CHAPTER 1

CLIMATE CHANGE, FOREST ECOSYSTEMS, AND GHG MITIGATION IN THE STATE OF RIO DE JANEIRO

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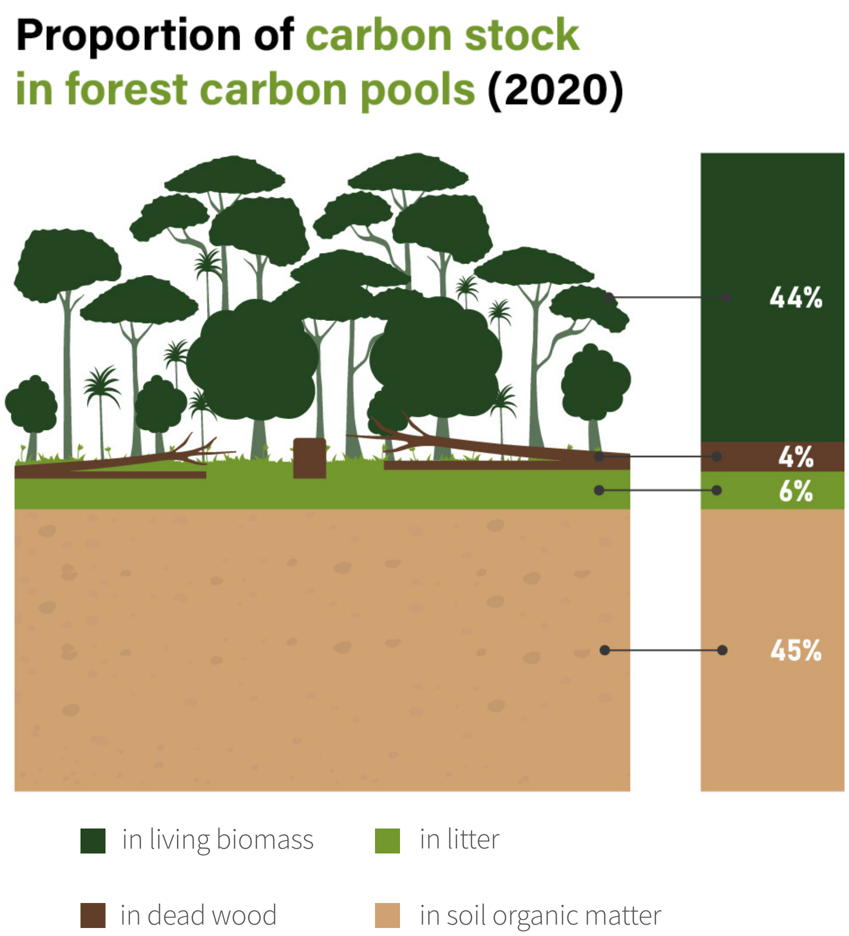
The challenges posed by climate change, which are already a reality in many aspects of daily life, require a multi-sectoral dialogue and strategies distinct from those already addressed by various societal actors, particularly scientists, policymakers, companies, and investors. Mitigation actions for greenhouse gas (GHG) emissions depend substantially on the contribution of forest ecosystems, especially tropical forests. Additionally, adaptation actions are crucial to minimize population risks in the face of current challenges, where Nature-based Solutions (NbS) once again emerge as key allies.

Thus, forest ecosystems, which have often been and still are perceived as obstacles to "development", as a reflection of delayed modernization, are in fact the main strategy for climate change mitigation and adaptation. However, these same ecosystems, along with their biodiversity and functionality, are affected by climate change. Therefore, it is necessary to reinforce the global alliance for the monitoring, conservation, and restoration of forest ecosystems, which have soil as their primary substrate.

Terrestrial ecosystems store large amounts of carbon (C) in plants and soil, playing an important role in global climate regulation, which is undergoing rapid changes due to anthropogenic actions, especially land-use dynamics (Heimann & Reichstein, 2008; Harris *et al.*, 2021). According to Food and Agriculture Organization of the United Nations (FAO, 2020), most forest carbon is found in living biomass (44%) and soil organic matter (45%), with the remainder in deadwood and litter (Figure 1).

