CHAPTER 4

SOIL CARBON STORAGE SCENARIOS DRIVEN BY LAND USE, LAND COVER, AND MANAGEMENT CHANGES IN THE STATE OF RIO DE JANEIRO

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1. INTRODUCTION

Soil is a major reservoir of biosphere carbon (FAO, 2018). Forests around the globe store, on average, 45% of carbon in the soil (up to 1 m deep) (Pan *et al.*, 2024). Based on data from the Brazilian National Forest Inventory (NFI), the technical team at Embrapa Soils estimated that forest soils accumulate 136 Tg (million tons) of carbon (Chapter 2 of this book), which means that most of the carbon in these forests is in their soil. This high proportion of carbon in the soil in the Atlantic Forest, when analyzed in conjunction with the study of Lima *et al.* (2020), demonstrates that soil is a resilient carbon reservoir. Despite significant losses of aboveground biomass associated with biodiversity loss in recent decades, the biome's soil still maintains a large carbon reservoir.

Assuming that: At least 1/3 of the pasture lands in the state of Rio de Janeiro are in an intermediate or severe state of degradation (Bolfe *et al.*, 2024); agricultural activities are carried out in rugged terrain; and there is a significant deficit of Legally Protected Areas (~ 111 thousand ha) and Reserves (~ 82 thousand ha) in the state of Rio de Janeiro (Ribeiro *et al.*, 2021), this chapter presents a theoretical exercise to assess the (realistic) potential for carbon sequestration or storage in the soils of Rio de Janeiro, if restoration actions or incentives for reforestation and good agricultural practices were promoted, as well as economic compensation mechanisms implemented, for each administrative region.

2. SOIL CARBON: CURRENT AND REACHABLE STOCKS

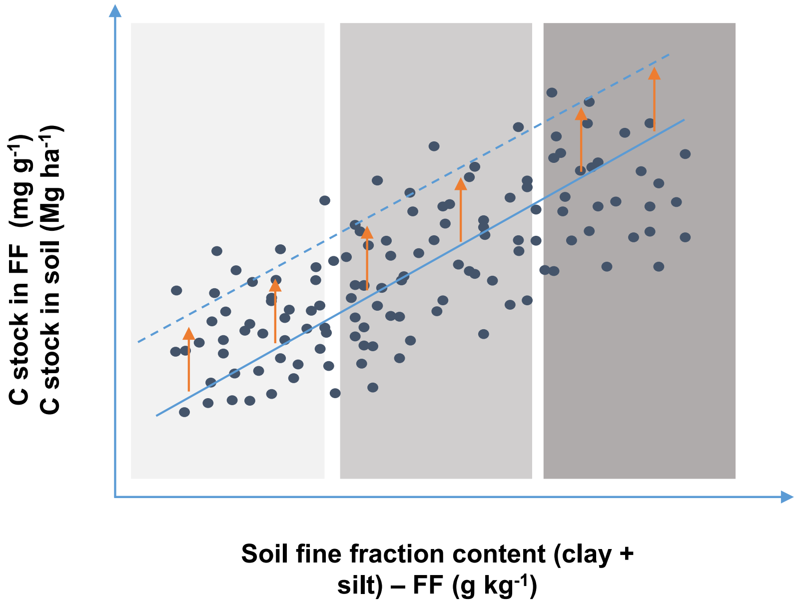
The potential for carbon accumulation or storage in soils in agroecosystems is difficult to estimate, considering that these environments can store more carbon than native vegetation, which is often used as a storage reference in carbon sequestration projects.

The concept of reachable soil carbon (C-att) (Ingram; Fernandes, 2001) has been adopted as the soil's capacity to gain carbon if carbon input is unrestricted, and plant and soil management increases carbon flow and stabilization in the finer soil fractions. In other words, the concept implicitly implies the upper limits that certain soils and land use/ land cover (LULC) classes can achieve through the adoption of better management practices. In other words, soils with low carbon stocks, smaller than those considered "reachable", would provide greater opportunities for carbon sequestration.

The term "reachable carbon" is associated with the finest soil fraction (<60 µm or 0.060 mm), also called mineral-associated organic matter (MAOM) (Cambardella; Elliot, 1992; Six *et al.*, 2002; Cotrufo *et al.*, 2019), which is the fraction of soil organic matter where most of the soil carbon stock is found (Feller and Beare, 1997; Cotrufo *et al.*, 2019). Therefore, the same approach by Karunaratne *et al.* (2024) was used in the present study to estimate the reachable carbon deficit in the soils of Rio de Janeiro state.

According to this approach, the difference between the carbon stock (Mg ha^{-1}) in a given land use and its 90^{th} percentile for the state's different administrative regions illustrates the reachable carbon deficit, which indirectly expresses the soil's carbon sequestration potential, and can be used to guide efforts and policies aimed at increasing the stock of this natural asset and fostering markets or other mechanisms for economic compensation (Giorgiou *et al.*, 2022; Karunaratne *et al.*, 2024). Given the limitations of the adapted methodology and the dataset used, it is worth noting that the C-att value defines only a threshold value, not the carbon saturation point for the state's soils. In other words, higher stock values can be achieved in different regions.

FIGURE 1. Theoretical relationship between total organic carbon stock (Mg ha^{-1}) or carbon stock in the fine fraction (FF) of the soil (mg g^{-1}) (y-axis), and the FF (clay + silt) content of the soil (g kg^{-1}) (x-axis)



The solid and dotted lines indicate the overall relationship between the soil FF content and the current organic carbon stock (solid line), and reachable organic carbon stock (dotted line). The reachable carbon stock deficit is indicated by the orange arrows.

Source: Adapted from Karunaratne *et al.* (2024).

The 90th percentile, adopted as a theoretical reference, demonstrates, for each administrative macro-region, the reachable for each LULC class (in this case, pasture and forest formation) representative of the region. Although a recent concept, derived from studies that consider finer fractions of soil organic matter (Karunaratne *et al.*, 2024), it clearly illustrates that soil carbon stocks can be increased to certain real values, in a more viable accumulation scenario, both in time and space. Table 1 summarizes the descriptive statistics of the soil carbon stock (0-50 cm) and provides an estimate of the reachable carbon deficit per hectare and the carbon sequestration potential for each region of the state.

TABLE 1. Average and 90th percentile values of soil carbon stock (Mg ha^{-1}) at 0-50 cm in the main land use/land cover classes from the Brazilian National Forest Inventory in the state of Rio de Janeiro

