Opportunities and Challenges of Implementing Biodiversity Credits in the Coffee Supply Chain in the East Coast of Brazil using a Roadmap

A white paper for the private sector interested in investing in the preservation and conservation of biodiversity in coffee plantations in

This manuscript is the product of a collaboration that began at the São Paulo School of Advanced Science (SPSAS) on Co-designing Biodiversity Assessments, held in São Pedro, São Paulo, Brazil, from October 27 to November 8, 2024. We are grateful to SPSAS and to FAPESP for funding and hosting a school that brought together such a wide range of expertise in biodiversity science and policy, and for creating the space in which this project first took shape.

Abstract

As carbon credits have not been proven to effectively conserve biodiversity - despite their undoubted significance in carbon storage - there have been growing demands for a change in the system of crediting real biodiversity conservation. This white paper presents a structured guideline (= a roadmap) for implementing biodiversity credits into agricultural supply chains as a mechanism to support both ecological and economic resilience. To test the proposed roadmap on a real-world case, we focus on coffee producers in Brazil's Atlantic Forest, a global biodiversity hotspot. Coffee supply chains face various sustainability challenges (e.g., climate change vulnerability, market fluctuations, regulatory compliance), making them an ideal model for integrating biodiversity credits as a strategy to enhance resilience while maintaining economic viability.

The roadmap is divided into three phases, each one subdivided to ensure a scalable application of biodiversity credits. The first phase, the feasibility study, includes a global GIS analysis, stakeholder mapping, and activity identification. It begins with a global analysis to select potential coffee-growing regions, biodiversity threats, and key stakeholders, ensuring both economic viability and biodiversity gains. The second phase, in-situ development, involves engaging local stakeholders through a co-creation process, extensive GIS analysis, and methodology selection. This step ensures that conservation strategies are adapted to local conditions and that interventions, such as agroforestry or habitat restoration, contribute to both biodiversity gains and agricultural productivity. The third phase, implementation and monitoring, focuses on executing planned strategies, quantifying biodiversity improvements, and issuing biodiversity credits. To ensures that the issuance of credits is based on biodiversity gains, the monitoring must be rigorous from baseline to final sampling, with the aim of quantifying intervention success using scientifically validated methods. Looking for a measurable and genuinely co-creative process, we propose a peer-reviewed process in which the project will be validated by recognized scientists.

Overall, this white paper depicts a process leading to the issuance of biodiversity credits that represent ecological improvements linked with economic benefits, such as increased coffee yields and market value due to improvements in ecological services. The proposed approach allows to prioritize regions where biodiversity is at high risk and, being inherently spatial, enables results to be disaggregated and visualized at global, regional and local levels, showing trends over time for deforestation and land use change, which helps identify where action is needed for sustainability initiatives.

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Introduction

Nature's Economic Value and the Urgency of Nature-Based Solutions

Nature provides the essential foundation for our global economy and human well-being through critical ecosystem services, including pollination, carbon sequestration and storage, soil formation, air quality regulation, freshwater provision, and raw materials. However, this natural capital is rapidly depleting. Land degradation has already reduced productivity in 23% of global terrestrial areas (IPBES, 2019), while land-use change, primarily driven by agricultural expansion, has become the leading cause of nature loss. Most strikingly, agriculture is responsible for more than 90% of tropical deforestation (Pendrill et al., 2022), fundamentally threatening the ecological systems that underpin our economic stability.

The economic implications of this degradation are severe. The World Bank estimates that the loss of ecosystem services could result in a permanent global gross domestic product (GDP) loss of 2.3% or USD 2.7 trillion annually by 2030 if critical tipping points are crossed (World Bank Group, 2021). Furthermore, in 2023 alone, natural catastrophes caused $280 billion in economic losses globally, with the World Economic Forum ranking them as the top risk over the next decade. Yet, nature-based solutions (NbS) present a cost-effective opportunity for disaster risk reduction and climate change adaptation, with 71% of studies confirming their effectiveness (Howden & Pollinator, 2024). Nonetheless, the complexity of the global trade market and distance between final consumers and producers, represents a challenge for financing and implementing the NbS. For instance, the crops resulting from tropical pollination services are globally traded, making the Global North the main consumers of pollination services that need to be preserved in the tropics (Silva et al., 2021). This is why biodiversity credits are a way of linking both ends of the global trade (Wauchope et al., 2024).

The Financial Gap and Investment Landscape

The global community must mobilize at least $200 billion in additional annual funding for nature conservation and restoration by 2030 (Howden & Pollinator, 2024). According to the United Nations Environment Programme (UNEP), investment in nature needs to increase more than fourfold by 2050, from USD 154 billion to USD 674 billion annually. Currently, the public sector dominates nature-related investments (83%), with nearly half dedicated to protecting biodiversity and landscapes. Private sector participation remains minimal at 17%, primarily through sustainable supply chains and mandatory biodiversity offsets (Waldron et al., 2020).

This challenge is particularly acute in low-income nations, where approximately 60% are either at risk or already in debt distress, limiting their ability to protect biodiversity and respond to climate threats (World Bank Group, 2023). While policy on nature is primarily driven by government expenditure, there is significant potential for supplementation through private sector investment via Payment for Ecosystem Services (PES) and/or related carbon markets (Ruggiero et al., 2019).

There have been several initiatives in the private sector to close the financial gap, and they have been mainly driven by financial institutions that are interested in understanding the financial exposure of their investments to nature-related risks (Maney et al., 2024, see also the Nespresso Initiative). Institutional investors increasingly incorporate nature-related criteria into their investment decisions, guided by initiatives like Finance for Biodiversity or frameworks such as Nature Action 100. These initiatives outline six critical actions that companies must take to protect and restore ecosystems:

1. **Ambition**: Companies must publicly commit to minimizing nature loss drivers and actively engage in ecosystem conservation by 2030.
2. **Assessment**: Organizations need to disclose their nature-related dependencies, impacts, risks, and opportunities throughout their value chain, in alignment with Target 15 of the Global Biodiversity Framework (GBF).
3. **Targets**: Time-bound, science-based targets must be set, and progress must be reported annually.
4. **Implementation**: Companies should develop comprehensive plans prioritizing rights-based approaches, particularly in collaboration with Indigenous peoples and local communities
5. **Governance**: Board oversight of nature-related issues must be established with clear management roles.
6. **Engagement**: External stakeholder engagement should create an enabling environment for plan implementation.