FIGURE 1. Proportion of carbon stocks in forest compartments



Source: Adapted by authors from FAO (2020).

Due to the importance of ecosystems in climate regulation, public policies and sustainable practices based on scientific evidence should be pursued by societies, governments, and officially constituted institutions. Thus, decision-making regarding forest management at regional, national, and international levels, aimed at biodiversity conservation and maintenance of forest services, requires consistent and up-to-date forest information (Nesha *et al.*, 2022).

Therefore, we believe that in tropical regions it is essential to create or strengthen local and regional capacities to compile, recompile, and analyze data to generate and disseminate information, especially regarding forest assets and their biodiversity, in order to meet the needs and specificities of diverse audiences.

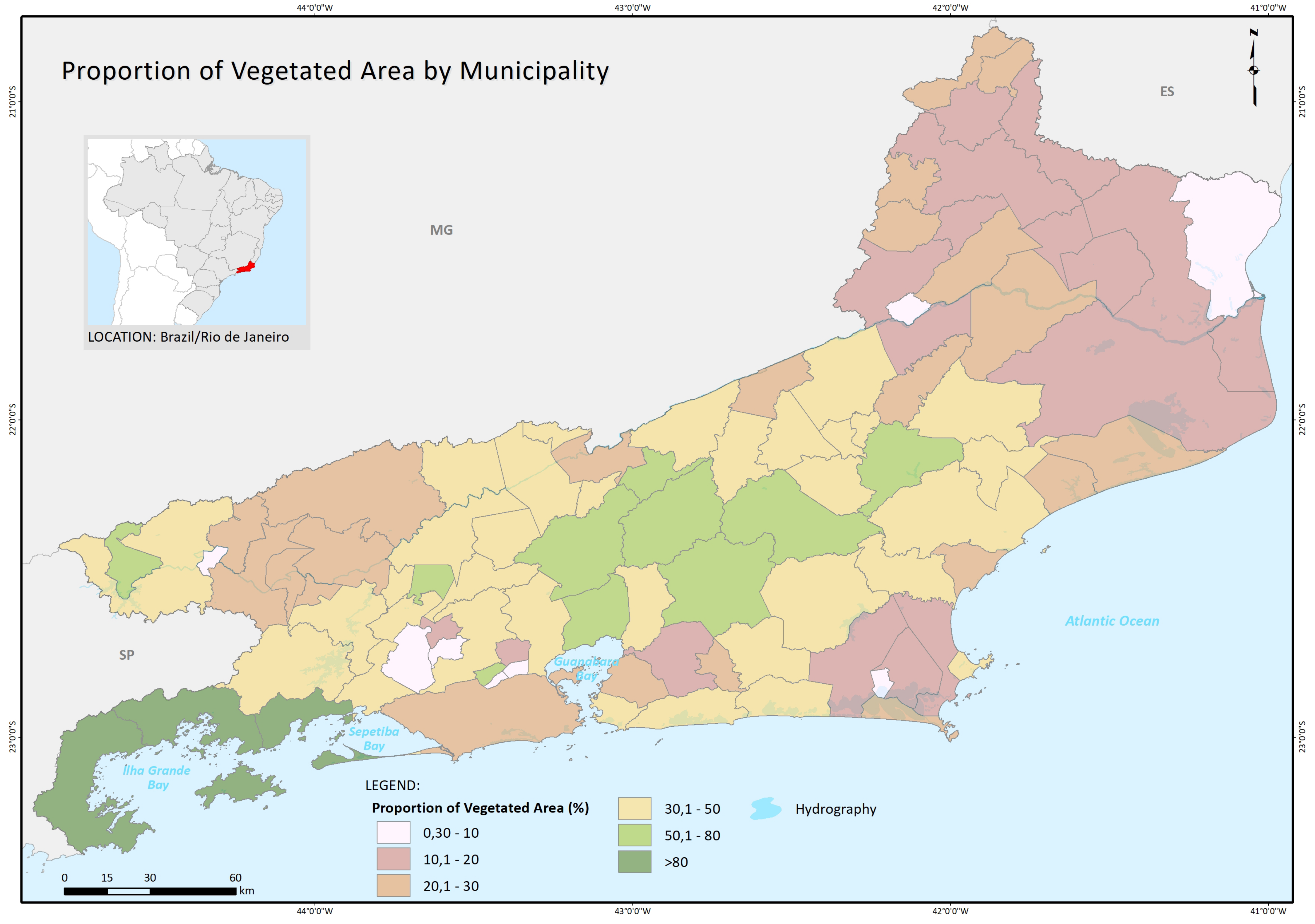
Considering the effects of climate change, large-scale forest inventories become essential to assess, develop scenarios, and contribute to adaptation and mitigation policies for impacts already in place. In this context, while total aboveground living biomass is a forest characteristic of particular interest, the contribution of soil remains underemphasized. Forest soils and woody biomass hold most of the terrestrial biomass carbon on Earth (Houghton, 1999).