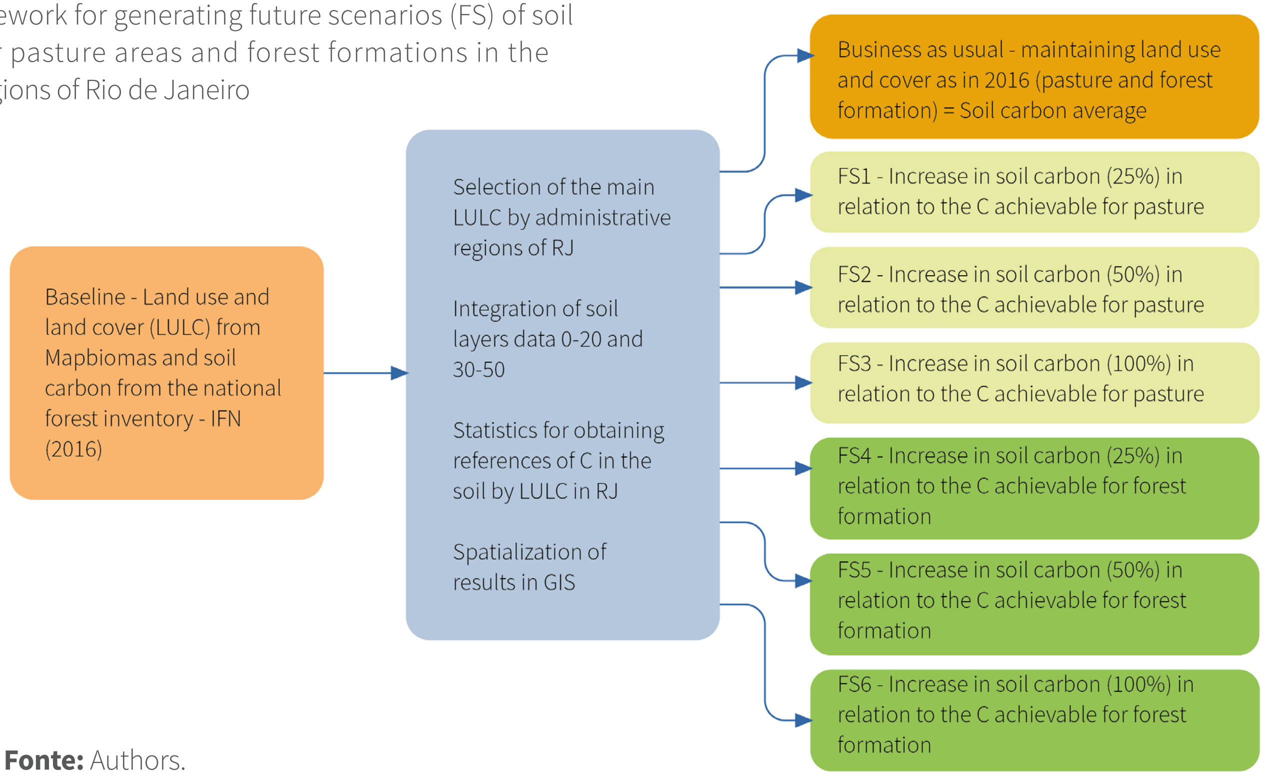
Region	Land use/land cover	Average C (baseline)	C at the 90th percentile (reachable C)	Sample size	Reachable C deficit	C sequestration potencial
Costal Low Lands	Forest formation	83,09	127,76	22	44,57	++
Costal Low Lands	Pasture	67,88	91,32	9	23,44	+
Central-South	Forest formation	91,24	195,25	10	104,01	+++
Southeast Coast	Forest formation	86,44	110,69	4	24,25	++
Metropolitan	Forest formation	87,30	114,46	14	27,16	++
Metropolitan	Pasture	60,13	90,03	4	29,90	++
Paraiba River Valley	Forest formation	103,27	126,85	15	23,58	++
North	Forest formation	99,46	166,56	17	67,10	+++
North	Pasture	84,62	144,81	14	60,19	+++
Northwest	Forest formation	107,01	194,56	7	87,55	+++
Northwest	Pasture	64,67	95,19	16	25,52	++
Uplands	Forest formation	115,61	184,33	19	68,72	+++
Uplands	Pasture	100,02	157,64	5	57,62	++

C sequestration potential (Reachable C deficit / 30 years): (+) 0.0-1.0 Mg ha^{-1} year^{-1}; (++) 1.0-2.0 Mg ha^{-1} year^{-1}; and (+++) 2.0 -3.0 Mg ha^{-1} year^{-1}.
Source: Authors.

3. SOIL CARBON STOCK SCENARIOS IN RIO DE JANEIRO: METHODOLOGICAL ASPECTS

Carbon stock values were measured via dry combustion in soil samples collected at 0-20 and 30-50 cm during the first phase of the NFI (SFB, 2018) in the Embrapa Soils laboratories. These data, together with a harmonized LULC map (MapBiomas, 2016) and maps of the administrative regions and municipalities of the state of Rio de Janeiro (CEPERJ, 2014), were used to generate soil carbon stock scenarios, as a function of LULC, for each administrative region of the state, considering their suitability and historical agricultural practice, according to the framework presented in Figure 2.

FIGURE 2. Framework for generating future scenarios (FS) of soil carbon stocks for pasture areas and forest formations in the administrative regions of Rio de Janeiro



Fonte: Authors.

Due to the methodology adopted by the Brazilian Forest Service, it was necessary to integrate the carbon stock values at 0-20 and 30-50 cm for the 0-50 cm layer, in Mg ha^{-1}, using the following equation:

C stock (0-50 cm) = [C stock (0-20 cm) + C stock (30-50 cm)] / 40 * 50

Using an Excel spreadsheet, the following were calculated: mean, minimum, 90^{th} percentile and number of points sampled in the NFI for the LULC class in each administrative region (n), based on the carbon stock data (0-50 cm) obtained in the 168 NFI sampling points, for each land use/land cover and administrative region. The result of this analysis supported the generation of the scenarios, as follows:

- Baseline C value for LULC classes and regions: the average carbon stocks (Mg ha^{-1}) for LULC classes and administrative regions, considered real stocks, that is, those that best represent the soil carbon stock values in the LULC classes in that region;

- Reachable C value for LULC classes and regions: the carbon stock values (Mg ha^{-1}) of the 90^{th} percentile of the most representative LULC classes in the NFI (forests and pastures), used as a reference for how much carbon can realistically be stored if good management and conservation practices are adopted; and

- Reachable C deficit for CUCTs and regions: difference between the reachable and the baseline C stock values, by CUCT and administrative region (the greater the difference between the baseline and reachable C stock for a given LULC, the greater the reachable carbon deficit, that is, the greater the soil carbon sequestration potential for that LULC and administrative region).

Using this data, it was possible to estimate scenarios for increasing soil carbon equivalent to 25, 50, and 100% of the carbon deficit up to the reachable C value. Again, these values define only a limit, not the carbon saturation value for the soils of Rio de Janeiro state, and can be considered conservative estimates of the carbon sequestration potential of Rio de Janeiro soils. Based on these estimated values, maps were derived for the following future scenarios (FS) for soil C stock:

- Business as usual: maintaining baseline soil C stock (average C stock) values in forest formations and pastures for 30 years;

- FS1: baseline (average) carbon stock + increase of 25% of the reachable carbon deficit in pastures in 30 years;

- FS2: baseline (average) carbon stock + increase of 50% of the reachable carbon deficit in pastures in 30 years;

- FS3: baseline (average) carbon stock + increase of 100% of the reachable carbon deficit in pastures in 30 years;

- FS4: baseline (average) carbon stock + increase of 25% of the reachable carbon deficit in forest formations in 30 years;

- FS5: baseline (average) carbon stock + increase of 50% of the reachable carbon deficit in pastures in forest formations in 30 years;

- FS6: baseline (average) carbon stock + increase of 100% of the reachable carbon deficit in forest formations in 30 years.

In addition, a complementary theoretical exercise was conducted, focusing on the state's deficit of Legal Reserve areas. To contribute to estimates of the potential for soil carbon accumulation through restoration actions, the difference between the baseline carbon stock values (in Mg ha^{-1}) of forest formations and pastures was calculated for each region, assuming the conversion from pastures with low productivity potential to forest. The potential for soil carbon accumulation in these converted areas, in Mg ha^{-1}, was then calculated for the conversion of 25% and 50% of the pasture areas in each region. The time required to achieve the reference values is approximately 20 to 30 years of restoration.