Innovative programs like the National Plan for Native Vegetation Recovery (PLANAVEG) and the Productive Forests Program demonstrate how integrated approaches can simultaneously address biodiversity conservation, climate action, and social needs (The Food and Land Use Coalition, 2024). The success of initiatives like the Reflorestar Program in Espírito Santo, Brazil, which combines PES with technical assistance for family farmers, illustrates the potential for scalable solutions that benefit both nature and local communities. Moving into public-private partnerships, the recent launch of the Brazil Restoration & Bioeconomy Finance Coalition (BRB Finance Coalition) during the COP29 commits to invest $10 billion by 20230 in accelerating the conservation and restoration of Brazil's forests. It signals a growing recognition of the need for new partnerships to accelerate climate finance and investment.

Among other financial instruments for conservation mechanisms, biodiversity credits represent another alternative to close the financial gap and channel private investments towards nature-positive impact investments (Wauchope et al., 2024). There have been several global efforts to harmonize and standardized methodologies for assessing nature-positive impacts. The International Advisory Panel on Biodiversity Credits (IAPB) launched the framework for high integrity biodiversity credit markets during the COP16 in Colombia, while the Biodiversity Credit Alliance (BCA), a partnership facilitated by United Nations Development Programme (UNDP) and UNEP Finance Initiative (UNEP FI), has engaged with different key stakeholders (academics, civil society and Indigenous populations) and published extensive work in credit demand and market integrity. Biodiversity credits certify that an area contributes to conserving biodiversity and that result is durable and additional to what would have occurred if the area had been subjected to another type of use or management (Biodiversity Credit Alliance, 2024).

Thus, conserved and/or sustainably managed areas can generate biodiversity credits, as long as independent audits technically validate them. Credits can be any entity, private or public, capable of managing, measuring, and monitoring biodiversity. Biodiversity improvements can be measured in various ways, such as by comparing them to a reference site, a protected area with the same ecosystem and/or species of interest, to ensure that biodiversity levels have improved due to different actions implemented in the area (ISS, 2024). These credits are bought, raising funds that are returned to the biodiversity managers (e.g., the land owner), creating a sustainable cycle of funding for environmental conservation, removing barriers for businesses wanting to invest in nature (Biodiversity Credit Alliance, 2024). The biodiversity credits is an economic instrument that can unlock the opportunity for connecting companies` investments with the conservation and restoration of biodiversity and the ecosystem services that sustain the supply chain of global trades. The World Economic Forum (2023) states five interrelated ways in which such investment can deliver value to the companies:

1. **Quality assurance:** Support quality assurance for companies buying nature-based carbon credits, by delivering biodiversity benefits (if robust additionality rules are met);
2. **Sustainable access**: Enable companies to ensure sustainable access to ecosystem services such as pollination, flood protection and soil fertility;
3. **Corporate contribution:** Demonstrate a corporate contribution to the global goals set out in the GBF, which will help businesses build a positive sustainability reputation among employees, investors and customers;
4. **Sustainable products**: Allow companies to create products bundled with nature improvements that help meet customer demand for nature outcomes, while ensuring the sustainability of their products;
5. **Responsibility for impacts**: Take responsibility for biodiversity impacts that remain after taking measures in line with the mitigation hierarchy to “avoid, reduce, restore and regenerate”.

Biodiversity as a Cornerstone for Global Food Production

Biodiversity is declining dramatically worldwide (Dirzo et al., 2014; Wagner et al., 2021), with habitat loss due to land-use change being a major cause, impacting human well-being and global food security (Diaz et al., 2019). Pollinators are indispensable for the reproduction of over 80% of the world’s flowering plants (Ollerton et al., 2011) and 75% of crop species (Klein et al., 2009). It is estimated that between 200,000 and 350,000 animal species contribute to pollination, including birds, bats, marsupials, and butterflies (European Commission, European Red List, United Nations, 2019). Among these, bees play a critical role, with 5–8% of global crop production directly dependent on their pollination services (Aizen et al., 2009). For instance, in Brazil the contribution of pollinators was estimated at ~12 billion USD for 2015 (Giannini et al., 2015), with a potential crisis reducing 17 to 51 million tons of production (Novais et al., 2016). Without their contributions, humanity would face significant crop production shortfalls, promoting further land use expansion to meet food demand (Garibaldi et al., 2014).

Given that most degraded ecosystems are located within agricultural landscapes (Pandit et al., 2018) and declining biodiversity threatens agriculture (Dainese et al., 2019), commodity chains must be a major demand force advocating and financing for restoration within agricultural areas (Maney et al., 2024). Considering that over 40% of the world's land surface is destined to agriculture (Foley et al., 2011), the restoration within agricultural areas will be a key part of achieving targets while addressing the global issues of habitat loss and climate change (Kremen & Merenlender, 2018). In the voluntary biodiversity credit market, this is particularly relevant for commodities chains that originate in the tropics, which is the location that produces 30% of global food supply (Lowder et al., 2021).

Project Aim: Bridging Agriculture and Conservation

Strengthening Supply Chains Through Biodiversity Insetting

This project seeks to explore the challenges and opportunities of implementing biodiversity credits in an agricultural supply chain. Using a commodity crop, we outline a step-by-step roadmap for implementing biodiversity credits as a financial mechanism to encourage private investment in conservation and restoration. For our case study, we focus on the coffee supply chain.

The project focuses on a set of steps to promote additionality on local biodiversity enhancement by ensuring that farming systems can synergistically balance both productivity and conservation objectives. By integrating biodiversity into farming practices, the project provides farm resilience to climate change, encourages diversification at multiple scales (from the plot to the landscape scale), and offers alternative production opportunities (Scherr et al., 2012, Bommarco et al., 2013, Schmidt & Bunn, 2021). This holistic approach avoids leakage problems by ensuring that ecosystem services are embedded in broader agricultural practices rather than isolated initiatives.

Building on the concept of biodiversity credits, the project will integrate the principles of insetting projects that focus on reducing current threats on biodiversity, the recovery of biodiversity habitats, and enhancement of friendly land uses such as agroecological practices (Kremen & Merenlender, 2018). There are many reasons for companies to engage in insetting. By investing in biodiversity restoration, companies can strengthen the resilience of their supply chains while mitigating nature-related risks, including carbon, water and biodiversity (Maney et al., 2024). Insetting enables companies to build stronger relationships within the supply chain. In addition, companies can report on positive impacts, support smallholders and use biodiversity as a primary driver. Co-benefits such as carbon sequestration can provide additional financial incentives, further encouraging investment in nature-friendly practices.