Land use changes caused by human activities in terrestrial ecosystems, particularly in forest ecosystems such as burning or deforestation for agriculture and mining can account for 15 to 40% of annual GHG emissions.

Such land use changes have exerted and continue to exert strong pressure on the Atlantic Forest, Brazil's oldest forest formation. According to Paduá (2004), this biome was subjected to several land exploitation cycles, with nineteenth-century reports documenting over 300 years of human activity that denied the identity and benefits of native Brazilian ecosystems. The marks of this past persist and hinder the recovery processes of the Atlantic Forest degraded areas.

The territory of the state of Rio de Janeiro is entirely covered by the Atlantic Forest, which was established around 50 to 70 million years ago, when three factors occurred simultaneously: i) formation of the Atlantic Ocean; ii) formation of mountain systems along the Atlantic edge of South America; and iii) increase in Earth's temperature (Marques *et al.*, 2016; Leitão-Filho, 1987). This evolution ensured the formation of distinct geomorphological regions and diverse soil-forming environments within the state's small territory. With an area of 4,378,158 ha, the state's surface corresponds to 0.5% of Brazil's total area, and its natural heritage has been almost entirely depleted. As a consequence of occupation and land use, forest cover in the state has been gradually reduced, currently representing just over 15% of the original forest, although about 33% of forest cover remains in various successional stages, with the largest remnants covering the mountain massifs (Figure 2).

FIGURE 2. Proportion of forest areas in the Atlantic Forest biome in municipalities of the state of Rio de Janeiro
Base year 2013, mapping scale 1:25,000.
Source: Silveira-Filho (2024).


Proportion of Vegetated Area by Municipality
LOCATION: Brazil/Rio de Janeiro
MG
ES
SP
Guanabara Bay
Sepetiba Bay
Ilha Grande Bay
Atlantic Ocean
LEGEND:
Proportion of Vegetated Area (%)
0,30 - 10
10,1 - 20
20,1 - 30
30,1 - 50
50,1 - 80
>80
Hydrography
0
15
30
60
km
44°0'0"W
43°0'0"W
42°0'0"W
41°0'0"W
21°0'0"S
22°0'0"S
23°0'0"S