4. RESULTS AND DISCUSSION

In general, regardless of the administrative region, higher carbon stocks at 0-50 cm were observed in forest soils (~96.7 Mg ha^{-1}) than in

TABLE 2. Total soil carbon stock at 0-50 cm (Mg) by administrative region of the Rio de Janeiro state, in pasture and forest formations, estimated by the different scenarios

Region	LULC	C stock (Mg) - LULC x region (ha)								
		Area (ha)	C Business as usual (C average)	FS1	FS1	FS2	FS2	FS3	FS3	FS4
				Pasture	Pasture	Pasture	Pasture	Pasture	Pasture	Forest formation
				(25% of C achievable deficit)	(C average + 25% of C achievable deficit)	(50% of C achievable deficit)	(C average + 50% of C achievable deficit)	(100% of C achievable deficit)	(C average+ 100% of C achievable deficit)	(25% of C achievable deficit)
Costal Low Lands	Forest formation	85.095,92	5.776.311,19							948.181,31
Costal Low Lands	Pasture	169.837,39	11.528.562,00	995.247,10	12.523.809,10	1.990.494,21	13.519.056,21	3.980.988,41	15.509.550,41	
Central-South	Forest formation	89.829,35	8.196.029,77							2.335.787,63
Southeast Coast	Forest formation	169.216,04	14.627.034,87							1.025.872,27
Metropolitan	Forest formation	211.661,93	18.478.086,15							1.437.184,47
Metropolitan	Pasture	172.053,45	10.345.574,21	1.286.099,57	11.631.673,78	2.572.199,14	12.917.773,35	5.144.398,29	15.489.972,50	
Paraiba River Valley	Forest formation	205.639,64	21.236.406,18							1.212.245,71
North	Forest formation	123.496,55	12.282.967,24							2.071.654,69
North	Pasture	478.299,19	40.473.677,66	7.197.207,09	47.670.884,75	14.394.414,19	54.868.091,85	28.788.828,39	69.262.506,05	
Northwest	Forest formation	66.372,10	7.102.571,31							1.452.738,34
Northwest	Pasture	408.099,30	26.391.781,70	2.603.673,53	28.995.455,23	5.207.347,06	31.599.128,76	10.414.694,13	36.806.475,83	
Uplands	Forest formation	300.763,55	34.771.274,71							5.167.117,89
Uplands	Pasture	240.792,07	24.084.022,80	3.468.609,76	27.552.632,56	6.937.219,53	31.021.242,33	13.874.439,05	37.958.461,85	

pasture soils (~78.9 Mg ha^{-1}), demonstrating the importance of forest preservation and restoration not only for carbon conservation and biodiversity, but also for other ecosystem services provided by forests, including food and fiber production, nutrient cycling, and water regulation. These results are corroborated by other authors (Vieira *et al.*, 2011; Gomes *et al.*, 2014), who demonstrate that typic forested biomes store more carbon in the soil than other land uses.

On the other hand, both pastures and other LULC provide higher carbon sequestration rates if good agricultural and management practices are planned in a coordinated manner and properly executed. It is noteworthy that Assad *et al.* (2013) reported, in a meta-analysis carried out on pastures in the Atlantic Forest biome, for the 0-30 cm layer, carbon stocks compatible with those found in the present study of 50 Mg ha^{-1}.

Continuation - C stock (Mg) - LULC x region (ha)				
FS4	FS5	FS5	FS6	FS6
Forest formation	Forest formation	Forest formation	Forest formation	Forest formation
(C average + 25% of C achievable deficit)	(50% of C achievable deficit)	(C average + 50% of C achievable deficit)	(100% of C achievable deficit)	(C average + 100% of C achievable deficit)
6.724.492,50	1.896.362,62	7.672.673,81	3.792.725,25	9.569.036,44
10.531.817,40	4.671.575,27	12.867.605,04	9.343.150,55	17.539.180,32
15.652.907,14	2.051.744,54	16.678.779,41	4.103.489,07	18.730.523,94
19.915.270,62	2.874.368,96	21.352.455,11	5.748.737,91	24.226.824,06
22.448.651,89	2.424.491,42	23.660.897,60	4.848.982,84	26.085.389,02
14.354.621,93	4.143.309,38	16.426.276,62	8.286.618,75	20.569.585,99
8.555.309,65	2.905.476,68	10.008.047,99	5.810.953,36	12.913.524,67
39.938.392,60	10.334.235,78	45.105.510,49	20.668.471,57	55.439.746,28

Source: Authors.

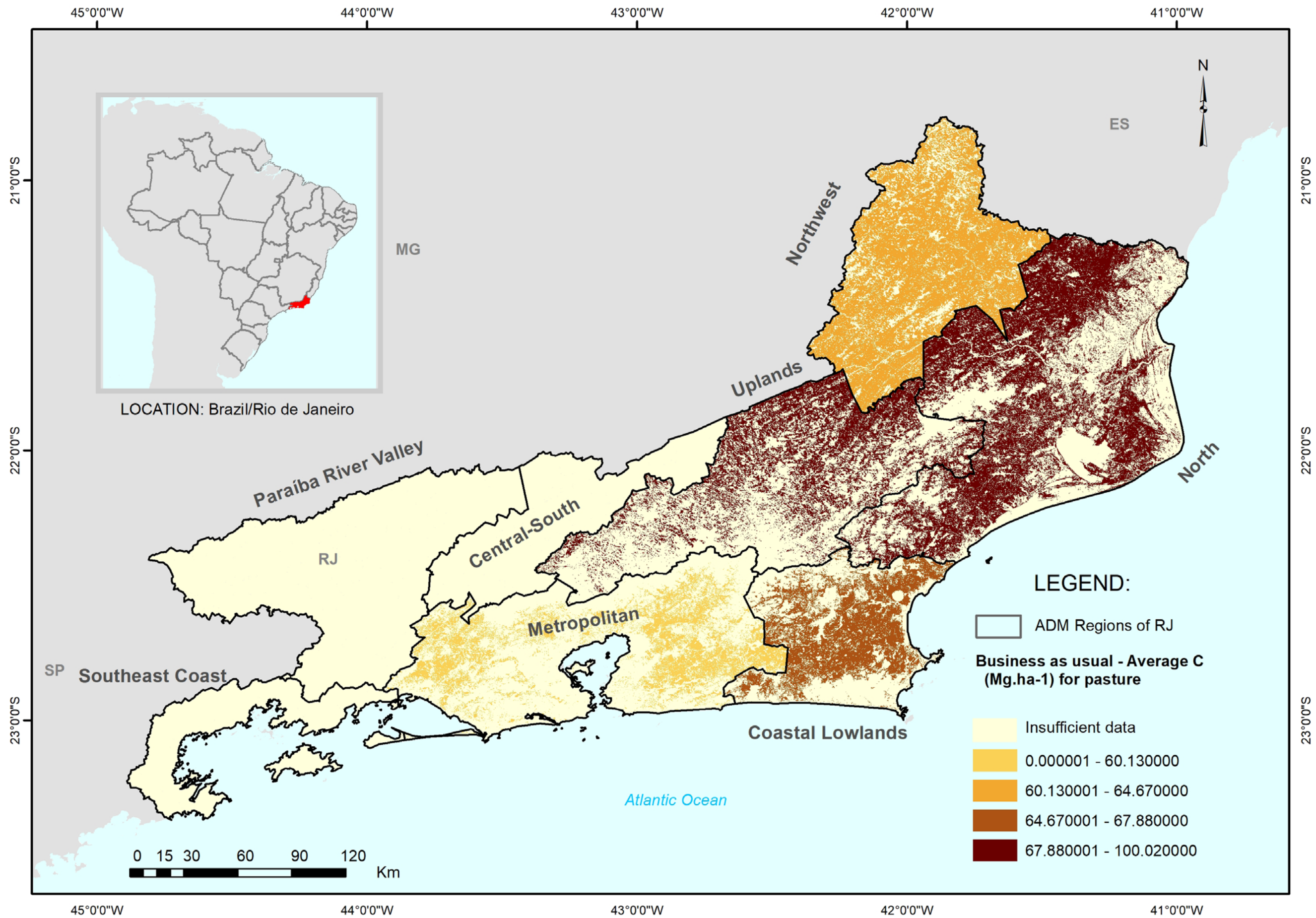
According to the proposed scenarios FS1, FS2 and FS3, of increases of 25, 50 and 100%, respectively, of the reachable C deficit in pastures, the carbon stocks of the state's pastures can be increased by 13.57 to 54.26 Tg (million tons) (or 49.66 to 198.60 Tg CO2eq) through the adoption of good soil management and conservation practices, as well as the integration of livestock systems with crops and forestry components in the regions of Costal Lowlands, Metropolitan, North, Northwest and Uplands, where data were available for the estimates. On the other hand, the soil C increases in forest formations for all regions of the state were estimated from 15.65 Tg (increase of 25% of the C-att deficit) to 62.60 Tg (100% of the C-att deficit), made possible by the adoption of efficient forest restoration techniques, such as active or assisted restoration, resulting in multiple benefits, both for biodiversity conservation and soil carbon sequestration.

