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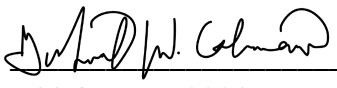
Signed: 

Date: 11 January 2021

A Soil History of the Brazilian Atlantic Forest Biome

Gabriel Coleman

HI7311: The Making of Brazil: An Environmental History

11 January 2021

Introduction

The only people allowed to use the word "dirt" are farmers and soil scientists. At least, that's what I've been told by the farmers and soil scientists I've known. It's a joke of course, but there's truth to the idea that those who don't work with soil are prone to discount its value. *Dirt* is something to be kicked off of shoes and swept out of doors, something to avoid contact with unless its covered by clean grass or comes in a plastic bag. But *soil* is something different entirely: a multispecies medium of chemical communication and a foundational component of life on Earth.

This paper is concerned with the role of soil over the history of Brazil's Atlantic Forest biome. Stretching along Brazil's coast from the Rio Grande do Norte to Santa Catarina, the Atlantic Forest is considered one of the world's hottest biodiversity hotspots due to the sheer number of species endemic to the biome.[1] However, the Atlantic Forest is greatly reduced from its pre-colonial state, taking up only 28% of its former footprint with 91% of what remains being highly fragmented.[2]

Focusing on the soil of the Atlantic Forest allows us to move between different time scales. *Dirt* is often seen as static: brown stuff that holds vegetables while they grow and keeps trees standing upright while they give us shade. But *soil* is dynamic, a translation matrix, where earthworm time, mushroom time, tree time, and human time meet and reconcile. As we will explore, soil can be built by moisture and temperature fluctuation over centuries or by

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[1] Chaer, G. M. et al. "Nitrogen-Fixing Legume Tree Species for the Reclamation of Severely Degraded Lands in Brazil." *Tree Physiology* 31, no. 2 (2011): 139.; França, E. J. De et al. "Atlantic Forest: A Natural Reservoir of Chemical Elements." *Journal of Radioanalytical and Nuclear Chemistry* 276, no. 1 (2007): 221.

[2] Zanini, Anani Morilha et al. "The Effect of Ecological Restoration Methods on Carbon Stocks in the Brazilian Atlantic Forest." *Forest Ecology and Management* 481 (2021): 2.

macrofauna in years, nutrients from the soil can be immobilized in trees for decades and then reintroduced by fire in hours. Even humans relate to soil on different time scales: sometimes we take from the soil only what will allow it to sustain the next seven generations and other times we extract as much as we can for a quick monetary payoff.[3]

Soil Community

Soil is made up of aggregates: bound together clusters of sand, silt, clay, organic matter, and microorganisms.[4] Aggregates can either be physiogenic: formed by physical forces like fluctuations in moisture and temperature over long periods of time, or biogenic, formed by plants, animals, and fungi over a shorter time period.[5] The underlying bedrock of the Atlantic Forest biome is highly weathered, and low in nutrients, meaning that biogenic aggregates have played an important role in the provision and cycling of nutrients for the forest's plant life.[6]

Plants, like all living things, need specific nutrients to build their bodies and survive. Macronutrients like carbon (C), nitrogen (N), phosphorous (P), and potassium (K), as well as micronutrients like calcium (Ca) and magnesium (Mg) are all essential for plant growth. Nitrogen in the form of N_2 is the most abundant element in the Earth's atmosphere, but in order for plants to make use of it nitrogen must be "fixed" in the soil as ammonia (NH_3), nitrates

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[3] Haudenosaunee Confedaracy. "Values." Haudenosaunee Confederacy. Haudenosaunee Confederacy, April 17, 2018. https://www.haudenosauneeconfederacy.com/values/.

[4] Frey, Serita D. "Aggregation | Microbial Aspects." In *Encyclopedia of Soils in the Environment*, 22–28. Amsterdam, Netherlands: Elsevier, 2005. 22.

[5] Silva Neto, Eduardo Carvalho da, et al. "Aggregate Formation and Soil Organic Matter under Different Vegetation Types in Atlantic Forest from Southeastern Brazil." *Semina: Ciências Agrárias* 37, no. 6 (June 24, 2016): 3928.