Guided process from satellite images to the farm gate

The roadmap consists of three main phases, each divided into several steps that can be adjusted as more information becomes available (Figure 1). To illustrate the roadmap, we use the example of the coffee supply chain. One guiding principle is to link the interests of companies (or credit buyers) with local interest, for instance, by promoting a transition to a more resilient agriculture through the enhancement of biodiversity, both farmers and coffee traders are securing the future of the coffee trade. Nonetheless, it remains a challenge to align global priority agendas with local realities and opportunities to contribute to such agendas. That´s the reason why we intend to offer a practical guide that starts at a global scale, moves to a regional assessment, and ends with how to engage local actors in the issuance of biodiversity credits.

In the first phase, we propose to carry out a feasibility study, which includes a global analysis to identify potential regions according to a set of eligibility criteria, for instance to look for the areas with the greatest biodiversity impact. Tropical regions are the places where agriculture is transforming ecosystems at a faster rate and where biodiversity is greatest (Ramankutty et al., 2018, Myers et al., 2000). As we intend to create market opportunities for biodiversity credits associated to the coffee supply chain, identifying stakeholders with the greatest impact in the market within Brazil - which is the major coffee producer spanning two of the biodiversity hotspot biomes (Figure 2, Table 2) - is a crucial following step as Brazil, and specifically the Atlantic Forest is home to 20% of the world's coffee production. This first phase aims to reduce operational, regulatory, financial, social and reputational risks for global supply chains sourcing from these tropical areas. These eligible criteria, listed in Table 1, have been selected to demonstrate the business case to stakeholders with an interest in global supply chains. In addition, we have also included the identification of areas sourcing international exports to ensure the link to pressures arising from the international market demand.

Habitat restoration is the main strategy for achieving positive biodiversity outcomes, and considering agroecosystems (or multifunctional landscapes) this could be done through three main actions: (1) conserving and connecting remnant habitat patches, (2) actively or passively restoring habitat by setting aside land for conservation, and (3) implementing ecological intensification systems (like agroforestry) that resemble the structural vegetation of biome in which coffee production occurs (Garibaldi et al., 2023). Considering that studies have shown that improvements in coffee cultivation practices and landscape planning can strongly improve biodiversity and production outcome (Wright et al., 2024), this step concludes by identifying potential interventions aiming for biodiversity net gain.

Table 1. *Outline of the key reason and criteria for integrating biodiversity credits across different impact categories: operational, regulatory, financial, reputational, and social.*

	Operational	Regulatory	Financial	Reputational	Social
Reason	Increase resiliency of the supply chain	- Identify future legislation - Reduce compliance costs and risks of fines and penalties	- Reduce financing costs and increase margins - Attract investors	Avoid actions that can lead into negative impact on business operations	- Identify positive and negative impacts to local communities through improved natural capital - Support social license to operate
Criteria	Areas where forest cover is higher than 15% of area's land cover that supports faster regeneration	- Areas of increased deforestation - Areas of proven faster regeneration	Areas of major productivity	- Areas with world protected areas - Areas in biodiversity hotspots	Areas with communities open to dialogue

The second phase is an *in-situ* development that aims to engage stakeholders, deepen GIS analysis in a regional context and select methodology to assess biodiversity. Among a series of guidelines for the biodiversity market, Indigenous peoples and local communities living in these areas should be actively involved in decision-making, project development and implementation (WBS, 2024). Therefore, once priority locations have been identified and key local actors (farmer, cooperative and NGOs) willing to participate, stakeholders will be engaged at the local level to define the potential interventions for generating positive biodiversity outcomes, which will be co-designed between local stakeholders and the project team (Oliveira da Silva et al., 2024). The project plan (intervention activity) and monitoring plan will be the outcomes of this phase, a desired map will be developed together with farmers locating the different interventions (Chazdon et al., 2020), which will also allow to estimate the positive biodiversity outcomes at a landscape level (Wauchope et al., 2024).

Lastly, the third phase includes the implementation and monitoring aim to culminate in the attribution of biodiversity credits, flowing through implementation, monitoring, reporting, and verification to ensure biodiversity outcomes and, finally, the issuance of biodiversity credits. During this phase, the selected interventions will be implemented according to co-designed methods agreed upon with all stakeholders (baseline), to be compared with future monitoring and to calculate the relative positive benefits for biodiversity (Wauchope et al. 2024). It is intended to use a combination of modern non-invasive methods (e.g., eDNA, acoustic surveys) to improve the accuracy of biodiversity surveys (Burian et al., 2021, Kotian et al., 2024, Tedersoo et al., 2024). Validation of the biodiversity credits will depend on periodic reviews of the results, which will need to be peer-reviewed by experts of specific target taxa (e.g., mammals, arthropods, vegetation) to validate that the results are reproducible and to ensure that a positive outcome has been achieved (see the Cool Farm biodiversity metric tool, Crowther et al., 2024). The academic community needs to be actively involved as part of this co-creative process.

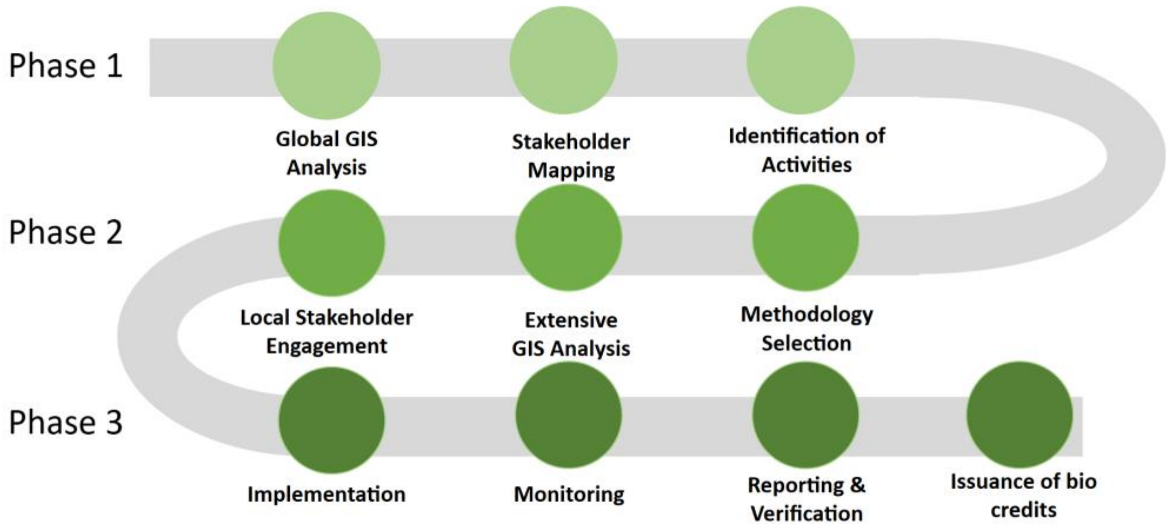

Figure 1. *Schematic representation of the proposed roadmap for biodiversity credit implementation, showing all steps from global to regional assessments, including Phase 1 (light green), Phase 2 (green) and Phase 3 (dark green).*