The results show that the regions with the largest reachable carbon deficits and, therefore, the greatest potential for carbon accumulation, under pastures, are the North region (with 53% of the state's potential), followed by the Uplands (25%) and Northwest (19%) regions. The regions with the greatest potential for carbon gain in forest formations areas are the Uplands (33% of the estimated total), the Central-South (15%), and the North (13%) regions. These results are consistent with the history of intense land use in these regions. However, the lack of sampling points under pastures in the Paraíba River Valley, Southeast Coast, and Central-South regions limited applying the scenarios of soil C increase in pastures in these regions.

Figure 3 presents the maps of the soil C stock baselines for pasture and forest formations, respectively, and under the six future scenarios (FS1 to FS6), indicating the regions where the greatest and smallest soil carbon gains could occur in pasture and forest formation areas. Such scenarios could come true if good agricultural and livestock practices, soil and water conservation policies, and economic incentives were included as cornerstones in the the state's agro-environmental planning. The color intensities in the different regions highlight what was previously mentioned: the North, Northwest, and Uplands regions have the greatest potential for carbon sequestration in pastures should they be better managed or combined with crops or tree plantations; and the more central regions, such as Uplands and Central-South, have high potential for soil carbon gain in forest formations through assisted or active restoration.

It is important to emphasize that the government has a duty, through its public policies and incentives, to support rural producers in building sustainable rural landscapes throughout the Rio de Janeiro state. In this context, the increase in soil carbon stocks in Rio de Janeiro, as envisioned in this document, will be associated with the provision of multiple ecosystem services by the soil. Carbon sequestration is just one of them, and producers can also benefit from the C credit market if they find it interesting. Undoubtedly, those farmers who already practice regenerative agriculture or livestock farming, and whose farms have soils with high levels of organic matter should receive economic or fiscal incentives for continuing managing their soils sustainably, avoiding the loss of stored carbon, benefiting the society as a whole.

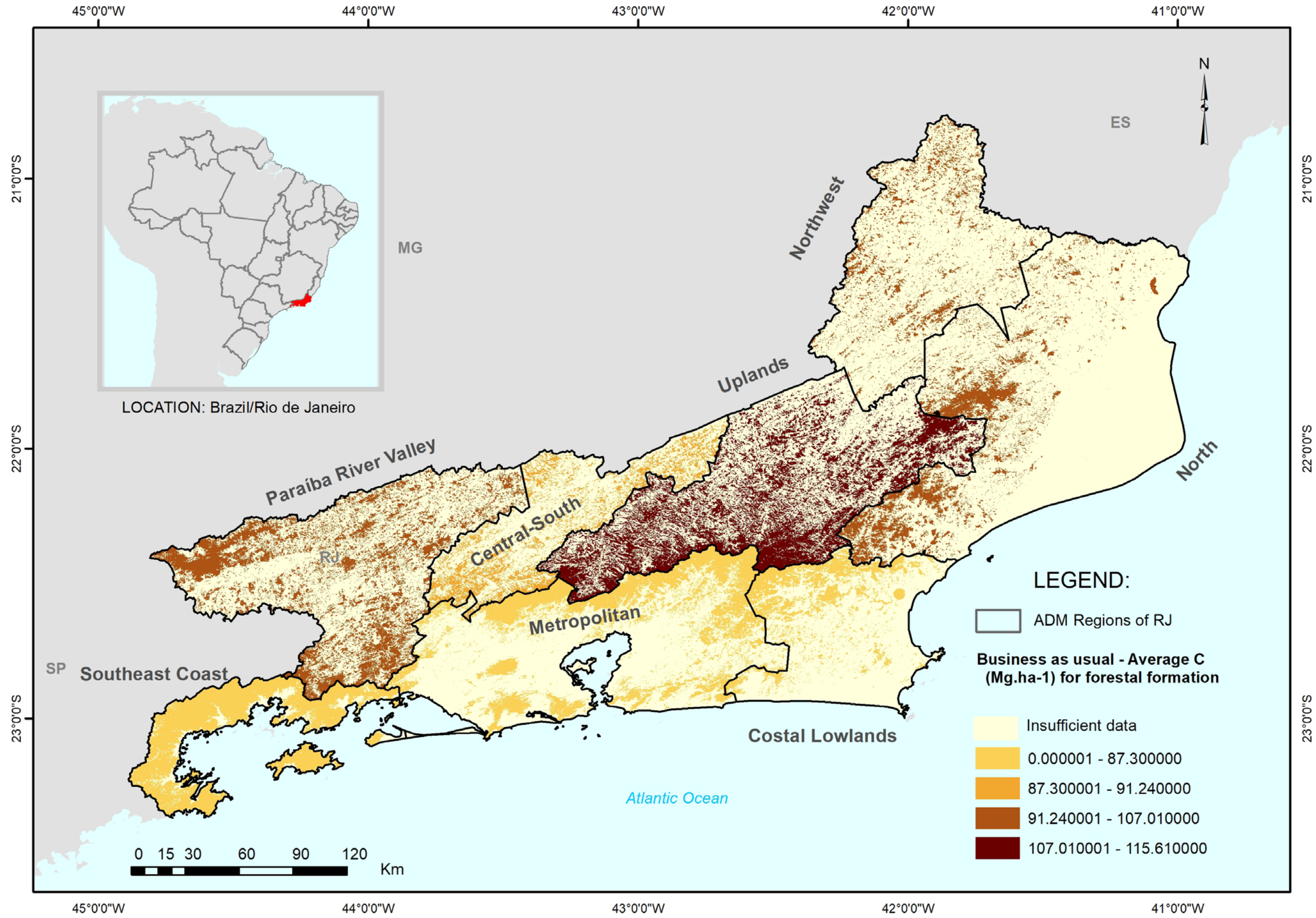
FIGURE 3A. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(A) - BusinessP

Source: Authors.