[6] Dean, Warren. *With Broadax and Firebrand: the Destruction of the Brazilian Atlantic Forest*. Berkeley, California: University of California Press, 2008. 9.; Silva Neto. 3933.

(NO^{-2}), or other organic compounds.[7] For this reason, soil nitrogen abundance is often the biggest determinant in plant growth and a key player in the Atlantic Forest's evolution.

Given the degraded nature of the present day Atlantic Forest, attempts to reclaim and restore its ecosystems to their precolonial state can illuminate the interspecies dynamics that developed the precolonial forest in the first place. Guilherme Montandon Chaer's study on the revegetation of degraded forest sites using leguminous trees points to one such dynamic. To compensate for the weathered quality of physiogenic soil aggregates, legumes and their interspecific partnerships must concentrate N and other nutrients in the soil, giving other biota the opportunity to take root in the burgeoning Atlantic Forest. Legumes are a family of plants that form partnerships with nitrogen fixing bacteria, called rhizobia, that live in nodules on their roots. These rhizobia are able to absorb atmospheric nitrogen and turn it into organic compounds able to be absorbed by the plant. Rhizobia almost always fix more nitrogen than their host plant can use which allows non-leguminous plants to benefit of this generative partnership.[8]

This resource sharing is aided by arbuscular mycorrhizal fungi which also often form relationships with legumes and other plant species. These fungi form networks of threadlike hyphae that can grow into a plant's roots, connecting it with other plants and parts of the soil. Arbuscular mycorrhizal fungi excrete acids to break down organic and inorganic matter into nutrients and move these nutrients, among other things, along their hyphae to share with other organisms along their network. Chaer finds that planting leguminous tree species inoculated with rhizobia bacteria and mycorrhizal fungi is effective at building soil and rebuilding forests.[9]

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[7] Markov, Sergei A. "Nitrogen Cycle." In *Salem Press Encyclopedia of Science*, 2019.
[8] Chaer. 139.
[9] Ibid. 140.; Tsing, Anna Lowenhaupt. *Mushroom at the End of the World: on the Possibility of Life in Capitalist Ruins, The*. Princeton, NJ: Princeton University Press, 2015. 138.

Eduardo Carvalho da Silva Neto's survey of soil aggregates corroborates this, finding higher percentages of biogenic soil aggregates with higher nutrient levels in advanced succession forests.[10] This plant/bacteria/fungi soil community could be seen as an ecosystem engineer, normally defined as a single species that drastically changes resource availability and physical composition of their environment.[11] Though this assemblage is not a single species, their collaborative action provides the base resources necessary to build the Atlantic Forest.

Forest Dynamics

As the Atlantic Forest expanded beyond its leguminous origins, the movement of nutrients through its increasingly diverse assemblage of inhabitants increased in complexity. Elvis Joacir de França captures this complexity by conceiving of the forest as a series of reservoirs or compartments. Nutrients are accumulated and moved between different compartments like the bodies of trees, leaf litter, understory plant biomass, and the soil itself. [12] In this system the soil is both a compartment itself and a transportation system where nutrients are transferred from one compartment to another. For instance, organic carbon and nitrogen that has been stored in a tree's biomass for decades could fall to the ground as leaf litter and then be consumed by an earthworm. Some of the carbon and nitrogen would be stored in the body of this earthworm for its lifetime and the rest would be introduced into the soil as the worm's castings which become biogenic soil aggregates. The majority of the carbon may remain stored in the

[10] Silva Neto. 3933.
[11] Cruz, Aline Pereira, et al. "Pre-Colonial Amerindian Legacies in Forest Composition of Southern Brazil." *Plos One* 15, no. 7 (July 23, 2020). 2.
[12] França, E. J. 221.

soil compartment, but the nitrogen could be absorbed by the roots of a different tree and stored in the compartment of its biomass.

Different compartments become greater stores of different nutrients. França's study finds that soil is a major reservoir of barium, iron, and potassium as well as other trace elements. Of the compartments Anani Morilha Zanini surveyed in various forest restoration projects, the soil compartment was the largest carbon sink. Eduardo Carvalho da Silva Neto adds to this finding, showing that organic carbon concentrations are proportionally lower in the soil of advanced succession forests due to the gradual transfer of carbon storage from the soil to the forest's increasing aboveground biomass.[13] When focusing on the relationships between the Atlantic Forest's various compartments the forest appears dynamic, with chemical nutrients cycling constantly from one compartment to another by way of soil. But when all the compartments are taken together the precolonial forest appears a vast reservoir, gradually accumulating vast stores of carbon, nitrogen, and trace elements in the increasingly complex relationships between its inhabitants.