Our Case Study: Biodiversity Credits in the Coffee Supply Chain

Coffee, the world's second most traded commodity after oil (Goldschein, 2011), is grown across more than 10.5 million hectares of tropical land (FAO, 2016). These tropical regions provide ideal conditions for coffee cultivation due to their hot, humid climates and seasonal rainfall. Coffee production heavily depends on biodiversity, particularly pollinators like bees for pollination and birds for pest control (Chain-Guadarrama et al., 2019). Different cultivation methods (shaded or non-shaded) and processing techniques (wet or dry) significantly impact water usage (Ulsido et al., 2024) and terrestrial biodiversity (Jawo et al., 2024), creating opportunities for biodiversity credits in coffee production. Nonetheless, the major coffee producer in the world (Brazil) occurs in sun grown monocultures associated to forest remnants with much potential for further improvements for biodiversity and coffee productivity through landscape forest restoration techniques (Gonzalez-Chaves et al., 2023). Given these characteristics, coffee was selected as a case study for our project, with its value chain serving as an example for the roadmap application.

Assessing the Coffee Supply Chain's Impact on Nature and Biodiversity: A Geospatial and Regional Analysis

To understand where the coffee supply chain may have a greater impact on nature and biodiversity, we perform a geospatial global analysis followed by a regional analysis with the following criteria:

- **Criteria 1: Global country importance for coffee production.** We determined the importance of a country for the coffee supply chains by extracting the coffee production quantity in 2023 from the United Nations Food and Agriculture Organization (FAO).

- **Criteria 2: Level of deforestation linked to areas of coffee production**. We used global tree cover and forest loss data (Hansen et al., 2013) and overlapped with areas known for coffee cultivation per country (Goldman et al., 2020) to analyze deforestation patterns derived from coffee production.

- **Criteria 3: Level of deforestation at regional level**. After selecting the country with the highest level of deforestation, we proceeded to analyze deforestation patterns, using statistical data from national databases. In this case, MapBiomas. The total deforestation per area or municipality was calculated for years 2022 and 2023 to identify those municipalities with growing concern for deforestation trends.

- **Criteria 4: Municipalities with at least 15% of forest cover**. This threshold is based on the minimum amount of forest cover at which restoration has the greatest impact of the recovery of ecosystem services known to benefit coffee production and ensure a certain level of regeneration and ecosystem integrity (González -Chaves et al., 2022, Banks-Leite et al., 2014). Using statistics of land cover from Mapbiomas, we aggregated the area represented by different types of forest classes (forest formation, savanna formation, mangrove and wooded sandbank vegetation) to estimate the percentage of forest in each of the municipalities for the most recent year for which data was available (2022).

- **Criteria 5: Municipalities within biodiversity hotspots.** Global biodiversity hotspots are places on Earth that are both biologically rich and deeply threatened (Conservation International, 2025). To qualify as a biodiversity hotspot, an area must meet two strict criteria (Michael et al., 2016):
    1. It contains at least 1,500 species of vascular plants found nowhere else on Earth (known as "endemic" species).
    2. Have lost at least 70 percent of its primary native vegetation.

  The presence of biodiversity hotspots is important from the point of view of ecosystem integrity, but also from the reputational standpoint since the importance of these habitats to secure global biodiversity.

- **Criteria 6: Municipalities with protected areas**. A protected area is a geographical space that is legally protected to conserve nature (UNEP-WCMC and IUCN ,2025). The World Database on Protected Areas (WDPA) is the most comprehensive global database of marine and terrestrial protected areas, updated monthly. It is one of the key global biodiversity data sets widely used by stakeholders, including scientists, businesses, and governments. The presence of a protected area is important from the point of view of ecosystem integrity, but also from the reputational standpoint since a lot of media attention has been drawn towards the conservation of these protected areas.

- **Criteria 7: Municipalities with the highest quantity produced of coffee.** *Coffea arabica* and *Coffea canephora* (known as Robusta) production in 2023 to determine the productivity of the municipality.

- **Criteria 8: Municipalities that export coffee overseas.** This criterion is needed to measure impact coming from international trade. Data from Comex Stat, Brazil foreign trade data, was extracted for years 2022 and 2023 for the HS (“Harmonized Commodity Description and Coding System”) code 09, which represents the Brazilian exports of “coffee, tea, maté and spices.” Export data was not further refined since it was not available by municipality.

Criteria 1: Global country importance for coffee production

Table 2 shows Brazil as the largest global producer of coffee in 2023, specifically of the *Coffea arabica* species. Brazil produced a staggering 3,405,267 metric tons of coffee beans in 2023. Brazil has been the world's leading producer of coffee beans for more than 150 years, so this is nothing new. Vietnam is the world's second-largest coffee producer nation, with 1,956,782 metric tons of coffee beans. Table 2 shows the two most widely recognized types of coffee beans: *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee) (DaMatta, 2004) and their predominance according to country of origin. The latter species (Robusta) is fully dependent on pollinators for production (Klein et al., 2003), and with the trend of expanding their production range as climate change continues to threaten the Arabica coffee production (Bunn et al., 2015; Imbach et al., 2017).

Table 2. *Leading global coffee producers: Green coffee production in the year 2023 and the predominant coffee type, split into Arabica (Coffea arabica) and Robusta (Coffea canephora). Source: mixed sources.*

Country	2023 production (in t)	Predominant coffee type
Brazil	3,405,267	Arabica
Vietnam	1,956,782	Robusta
Indonesia	760,192	Robusta
Colombia	680,857	Arabica
Ethiopia	559,400	Arabica
Honduras	384,361	Arabica
Uganda	384,000	Robusta
Peru	369,550	Arabica
India	332,848	Robusta
Central African Republic	316,108	Robusta

Criteria 2: Level of deforestation linked to areas of coffee production

Figure 2 includes the major global producers of coffee. It also depicts impacts derived from anthropogenic pressures, concretely land use change led by deforestation, which is intrinsically related to coffee production, as coffee producers clear up more land to extend their coffee cultivation. To understand deforestation linked to areas of coffee production, commodity data was used for the years 2001-2015 by an administrative boundary (Goldman et al., 2020) and analyzed in combination with tree cover and forest loss (Hansen et al., 2013) to understand patterns of land use change and deforestation per country potentially attributable to the presence of coffee cultivation.