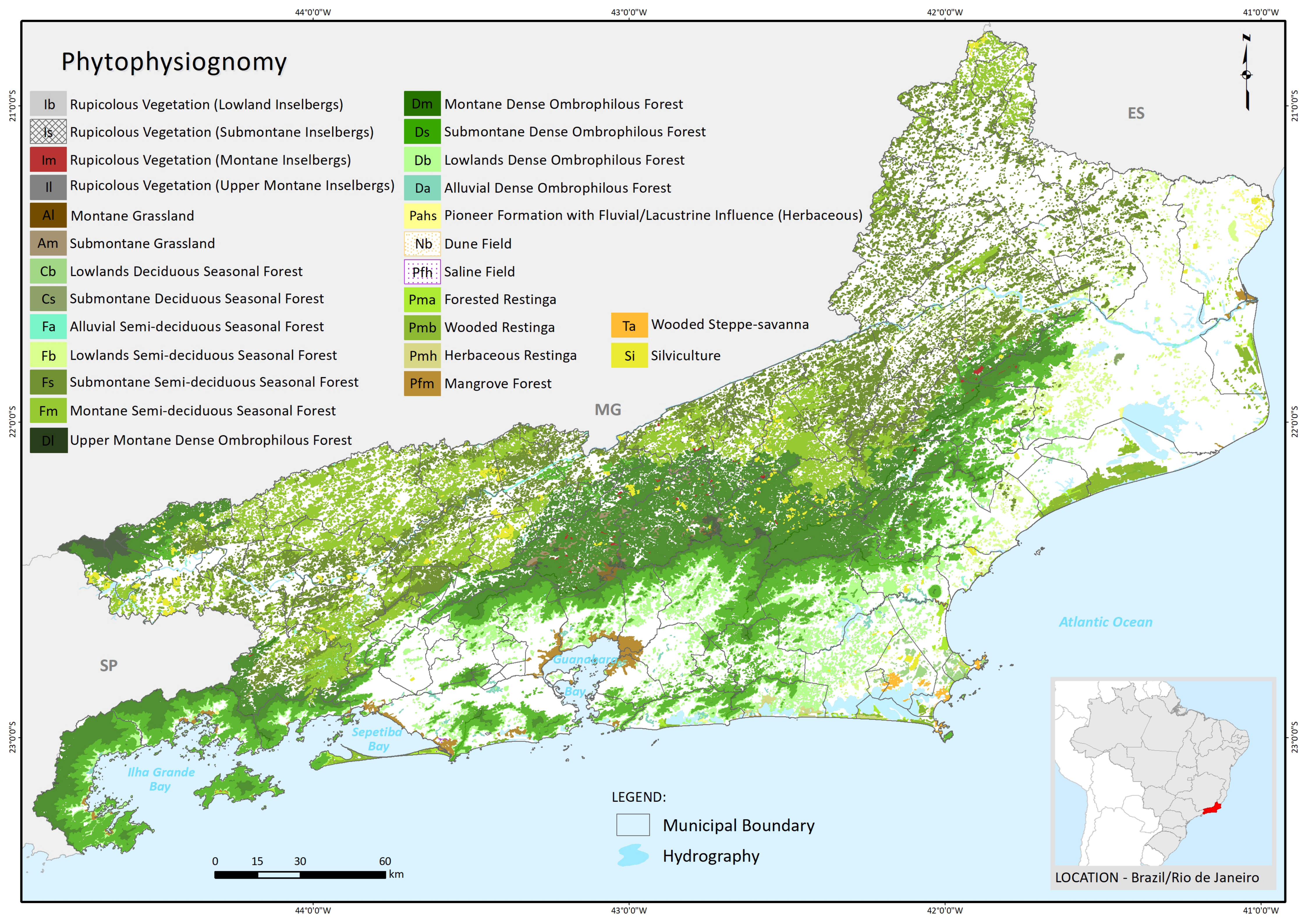
This rich natural heritage has a diversity of habitats, ranging from restingas and mangroves in coastal and river plains, lowland forests, mountain massifs, to high-altitude grasslands reaching around 2,790 meters at Pico das Agulhas Negras (Figure 3). This wide altitudinal variation in a relatively small territory, associated with diverse geomorphology, climate, and other factors, is responsible for the high diversity of fauna and flora, recognized as among the richest in the country. The state is also considered an important region of biodiversity endemism (Silveira-Filho & Rambaldi, 2018).