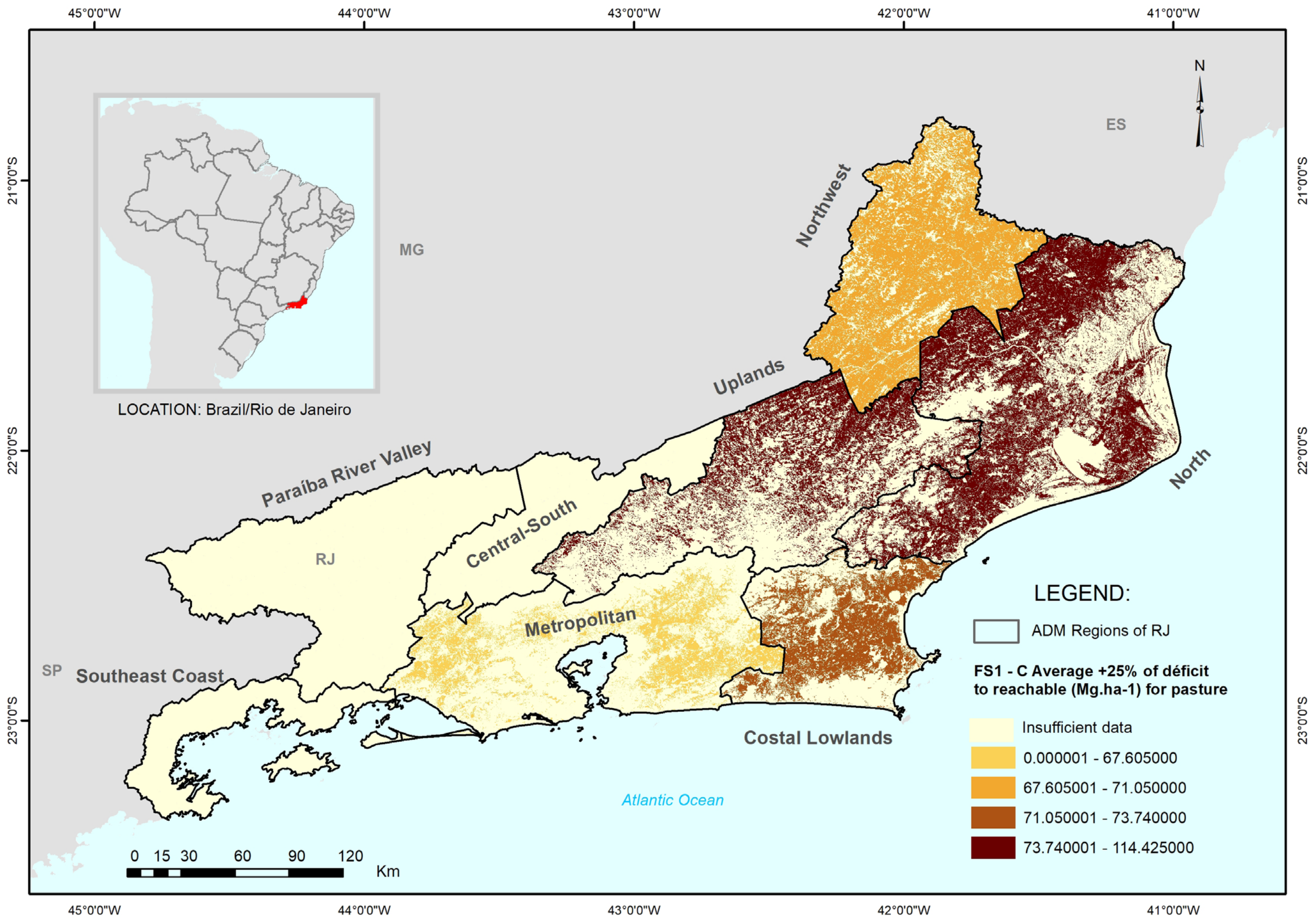
FIGURE 3B. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(B) - BusinessF

Source: Authors.

FIGURE 3C. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)

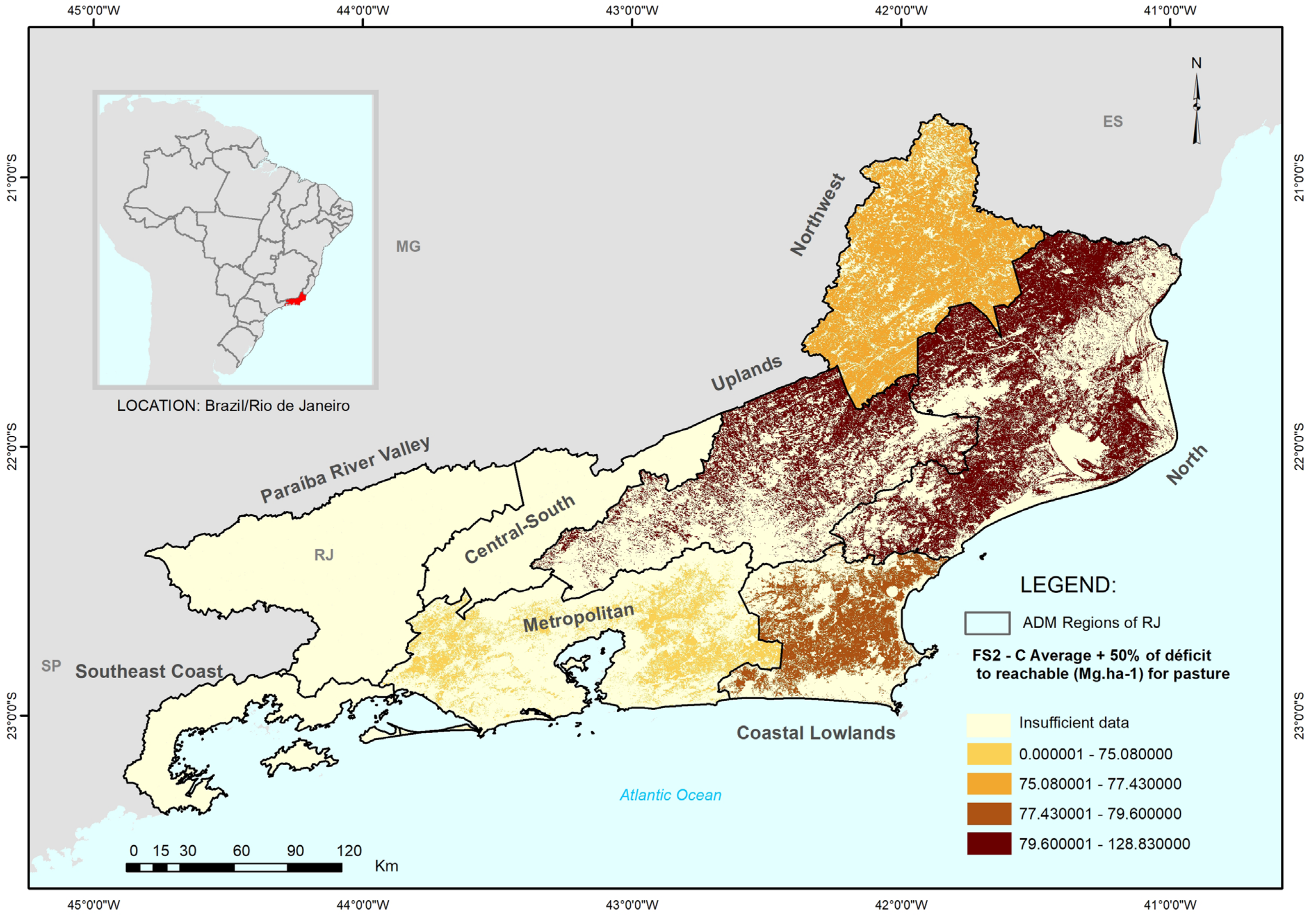


(C) - FS1

Source: Authors.