Tree cover and forest loss layers have been added derived from time-series analysis of Landsat images in characterizing global forest extent and change from 2020 to 2023. Tree cover is defined as canopy closure for all vegetation taller than 5m (Hansen et al., 2013). Deforestation is represented by forest cover loss from December 2020 until December 2023, a change from a forest to a non-forest state. The timeframe is considered to be in line with the requirements of the European Union's Deforestation Regulation, which guarantees that the products consumed in the European Union do not contribute to global deforestation or forest degradation. The regulation applies to products that contain, are fed with, or are manufactured from materials from deforested lands after December 31, 2020 (European Commission, 2024).

In addition, the layers of biodiversity hotspots and the World Database on Protected Areas (WDPA) were also added to have a first visual of the potential interest of these regions for biodiversity credits.

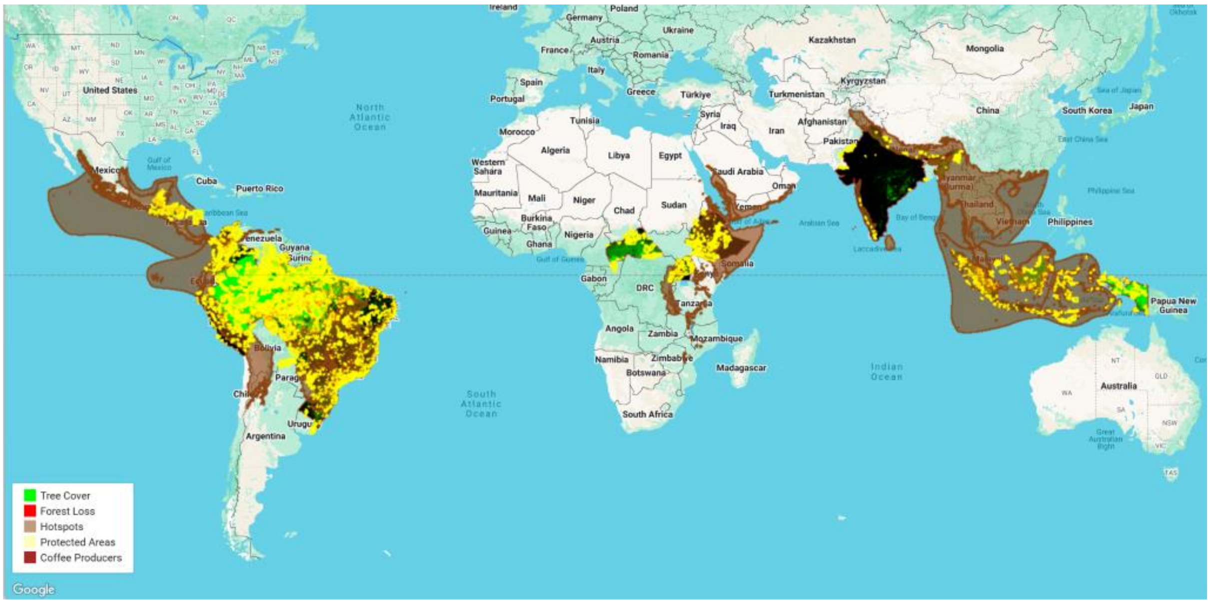

Figure 2. *A map of the world´s largest coffee producers overlaid with layers of tree cover, forest loss, World Protected Areas and biodiversity hotspots (source: mixed sources).*

Table 3. *Rates of deforestation linked to coffee production per country during 2022 & 2023 (Source: Hansen et al., 2013 & Goldman et al., 2020)*

	Deforestation of coffee areas during 2022 and 2023 (square meters)			
Country	**2022**	**2023**	**Accumulated**	**Differential (2023/2022)**
Brazil	56,205,133,119.2	45,623,977,580.4	101,829,110,699.6	-19%
Indonesia	11,773,711,482.5	19,117,139,286.8	30,890,850,769.4	62%
Peru	2,401,408,099.0	2,388,031,509.5	4,789,439,608.5	-1%
Vietnam	2,085,764,203.4	2,012,320,037.9	4,098,084,241.3	-4%
Colombia	2,355,109,677.3	1,687,022,977.5	4,042,132,654.8	-28%
India	885,754,160.5	1,450,145,468.6	2,335,899,629.1	64%
Uganda	1,021,322,095.2	1,196,282,133.0	2,217,604,228.3	17%
Ethiopia	462,198,127.5	1,168,925,707.1	1,631,123,834.6	153%
Central African Republic	852,601,388.8	923,410,733.8	1,776,012,122.5	8%
Honduras	520,126,369.9	768,494,159.0	1,288,620,528.9	48%

Table 3 shows the deforestation in square meters in 2022 and 2023 in coffee growing areas, with Brazil as the country most affected by coffee-related deforestation. This is followed by Indonesia and Peru.

Criteria 3: Level of deforestation at regional level

Within the coffee-related areas in Brazil, the municipalities of Espiritu Santo have been selected as the ones considered for further analysis in this case study because, according to our stakeholder mapping, the Instituto de Pesquisas Ecológicas (IPÊ, 2024), an identified critical key stakeholder for the implementation and deployment of conservation projects, has an important ongoing work with local communities and coffee farmers in this region. As depicted in Figure 3, the municipalities highlighted in red are those that lost more than 41 hectares to deforestation between 2022 and 2023.