The Atlantic Forest did not evolve without human input. When Pero Vaz de Caminha wrote of the indigenous people he encountered in the 16th century he described them as eating only "*inhame*… and those seeds and fruits that the earth and the trees give of themselves."[14] Caminha did not realize the degree to which indigenous people had shaped the Atlantic Forest to their benefit. Aline Pereira Cruz applies the ecosystem engineer label to the Southern Jê (Xokleng & Kaingang) and Guarani people for their outsized influence on the Atlantic Forest.

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[13] Ibid. 226.; Silva Neto. 3936.

[14] Caminha, Pero Vaz de, and Stuart B. Schwartz. "The Letter of Pero Vaz De Caminha." In *Early Brazil: a Documentary Collection to 1700*. Cambridge: Cambridge University Press, 2011. 6.

Pinhões, the edible seeds of the penhuén and Brazilian pine trees in the genus *Araucaria*, are culturally important to the Southern Jê who have inhabited parts of southern Brazil, Argentina, and Chile since around 4000 BP. These pine species thrive in disturbed landscapes, are able to regenerate from cut off roots and stumps, and are resistant to fire. Cruz finds that the arrival of the Southern Jê in Brazil corresponded with a expansion of *Araucaria* dominant landscapes over former grassland and concludes that the Southern Jê were the cause of this expansion, using fire as a disturbance mechanism. [15]

When a forest or a grassland burns, its aboveground biomass and all the nutrients and chemicals stored within it are returned to the soil, already partially broken down by the fire. The quick regeneration and fire resistance of pine species like *Araucaria* allows them to take advantage of this nutritional abundance before other species can recover after disturbance.[16] The Southern Jê made use of this dynamic to create the kind of forest structure that would allow them and their partner plant species to survive.

The Tupi, the people Caminha interacted with, had their own cultural subsistence species and their own methods of forest disturbance. The Tupi expanded from the Amazon through the Atlantic Forest and arrived in southern Brazil around 1800 BP.[17] As they traveled, they planted cassava (the *inhame* Caminha refers to), beans, maize, and genipapo. The Tupi burned patches of forest where they cultivated these crops, using fire to reintroduce the forest's accumulated biomass into the soil. Their habit of regularly moving camp would have allowed the forest land

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[15] Reis, Maurício Sedrez Dos, Ana Ladio, and Nivaldo Peroni. "Landscapes with Araucaria in South America: Evidence for a Cultural Dimension." *Ecology and Society* 19, no. 2 (2014).; Cruz. 3.

[16] Tsing discusses similar dynamics between lodgepole and ponderosa pines in the Cascade Mountains: Tsing. 200.

[17] Cruz. 2.

to lie fallow and recover somewhat before it was cleared and cultivated again.[18] Indeed, the habit of "allowing their gardens to become overgrown" that Brazilian statesman José Bonifâcio de Andrade e Silva saw as *indolence* is somewhat similar to the contemporary practice of growing cover crops to prevent soil erosion and reduce the loss of soil nutrients from cultivation.[19] The use of fire as a disturbance mechanism and introduction of culturally distinct food crops shows the Tupi and Southern Jê as ecosystem engineers of the precolonial Atlantic Forest. Caminha may have seen indigenous people as taking fruits "the earth gives freely," but the reality of the relationship was that these people were reaping the fruits of an interspecies landscape consciously co-created for their benefit.