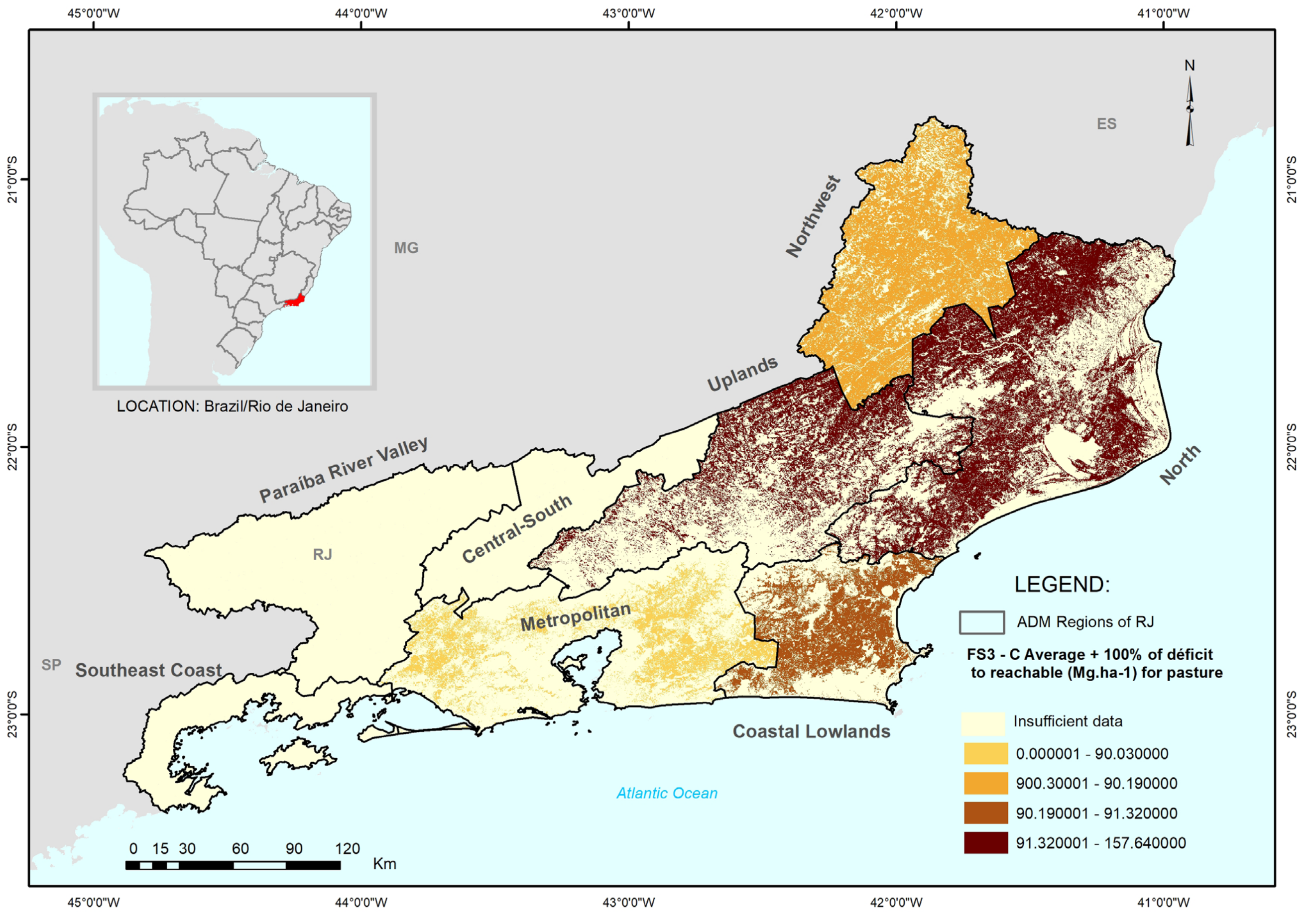
FIGURE 3D. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)

(D) - FS2



Source: Authors.

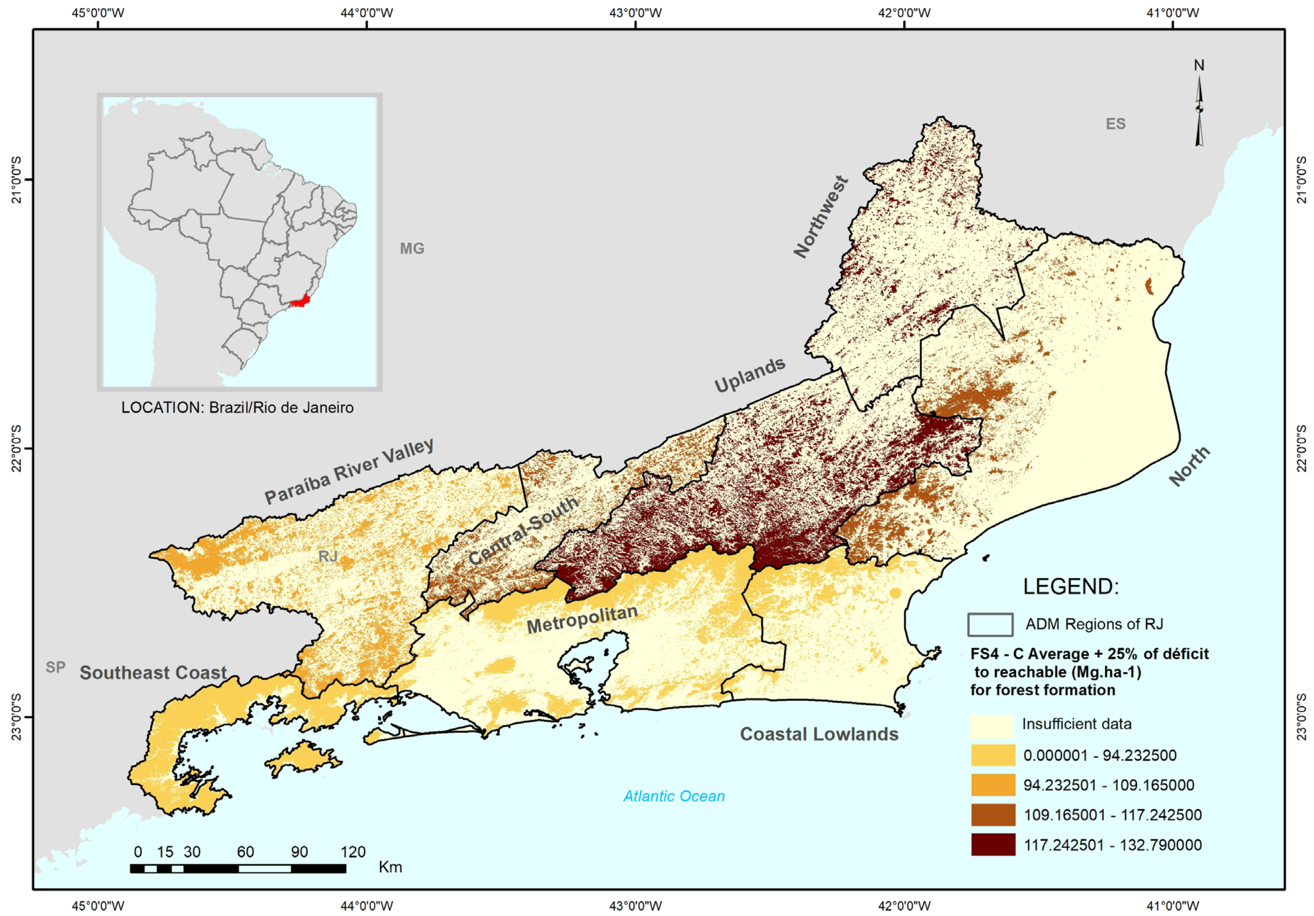
FIGURE 3E. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(E) - FS3