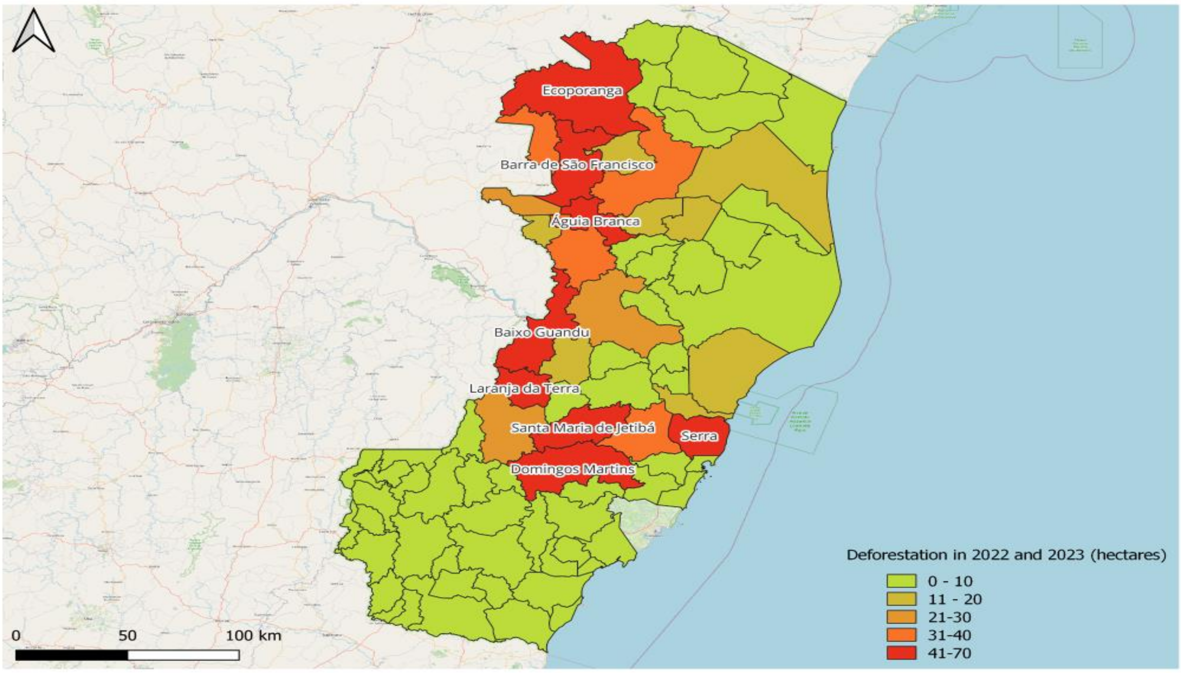

Figure 3. *Municipalities considered for this analysis (Source: Mapbiomas, 2025)*

Criteria 4. Municipalities with at least 15% of forest cover

We calculated the percentage of forest cover surrounding coffee fields per municipality (see González-Chaves et al., 2022). We considered a 2km buffer around each coffee pixel, as it is a good predictor of bee diversity on coffee farms during the coffee blooming period, hence a good proxy for pollination and pest control service (González-Chaves et al., 2020, Hohlenwerger et al., 2024). In Figure 4, the analysis shows in dark green all the municipalities with a forest cover of more than 15% of the total area per municipality, i.e., municipalities where forest regeneration is more likely to enhance pollination services and increase productivity (González-Chaves et al., 2023).

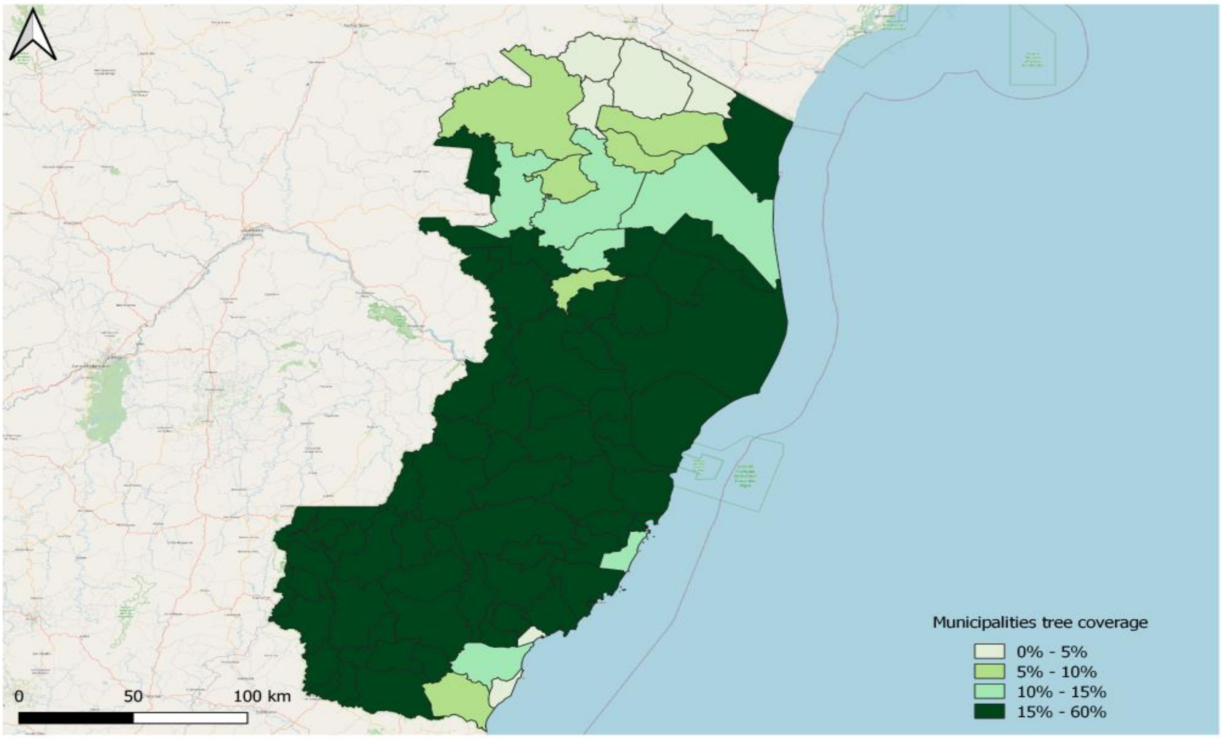

Figure 4. *Tree coverage per municipality (Source: Mapbiomas, 2025).*

Criteria 5 & 6: Municipalities with biodiversity hotspots and world protected areas

Figure 5 displays the Espírito Santo municipalities. All of them fall within the Atlantic Forest biodiversity hotspot, which ranks among the world's top global biodiversity hotspots (Myers et al., 2000). The Atlantic Forest encompasses unique ecosystems with a high degree of endemism and plays an important role in mitigating climate change. Once covering over 350 million acres, human activity has destroyed 88% of the original vegetation in Brazil's Atlantic Forest, making it one of the most endangered biomes in the world (WWF, 2025). There is also a high presence of World Protected Areas (WPA) in the municipalities, as forty-four (44) out of the sixty-three (63) municipalities in Espírito Santo manage WPA. Aracruz and Fundão are the municipalities with more WPA, with four (4) and three (3) protected areas respectively.