Without claiming that indigenous Brazilians were perfect environmental stewards, it is important to note some important cultural distinctions between them and the European colonists. Maurício Sedrez dos Reis points out that the cosmology of the Mapuche, another tribe for whom *Araucaria* are central, is closely intertwined with the trees themselves: "the development of a forest begins with the contact of the roots of masculine and feminine plants, forming the new plants and protecting the families of the [Mapuche] people." This shows, as Reis claims, that the forest is "perceived as a biocultural unit" with the fate of the people being closely intertwined with that of the trees.[20] Similarly, in Huguenot Jean De Léry's record of a conversation with a Tupinamba elder, the elder draws a contrast between the extraction of brazilwood by the French with the Tupi land ethic: "We have kinsmen and children, whom, as you see, we love and

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[18] Richards, John F. *The Unending Frontier: an Environmental History of the Early Modern World*. Berkeley, CA: University of California Press, 2003. 397.
[19] Dean. 155.
[20] Reis. 42.

cherish; but because we are certain that after out death the earth which has nourished us will nourish them, we rest easy and do not trouble ourselves further about it."[21]

We can also contrast the environmental impacts of indigenous Brazilians and colonists in terms of nutrient cycling. The Southern Jê and the Tupi drastically changed the dynamics of nutrient cycling from one compartment to another: using fire to quickly return stored biomass to the soil and introducing new compartments in the form of their food crops and their own bodies. However, the cultures of these indigenous peoples and their systemic impacts remain in and of the forest. Taking all the compartments as an aggregate would show that the total chemical reservoir of the Atlantic Forest was not significantly depleted by the introduction of indigenous practices, and the forest remained an essentially closed system.

Brazilwood Salvage

The closed system of the Atlantic Forest was opened with the introduction of Portuguese and French merchants and the export of brazilwood. Brazilwood, called *ibirapitanga* by the Tupi is a dyewood that the Europeans recognized as similar to an Asian tree from the same genus.[22] The tree is a legume, and its tendency to grow in second growth forests, gaining a quick foothold on previously deforested land, hints at the strength of its nitrogen-fixing partnerships. Not only was Tupi knowledge important in European discovery of the properties of brazilwood, but their labor and knowledge of where brazilwood grew was essential in its extraction for the European market.[23] Anna Tsing refers to this as *salvage accumulation*, the incorporation of goods

[21] Léry, Jean de. *History of a Voyage to the Land of Brazil, Otherwise Called America*. Edited by Janet Whatley. Berkeley, CA: Univ. of California Press, 2006. 102.
[22] Dean. 45.
[23] Ibid. 46.

produced outside of capitalist control into capitalism.[24] Brazilwood trees were not planted or grown because they had exchange value, they grew as part of a secondary forest assemblage within the Atlantic Forest. The Tupi made use of brazilwood to dye cotton and may have even had a role in spreading it, but neither the dyewood or the cotton it dyed was exchanged for currency. Even the trade between Tupi laborers and European merchants occurred outside the market, bartering wood for steel tools and other goods.[25] It wasn't until ships loaded with brazilwood reached European ports that they were translated into the market, assigned a monetary value, and competed against Asian dyewoods and those coming in from other ports.

The salvage accumulation of brazilwood led to incredibly fast exploitation of the species. The first samples of brazilwood were brought to Portugal in 1501 and just one hundred years later in 1607 the market was strictly regulated with the tree on the edge of commercial extinction.[26] The exploitation of brazilwood also represented the first major breach of the Atlantic Forest's chemical reservoir. Brazilwood is not the only leguminous tree in the Atlantic Forest, but the almost complete elimination of a nitrogen-fixing species would clearly have had an impact on the health of the second growth forests and mutualistic soil communities the species was a part of. The salvaging of brazilwood by European markets also represents the first major drawdown of the Atlantic Forest's reservoir, removing significant amounts of biomass and an entire chemical compartment from the Atlantic Forest system. Though salvage accumulation takes place at the edges of capitalist systems, the exploitation of brazilwood was a harbinger of things to come, and the Atlantic Forest would not remain at the edge of capital for long.

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[24] Tsing. 63.
[25] Dean. 45-47.
[26] Dean. 46.

Cane Plantation

The species that brought capital into the very heart of the Atlantic Forest was sugarcane, *Saccharum officinarum*, a giant grass species native to the Ganges delta.[27] Like the Southern Jê and the Tupi before them, Portuguese colonizers brought their own culturally important species with them and shaped the Atlantic Forest around it. However, unlike these indigenous peoples the Portuguese did not grow cane for subsistence, they grew it to sell.