Source: Authors.

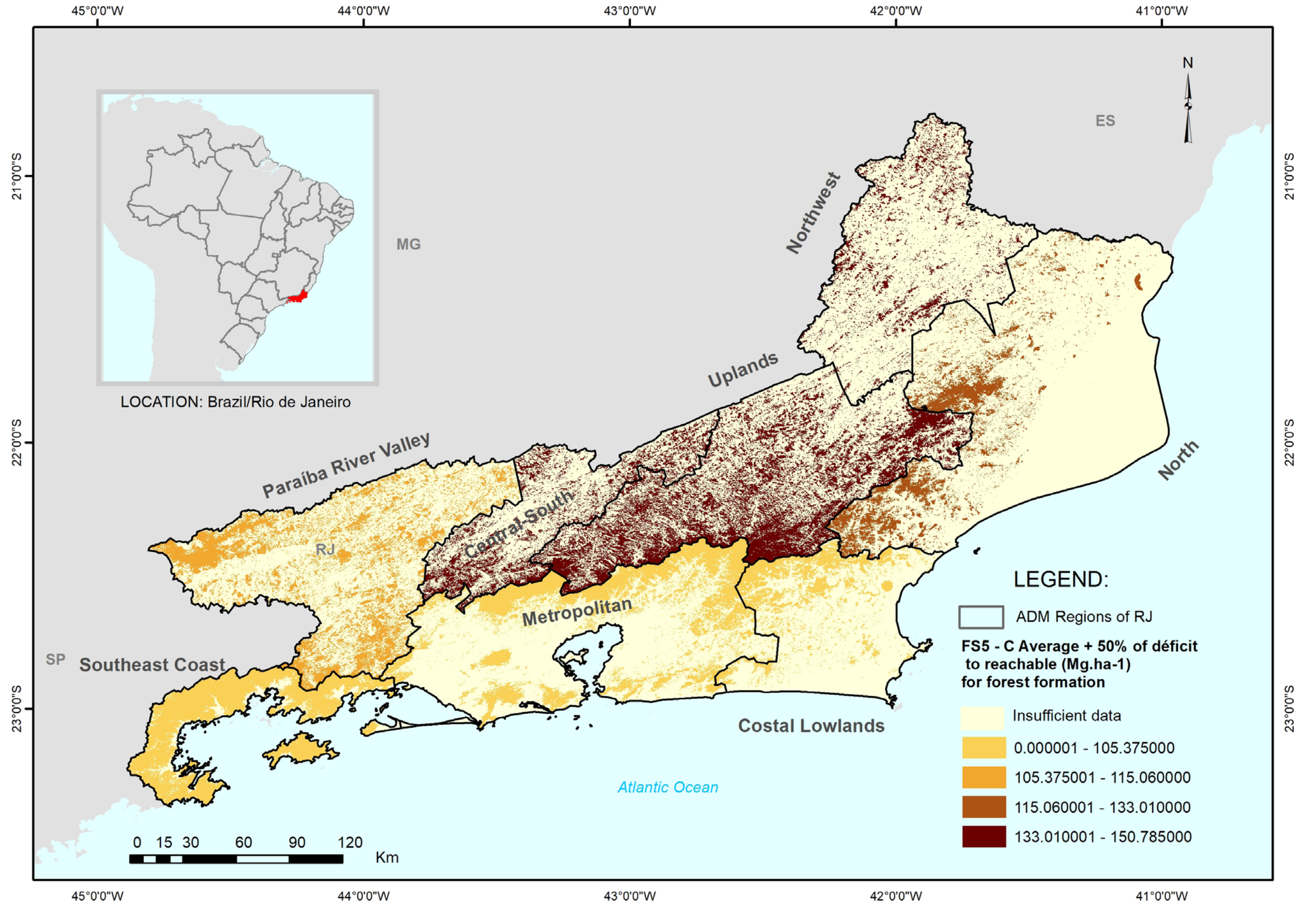
FIGURE 3F. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(F) - FS4

Source: Authors.

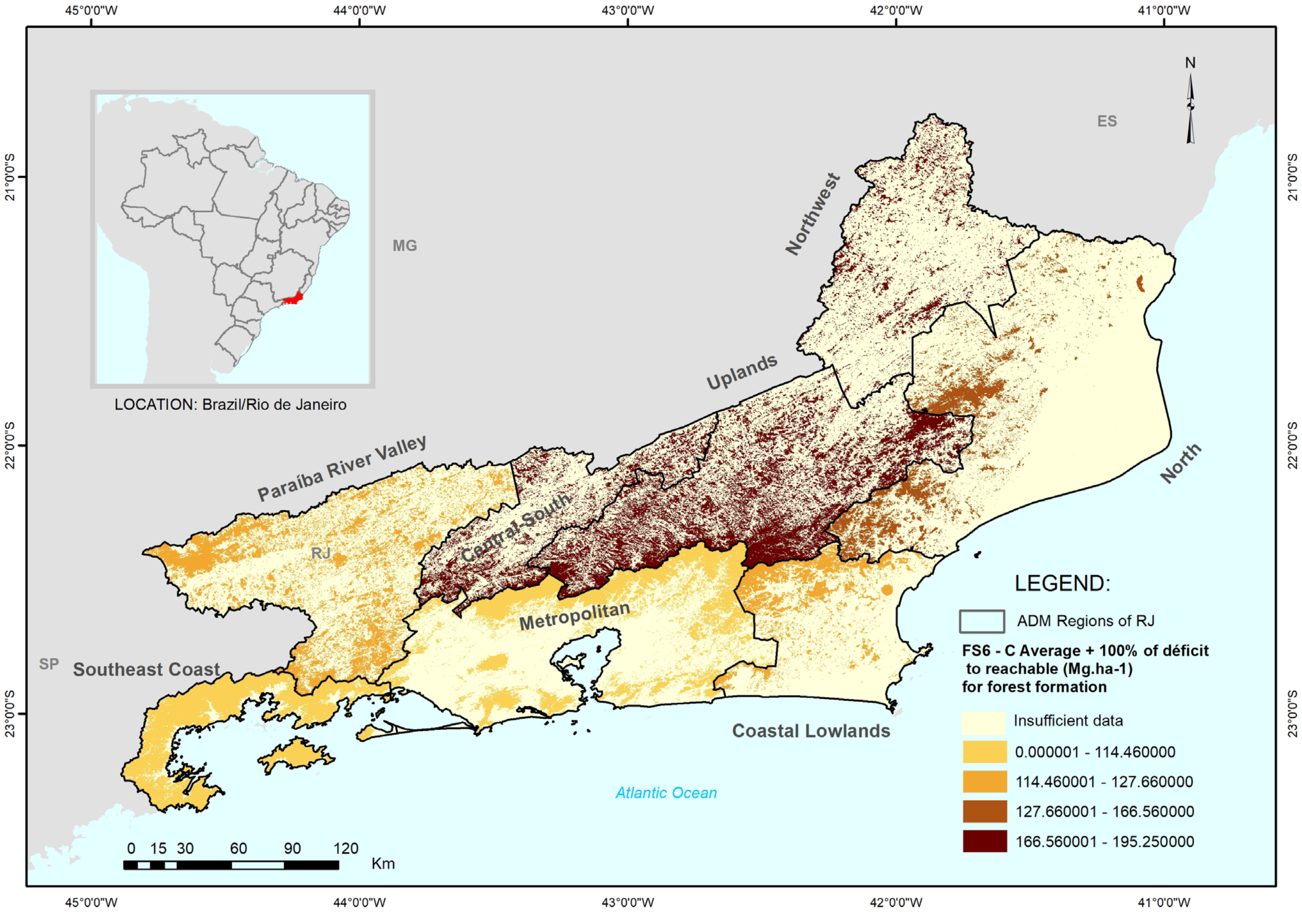
FIGURE 3G. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(G) - FS5