Housing 8% of Brazil's population across its 92 municipalities over 16 million inhabitants Rio de Janeiro is one of the most densely populated states in the country, with the second-highest population density (365.23 inhabitants/km^2), and around 90% of the population living in urban environments (IBGE, 2024). As one of the first regions in the country settled by colonizers, Rio de Janeiro's secular human activity has profoundly modified its landscape, currently consisting of a mosaic of natural and semi-natural areas surrounded by urban zones.

In its rural environment, Rio de Janeiro has approximately 65,000 establishments, of which 43,599 (about 66.8%) are family farms (EMATER-RIO, 2024). Additionally, around 88% of rural holdings are classified as small properties, indicating an urgent need for strategies focused on soil conservation management.

Soils show great variability in characteristics and properties due to their formation environments and anthropogenic modifications (Figure 4). Soil can be defined as the surface layer of the Earth's crust, composed of mineral and organic material, capable of storing water and air, and providing support for plant growth and other soil organisms. As a growth medium for plants, soil has four main functions: i) supporting root growth; ii) storing water and supplying it to plants; iii) storing air for plant roots; and iv) providing nutrients to plants (Anjos & Pereira, 2013). In other words, soils sustain life, forests, and food security, providing multiple ecosystem services.

FIGURE 3. Vegetation cover classes in the state of Rio de Janeiro Base year 2013, mapping scale 1:25,000 .
Source: Silveira-Filho (2024).