At the time, sugar was an expensive and popular commodity and Brazil was not the first European sugarcane endeavor. Attempts to grow cane in southern Europe were unsuccessful as it became apparent that cane needed a combination of moist nutrient dense soil, heat, and ventilation to thrive.[28] The first successful cane plantations were in Sao Tome and Madeira off the western coasts of Africa, but there were still difficulties. The high nutrient requirements of the grass meant that fields required regular nutrient input through the application of manure and the firewood necessary to boil cane juice into syrup was difficult to transport across the islands so crushed cane was burned instead. Because the methods used to crush cane and extract its juices was still rudimentary, this meant a lot of sugar, and by extension profit, was literally going up in smoke.[29]

The introduction of cane to Brazil in the 1540s marked a dramatic evolution of the sugar trade and the concept of the plantation.[30] As Ambróso Fernandes Brandão puts it in his descriptive dialogue advertising Brazil, the Atlantic Forest provided "plenty of good land to plant

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[27] Toussaint-Samat, Maguelonne. *A History of Food*. Chichester: Wiley-Blackwell, 2009. 496.
[28] Ibid. 496.
[29] Ibid. 501.
[30] Erasmo, São Jorge de, and Stuart B. Schwartz. "Excerpt from a Letter to the Administrator of Engenho." In *Early Brazil: a Documentary Collection to 1700*, 198–202. Cambridge: Cambridge University Press, 2011. 198.

cane on, enough water so that the press will never have to stop, and a quantity of wood in thick stacks of timber."[31] Fields were cleared using fire as the Tupi had done, reintroducing the nutrients stored in aboveground biomass into the soil. This sudden abundance of nutrients meant that manuring wasn't necessary and cane grew plentifully.[32] There was no need to burn crushed cane as the forest provided the vast amounts of timber needed to boil the cane juice down into syrup, and the sugar mills needed a lot, six palms by six palms by twelve palms per week according to João Fernandes Vieira's *Instruction on How to Manage a Sugar Mill and Estate*.[33]

Brazilian cane plantations were a huge economic success, ushering in what Maguelonne Toussaint-Samat calls "the era of the 'sugar standard,'" a two century period where cane syrup was used as an international currency, not only in colonies but around the world.[34] The Atlantic Forest had suddenly gone from the fringes of capital with the exploitation of brazilwood, to the place where money was minted in the canes of its sugar plantations. However, this incredible profitability would still not have been possible without the process of salvage accumulation.

The primary reason why Brazilian sugar was so profitable was not because of the land itself, but because the land was not assigned any value. The Portuguese crown freely granted parcels of land to would-be plantation owners in the form of *sesmaria*. There were no strings attached to these sesmaria, no requirements for specific cultivation or conservation behaviors, and grantees were free to request another sesmaria after the soil and timber on their previous one

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[31]Brandão, Ambrósio Fernandes, and Stuart B. Schwartz. "Great Things of Brazil." In *Early Brazil: a Documentary Collection to 1700*, 205–24. Cambridge: Cambridge University Press, 2011. 216.

[32] Dean. 56.

[33] Vieira, João Fernandes, and Stuart B. Schwartz. "Instructions on How to Manage a Sugar Mill and Estate." In *Early Brazil: a Documentary Collection to 1700*, 224–29. Cambridge: Cambridge University Press, 2011. 225.

[34] Toussaint-Samat. 502.

was exhausted. There were attempts at conservation efforts: José Bonifâcio de Andrade e Silva proposed a resolution that would require plantation owners to leave some forest fallow on each sesmaria and practice cultivation on the land, but it and similar proposals were generally ignored.[35] A report from Minas Gerias referenced in Warren Dean's *With Broadax and Firebrand* exemplifies this lackadaisical behavior, saying that "farmers practice no form of cultivation at all… do not install the requisite improvement on [lands] they possess and abandon them for whatever motives of fantasized convenience."[36]

This is another example of Tsing's salvage accumulation. The clearing of a plantation not only forms a rupture in the chemical reservoir of the Atlantic Forest, but neglects to assign the forest's chemical wealth any monetary value, since it was accumulated outside the capitalist system. The only difference between the cane plantation and brazilwood exploitation is that the point of translation has moved. Brazilwood became a commodity upon arrival at European ports, but with the importance of sugar syrup as an international currency, the salvaged soil fertility was translated into a commodity within the body of the cane plant itself. Both the sugarcane plantation and the cane plants became a machine or a sort of drill used to mine capital from the Atlantic Forest's biogenic aggregation.

