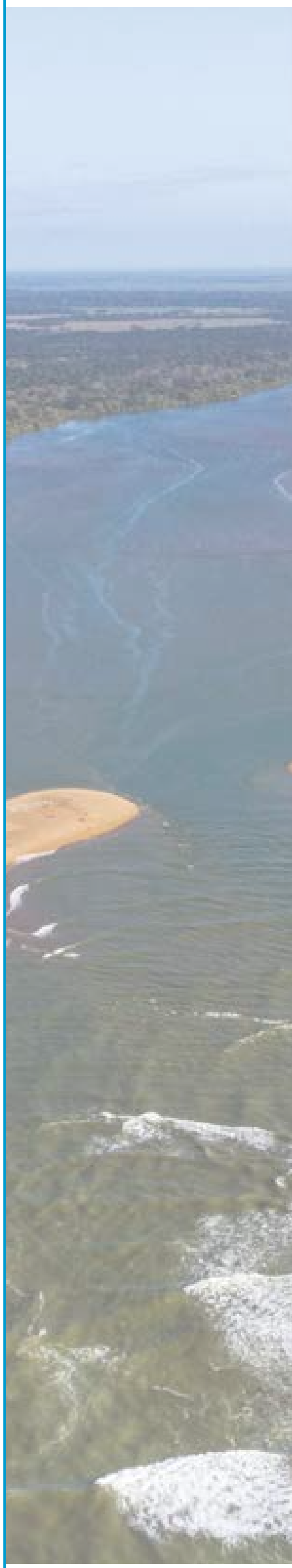
Acknowledging the advances in the basic sanitation led by the investments of TTAC's Programme 31 (*Sewage collection and treatment*), CIF, Renova Foundation and the Watershed Committee should strengthen technical support to municipal governments to enhance the water quality and environmental health in the Rio Doce watershed. These efforts could consider nature-based solutions and be appropriate for both urban and rural areas. The programme could consider options for investment by State Development Banks and or the private sector investors motivated by the New Legal Framework for Basic Sanitation.



Recommendation 5

Expand the existing monitoring plan in order to inform and prioritise biodiversity restoration activities

Renova Foundation, together with CIF and its Technical Chamber on Biodiversity, should expand the monitoring plan for terrestrial, freshwater and marine biodiversity reflecting the impacts of the disaster and the effectiveness of the restoration efforts. The monitoring could include marine, coastal and terrestrial Protected Areas, which constitute a natural repository of the biodiversity of the Rio Doce watershed. This expanded monitoring plan can offer the opportunity to engage community members throughout the watershed, adopting practical activities within the citizen science approach.



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