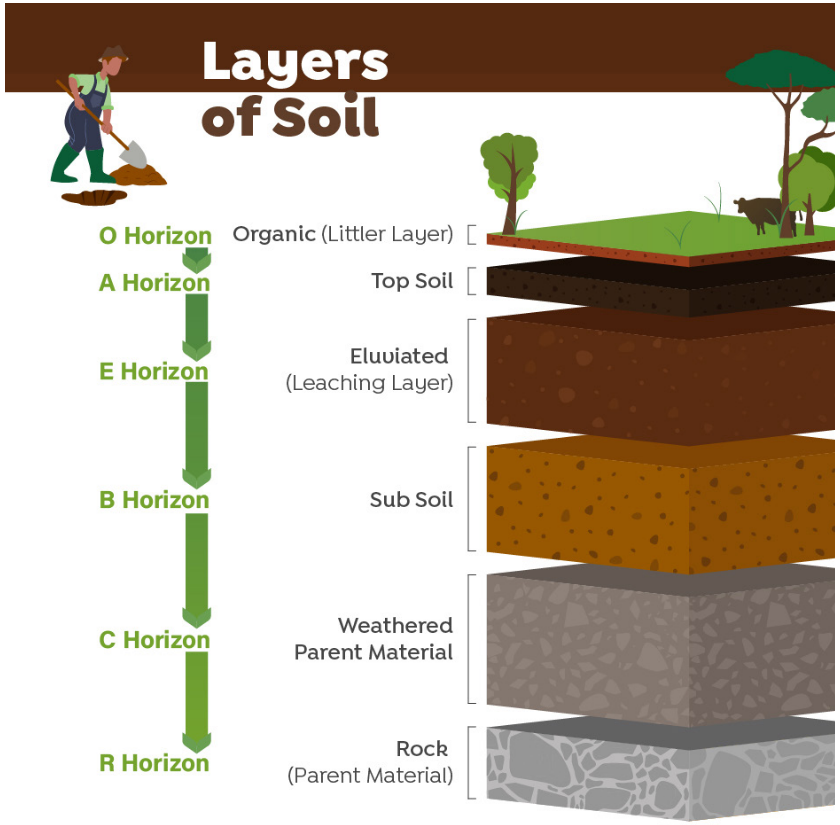


Phytophysiognomy
Ib Rupicolous Vegetation (Lowland Inselbergs)
Is Rupicolous Vegetation (Submontane Inselbergs)
Im Rupicolous Vegetation (Montane Inselbergs)
Il Rupicolous Vegetation (Upper Montane Inselbergs)
Al Montane Grassland
Am Submontane Grassland
Cb Lowlands Deciduous Seasonal Forest
Cs Submontane Deciduous Seasonal Forest
Fa Alluvial Semi-deciduous Seasonal Forest
Fb Lowlands Semi-deciduous Seasonal Forest
Fs Submontane Semi-deciduous Seasonal Forest
Fm Montane Semi-deciduous Seasonal Forest
Dl Upper Montane Dense Ombrophilous Forest
Dm Montane Dense Ombrophilous Forest
Ds Submontane Dense Ombrophilous Forest
Db Lowlands Dense Ombrophilous Forest
Da Alluvial Dense Ombrophilous Forest
Pahs Pioneer Formation with Fluvial/Lacustrine Influence (Herbaceous)
Nb Dune Field
Pfh Saline Field
Pma Forested Restinga
Pmb Wooded Restinga
Pmh Herbaceous Restinga
Pfm Mangrove Forest
Ta Wooded Steppe-savanna
Si Silviculture
44°0'0"W
43°0'0"W
42°0'0"W
41°0'0"W
21°0'0"S
22°0'0"S
23°0'0"S
ES
MG
SP
Atlantic Ocean
Guanabara Bay
Sepetiba Bay
Ilha Grande Bay
LEGEND:
Municipal Boundary
Hydrography
0 15 30 60 km
LOCATION - Brazil/Rio de Janeiro

Among the main activities and alternative land uses in the rural environment of Rio de Janeiro, the most economically significant are: i) cattle ranching, present in 89 municipalities, with pasture areas in all 92 municipalities, occupying 52% of the state territory; ii) vegetable farming, present in 85 municipalities; iii) small and medium animal husbandry, mainly broiler poultry, beekeeping (found in 77 municipalities), and egg production (found in 76 municipalities); iv) fruit farming, the most economically important agricultural activity in the state, especially pineapple, citrus, and banana crops; and v) other traditional crops such as sugarcane, cassava, corn, and coffee. Additionally, crops such as bay laurel (*Laurus nobilis* – Lauraceae), native to the South Mediterranean, and annatto (*Bixa orellana* – Bixaceae), widely distributed in Brazil, are cultivated. Less economically significant, but still important, are floriculture, artisanal fishing, forestry, and cereals (EMATER-RIO, 2024).