The abundance of forested land made available for cane planting in the form of sesmarias created a constant labor shortage that required another salvaged source, enslaved people. The joint exploitation of African enslaved people and land brings us to Anna Tsing's construction of the plantation. The plantation, as Tsing conceives it, is based upon the alienation of human and nonhuman life from the interspecies communities to which they belong. Unlike leguminous

[35] Dean. 150.
[36] Ibid. 148.

brazilwood, sugarcane has no relationships with the fauna, flora, and soil communities of the Atlantic Forest, having been alienated from its indigenous landscape in south Asia. Likewise, enslaved people from Africa have no relationship to the land or the people around them other than the slave driver and the sugarcane. These simplified alienated relationships are, as Tsing puts it, *scalable*. Alienation reduced each cane plant and each human to an interchangeable unit in the machine of the plantation. If one unit fails, it can be replaced. If more cheap land becomes available, and the sesmaria system made sure more land would always be available, more units of labor and cane could be produced to increase the output of sugar, itself an interchangeable monetary unit.[37]

In discussing the riches of Brazil, Brandão depicts Portuguese colonists as taking sugar "from the bowels of the earth."[38] This depiction neatly illustrates the Brazilian plantation system from the perspective of the soil. Though the Portuguese system of burning forest to plant sugarcane seems at first to reflect the subsistence practices of the Tupi and the Southern Jê, there are some important differences. Where these indigenous practices focused on subsistence and co-dependance with the Atlantic Forest, the Portuguese system was based on sugar as a commodity and complete exhaustion of the forest's reservoir. Where the Tupi and Southern Jê created new landscape formations nested in and interfacing with the forest's interspecies assemblages, the colonists completely replaced the complex interdependent forest system with their own simplified and scalable plantation system. And where indigenous changes to the Atlantic Forest's nutrient cycling dynamics and system of compartments retained these chemical amassings within the larger reservoir of the forest, the plantation system's purpose was to draw down the forest's

[37] Tsing. 39.
[38] Brandão. 208.

chemical reservoir and use cane as a drill to extract biomass and soil nutrients in the form of commodity sugar to be traded on the global market. Foreshadowed by the exploitation of brazilwood, the introduction of sugarcane plantations to Brazil represents a significant rupture in the chemical reservoir of the Atlantic Forest.

Conclusions

Toussaint-Samat's era of the sugar standard lasted only 200 years, ending in the early 1800s when the [39]introduction of beet sugar caused sugar prices to plummet.[40] However, the legacy of sugarcane plantations continued to impact the Atlantic Forest. When the forest was used to grow coffee, the wisdom was to plant only on land previously occupied by "virgin" forest, despite the coffee plant's preference for shade.[41] The use of fire in clearing new fields and pastures continues as a practice in the region today. As Anna Tsing points out, the idea of the plantation, honed in the West Indies and Brazil's Atlantic Forest, lives on in the world today. Factories and modern agriculture systems were built using plantation blueprints and ideas of scalability and interchangeability through alienation are at the root of modern capitalism and ideas of progress.[42]

The Atlantic Forest lives on as well, in fragmented patches of secondary growth and in the soil which continually washes away into deepening gullies created by deforestation.[43] The threat of climate change has increased interest in restoring the Atlantic Forest as a carbon sink,

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[39] Santana, Romário O. De, Rafael C. Delgado, and Alexandre Schiavetti. "The Past, Present and Future of Vegetation in the Central Atlantic Forest Corridor, Brazil." *Remote Sensing Applications: Society and Environment* 20 (July 30, 2020). 2.
[40] Touissant-Samat. 504.
[41] Dean. 181.
[42] Tsing. 40.
[43] Chaer. 140.

and as necessary as that is, the forest's history calls for a deeper change than a reduction of atmospheric CO_2.[44] Focusing on soil complicates scalability and teaches complexity, asks us to look closer at the trees sitting in dirt soaking up carbon. A soil focus shows the bacteria, fungi, macrofauna, and understory plants that move and focus carbon and other nutrients essential to the healthy interconnected function of the biome. The soil of the Atlantic Forest rejects simple solutions which mirror the simplified plantation, the cause so much alienation and multispecies trauma. Soil, instead, invites us down to earth.

[44] Zanini. 6.

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