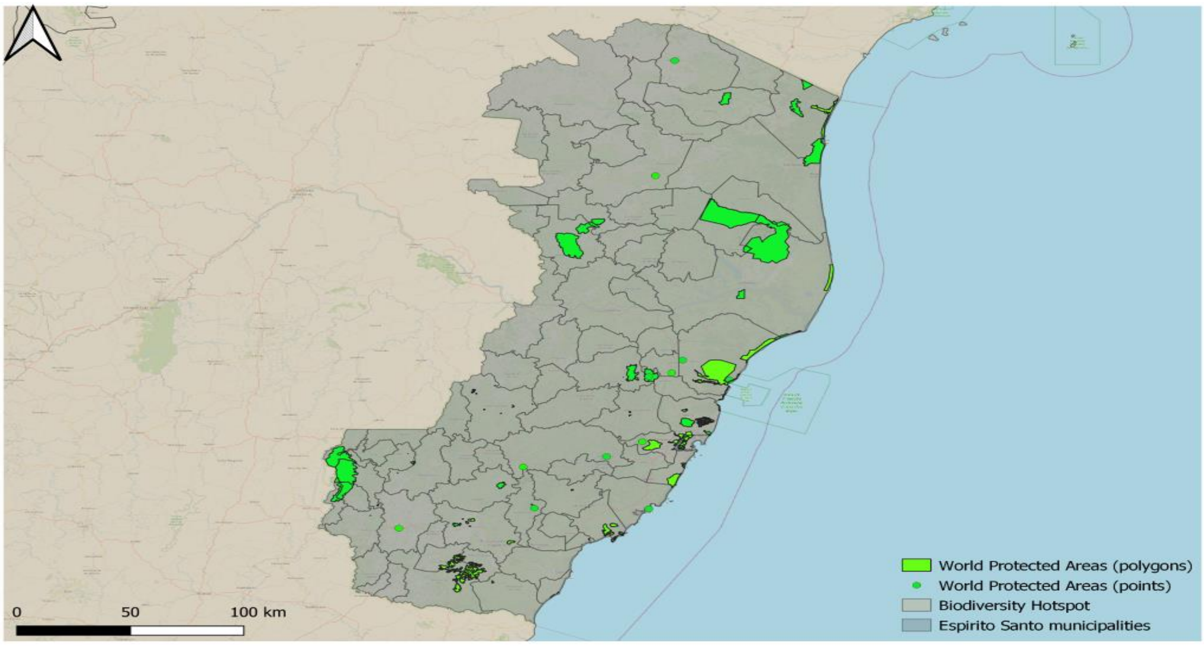

Figure 5. *Municipalities that overlap with World Protected Areas and biodiversity hotspots (Source: Conservation International and WDPA, 2025).*

Criteria 7: Municipalities with the highest quantity produced of coffee

Figure 6 shows the total quantity of coffee produced in 2023 between *Coffea arabica* and *Coffea canephora* in US tons. The municipalities of Linares and Rio Bananal, followed by Nova Venécia, Vila Valério and Jaguaré were the top producers of coffee in 2023.

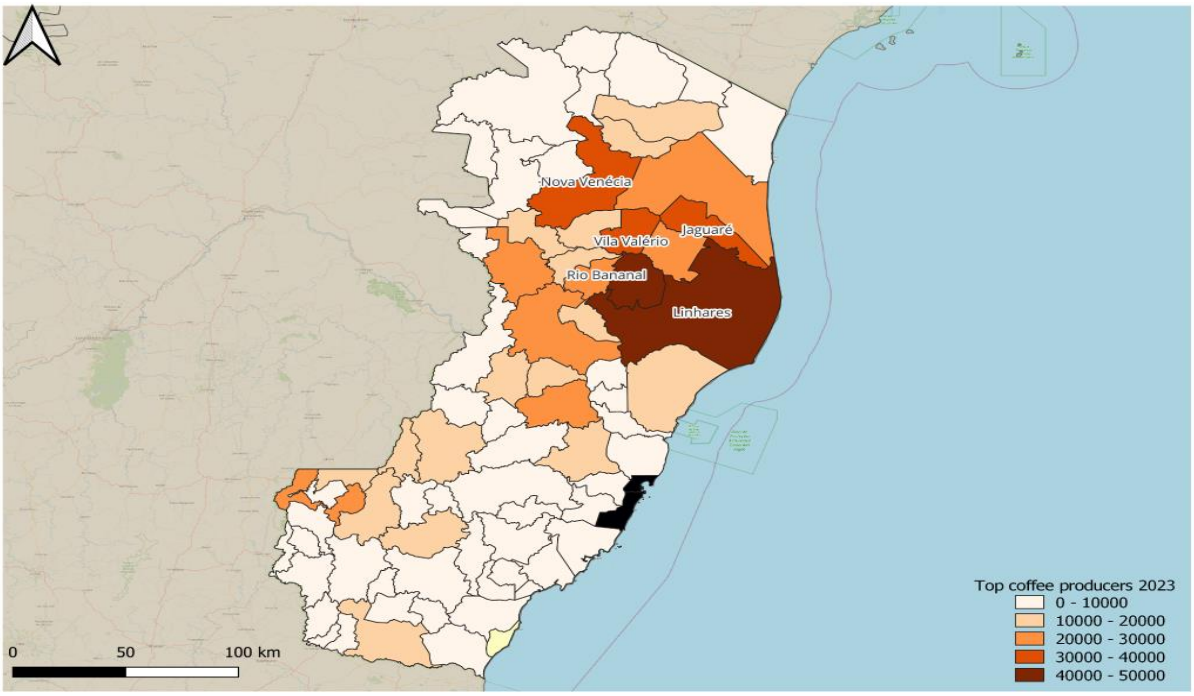

Figure 6. *Municipalities top coffee producers in 2023 (Source: Brazilian Institute of Geography and Statistics, IBGE, 2025).*

Criteria 8: Municipalities that export coffee overseas

Figure 7 depicts the municipalities that exported the most in monetary value (US$FOB) in 2023. The names of the municipalities that exported more than US$ 10,000,000 are highlighted. It is notable that not all the municipalities with high coffee exports in the year 2023 were coffee producers, which may indicate that coffee supply chains are spread across municipalities.