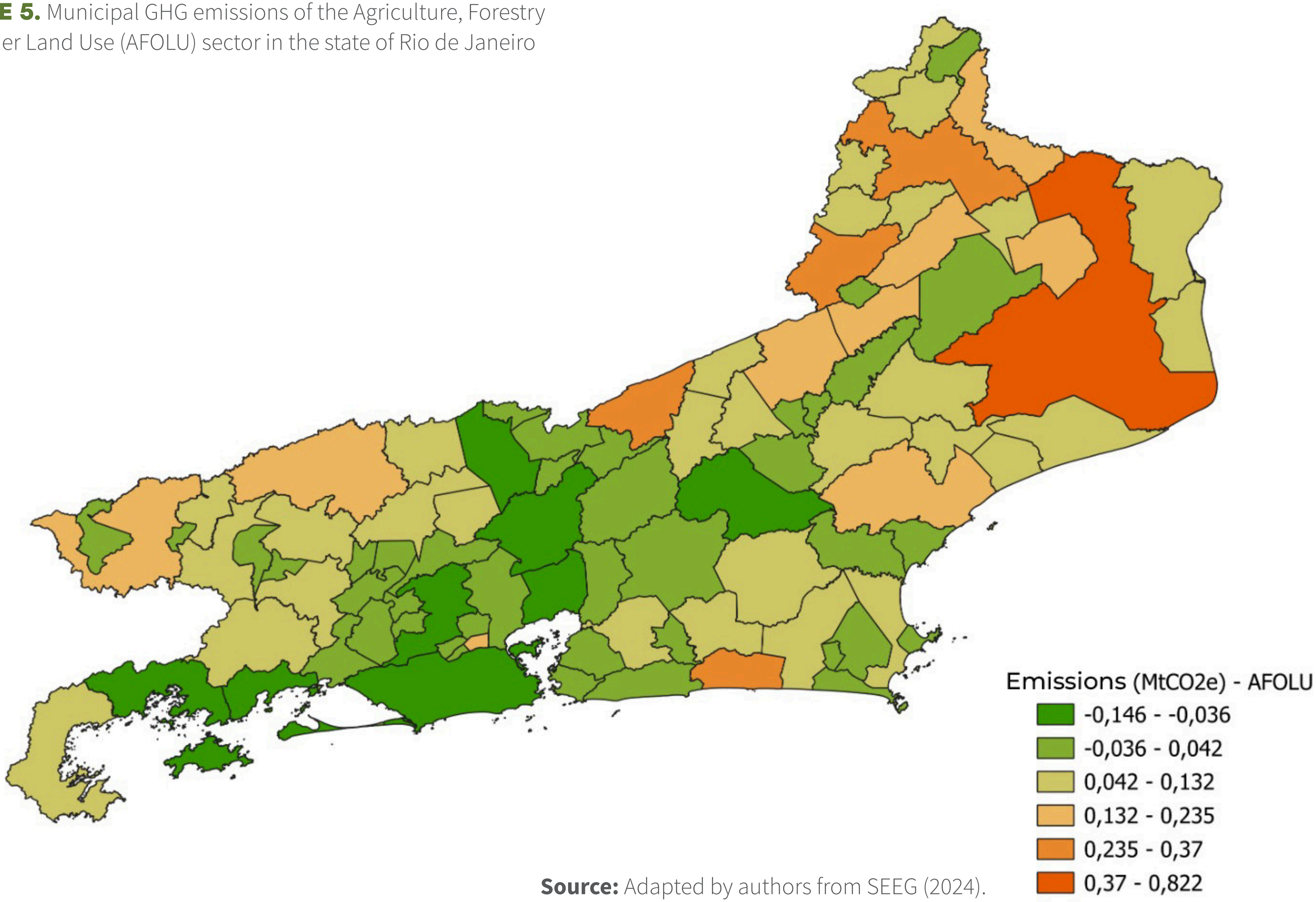
In this context, the state of Rio de Janeiro has great potential to contribute to GHG emission mitigation and to promote conservation practices that ensure water security, food security, and other ecosystem services.

FIGURE 4. Diagram of soil layers



Source: Adapted by authors from FAO (2020).

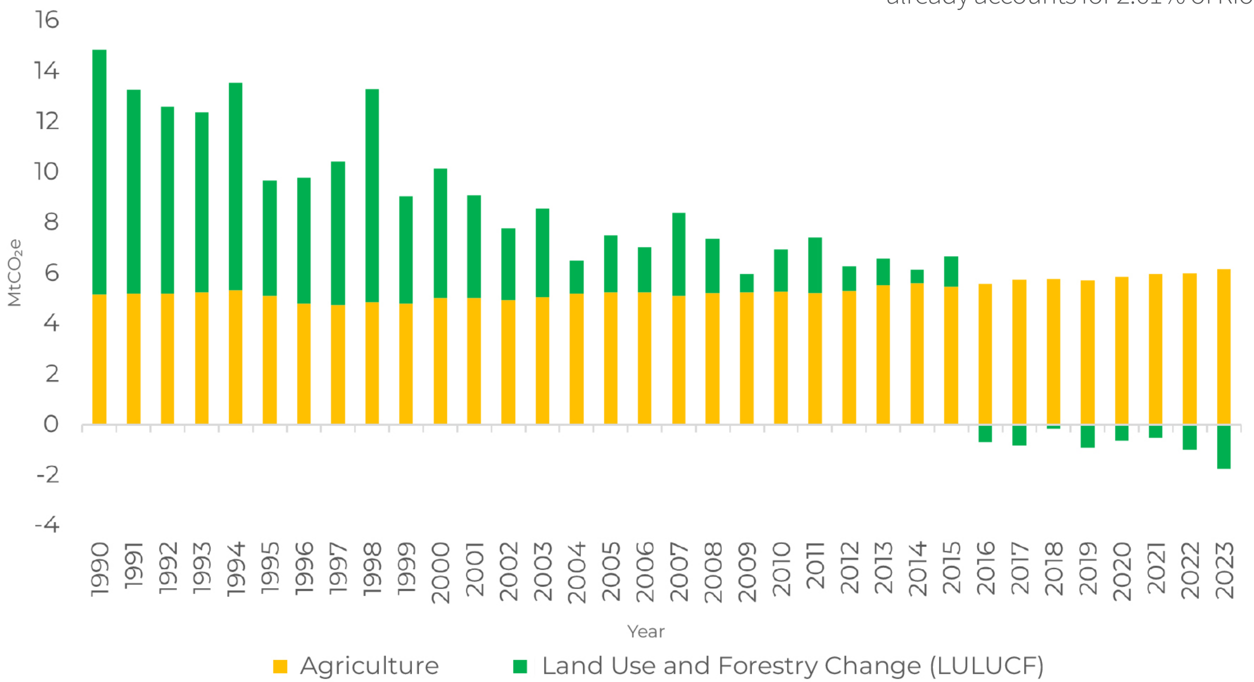
FIGURE 5. Municipal GHG emissions of the Agriculture, Forestry and Other Land Use (AFOLU) sector in the state of Rio de Janeiro