Source: Authors.

FIGURE 3H. Future soil C stock scenarios for the administrative regions of Rio de Janeiro state: Business as usual (C stock baselines ~ average C stocks) for pastures (A), and forests (B); C stock baselines (average C stocks) + increases of 25 (FS1), 50 (FS2), and 100% (FS3) of the reachable carbon deficit in pastures (C, D, and E, respectively); and C stock baselines (average C stocks) + increases of 25 (FS4), 50 (FS5), and 100% (FS6) of the reachable carbon deficit in forest formations (F, G, and H, respectively)



(H) - FS6

Source: Authors.

5. EFFORTS TO INCREASE SOIL CARBON STOCKS IN RIO DE JANEIRO STATE

Rural property planning is the foundation for building sustainable landscapes, increasing soil organic matter levels, and, consequently, increasing the supply of soil ecosystem services. The principles of sustainable, conservation, agroecological, or regenerative agriculture are widely known and should form the foundation for building healthy soils with high levels of organic matter. Practices such as contour planting, crop rotation or intercropping, no-till farming, green manuring, and integrated pest and waste management should be incorporated into Rio de Janeiro's production systems, regardless of the region.

Establishing a relationship of trust with farmers and local and state governments is essential to establishing and consolidating compensation mechanisms for sustainable land use in Rio de Janeiro, including C offset markets. Some challenges to consolidating soil carbon-based offset markets include: i) the lack of regulations at different levels; ii) scattered and contradictory information in the academic and non-academic literature, which often hinder rather than contribute to the discussion on carbon market regulation; iii) inadequate project timelines, which inspire distrust in both sellers and buyers; iv) the lack of information and training on the topic; v) inefficient communication among stakeholders; and vi) the difficulty of operationalization, and the high cost of monitoring and certifying soil carbon gains.

Furthermore, the production decline in rural areas, resulting from the low level of productivity, the difficulty in accessing technical assistance and rural extension, and the limited financial and marketing support, will require joint efforts in various spheres in favor of establishing a new development model for these areas (Vidal *et al.*, 2020).

Multi-activity, with incentives for developing specific niches (such as housing for leisure, rest, and rural tourism), the production of value-added goods (organic and artisanal), and traditional productive activities (community- and family-based), can also benefit from the different compensation mechanisms for the conservationist use of soil, forests and biodiversity, with gains that extend to the entire society, going beyond the limits of the rural landscape.

Public policies, such as the Brazilian Low Carbon Agriculture Plan (Plano de Agricultura de Baixo Carbono), Organic Agriculture Program (Programa de Agricultura Orgânica), and National Water Resources Policy (Política Nacional de Recursos Hídricos), as well as environmental (or economic) compensation mechanisms that support farmers who adopt sustainable production practices, with favorable credit conditions or in the form of compensatory incentives, must be aligned with social demands and conducted with the least political interference.

To this end, and to overcome these challenges, the State Secretariat for Environment and Sustainability (Secretaria de Estado de Ambiente e Sustentabilidade), the State Secretariat for Agriculture, Fisheries, and Supply (Secretaria de Estado de Agricultura, Pesca e Abastecimento), and the Technical Assistance and Rural Extension Company of Rio de Janeiro (Empresa de Assistência Técnica e Extensão Rural do Rio de Janeiro) are working collaboratively to develop the Agroecological Transition Assessment Instrument (Instrumento de Avaliação da Transição Agroecológica). This instrument brings together a set of methodological tools to characterize and classify the different phases of the agroecological transition of agroecosystems in the Rio de Janeiro state, enabling the development of a participatory transition plan, developed by the Social Nucleus for Agroecosystem Management

(Núcleo Social de Gestão do Agroecossistema) and the team of extension workers responsible for monitoring the transition (SEAS, 2025). These actions are supported by the following legal instruments:

1) Technical Note SEAS/SEAPPA/EMATER-RIO n. 01/2024, instrument for assessing the agroecological transition (IATA) and preparing the agroecological transition plan in agroecosystems within the state of Rio de Janeiro (Rio de Janeiro, 2024);

2) Joint Resolution SEAPPA/SEAS/EMATER-RIO/INEA n. 16, of November 26, 2024, which establishes criteria and procedures for recognizing agroecological transition in the production unit, and establishes a methodology for classifying the transition phases of agroecological production in agroecosystems within the state of Rio de Janeiro (Rio de Janeiro, 2024).

Along these lines, the State Secretariat for Agriculture, Fisheries, and Supply and the ILPF Network (Crop-Livestock-Forest Integration Network), a public-private entity, signed a Memorandum of Understanding in May 2025 to strengthen sustainable agriculture in the state of Rio de Janeiro through the implementation of integrated, low-carbon production systems. The work plan outlined in the Technical Cooperation Agreement will involve several teaching, research and extension institutions in the state, as well as state decision-makers, and include technical training, technical dissemination events, territorial assessments, and scientific research focused on the state's needs.

Finally, the capacity and potential of conservation agriculture for improving soil health and, consequently, productivity, including enabling the delivery of multiple ecosystem services, are noteworthy. Rio de Janeiro's soil has the capacity to store significant amounts of carbon, as demonstrated by robust estimates generated from real data collected using a consistent sampling and carbon analysis methodology.

Embrapa Solos will continue working with the NFI samples to obtain more accurate estimates of reachable carbon in the different regions of the state. The data from the first NFI phase obtained so far already provide a regional overview of the potential of agriculture and the forestry sector to sequester carbon in the soil in the context of the farmers' adaptation to climate change, recognizing the externalities generated in the field by the adoption of conservation and sustainable practices. The carbon stored in the soil, resulting from good production and soil conservation practices, will certainly increase the farmers' resilience in the face of ongoing climate change, and benefit the both rural and urban populations through the multiple goods and services generated on their farms.

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