Source: Adapted by authors from SEEG (2024).

The municipalities and governmental regions that stood out as the main AFOLU emitters in 2023 are located in the North and Northwest of Rio de Janeiro. Their municipalities have the lowest Atlantic Forest cover rates, resulting from the historical land use changes and soil degradation, mostly linked to agricultural activities (Figure 5).

FIGURE 6. Historical series of GHG emissions from agriculture and land use change in the state of Rio de Janeiro



Source: Adapted by authors from SEEG (2024).

Unlike the national GHG emissions profile, in which the Agriculture, Forestry and Other Land Use (AFOLU) sector accounted for 27.4% in 2023 (SEEG, 2024), in the state of Rio de Janeiro, Agriculture and Land Use and Forestry Change (LULUCF) represented the smallest contributions to the state's emissions, with total emissions estimated at 6.17 and -1.75 Mt of CO_2 equivalent, respectively (Figure 6). In the net emissions scenario, the Agriculture sector represents 9.2% of total emissions, and negative emissions from LULUCF represent 2.61% of the state's positive emissions. In other words, in the current scenario, carbon removal from this sector already accounts for 2.61% of Rio de Janeiro's total emissions (SEEG, 2024).

As shown in Figure 6, emissions from the Land Use Change (LULUCF) subsector are expected to decrease in the coming years. This results from reductions in emissions from deforestation, other land-use changes, and forest restoration categories. More detailed analyses show an increase in emission removals promoted by the conservation of native vegetation.

Given the land-use scenario and its relation to GHG emissions presented so far, some initiatives within the scope of state public policy aimed at combating deforestation and fires, as well as creating and managing Conservation Units (CUs) and promoting forest restoration to reduce GHG emissions, stand out: Olho no Verde Program, Program to Support the Creation and Management of Municipal Conservation Units (PROUC), State Program Supporting Private Natural Heritage Reserves (RPPNs), CEDAE's Replanting Lives Program, and the Forests of Tomorrow Program.

These contributions can be even more significant if soil carbon monitoring, assessment, and accounting at the landscape scale are applied to sustainable practices, such as the Integration of Crop-Livestock-Forestry (ILPF), in addition to expanding Atlantic Forest restoration based on the suitability of rural properties.

The maintenance of healthy and functional soils contributes to Goal 15 of the United Nations (UN) 2030 Agenda for Sustainable Development, which is to "Protect, restore and promote the sustainable use of terrestrial ecosystems," aiming to combat desertification, soil degradation, and biodiversity loss, while ensuring the sustainable management of forests and freshwater ecosystems and the conservation of mountains and arid areas.

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