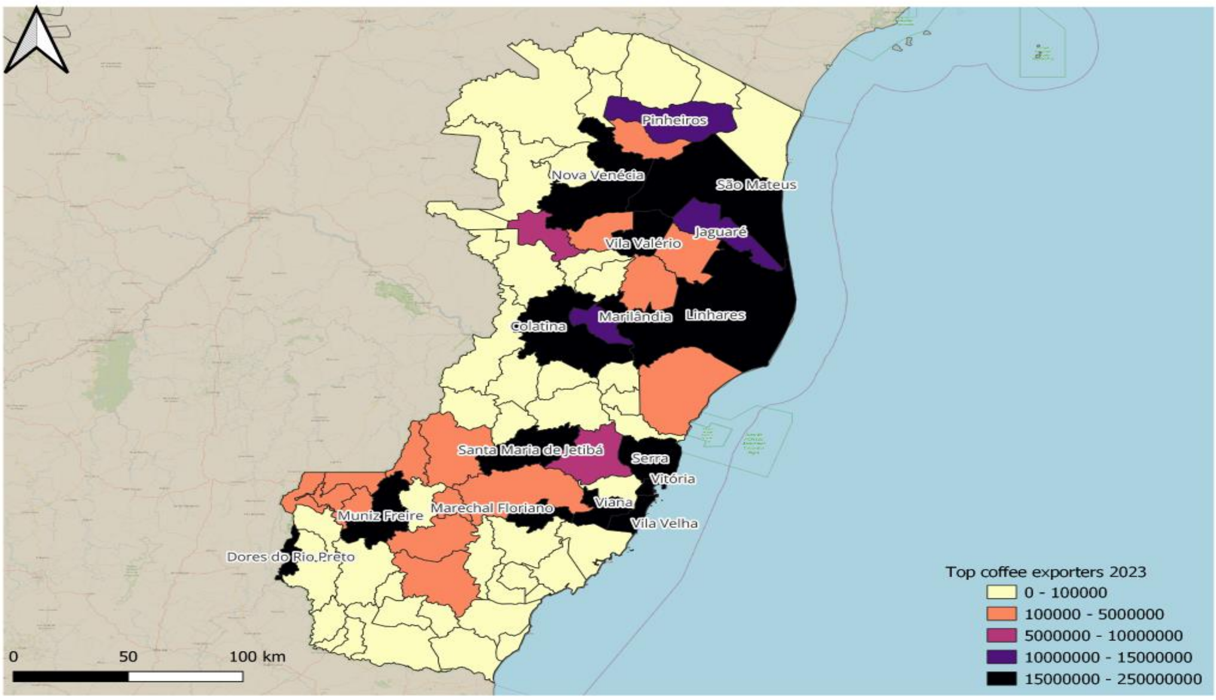

Figure 7*. Municipalities top coffee exporters in 2023 (Source: Comexstat, 2025).*

Final prioritization

A final prioritization based on these criteria was applied to the municipalities of the Espírito Santo estate. For the prioritization, we first looked at the upward trend of deforestation, comparing the deforestation data between 2023 and 2022, followed by the selection of municipalities with a forest cover of more than 15% of the municipal area, followed by the presence of biodiversity hotspots and world protected areas in the municipality. After applying these filters, we selected those municipalities that were coffee producers and also exported coffee. The final prioritized municipalities are shown in Figure 8. Figure 8 shows the prioritized municipalities according to the above criteria and the total amount of coffee produced in 2023. Linhares, followed by Vila Valerio, are the municipalities that meet all the required criteria.

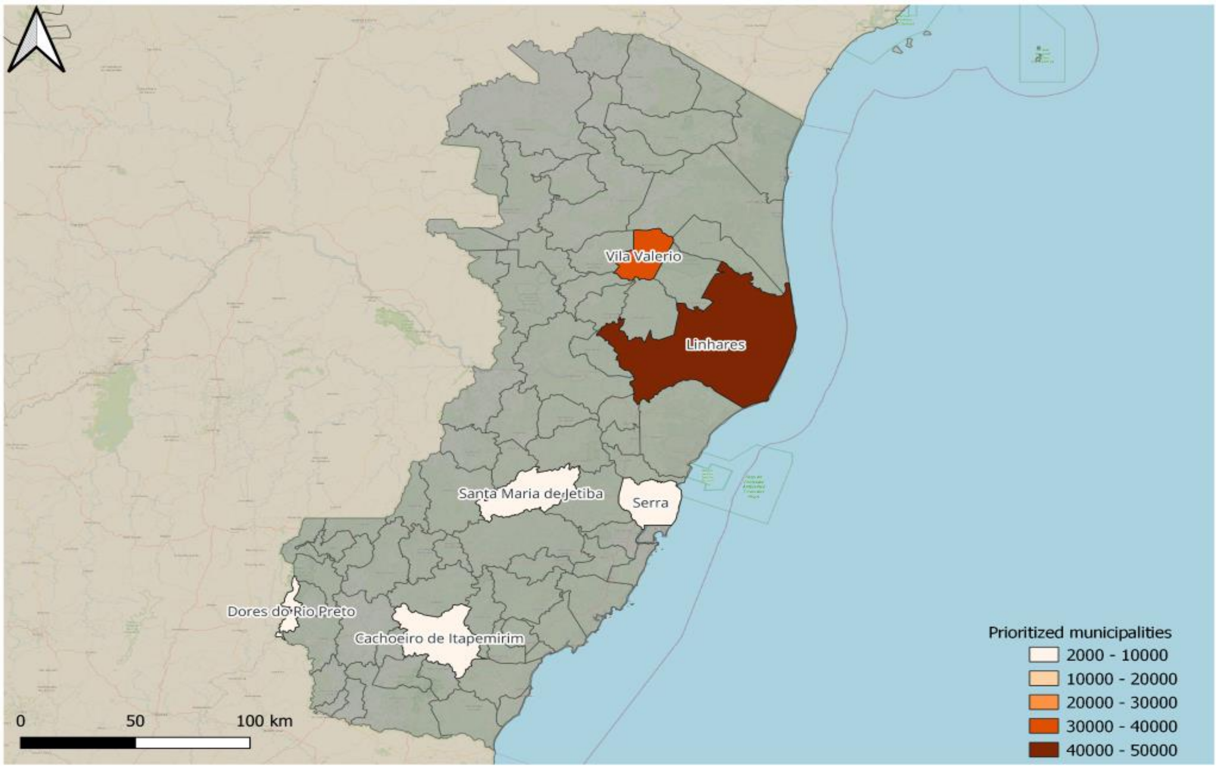

Figure 8. *Prioritized municipalities (Source: mixed sources).*

Stakeholder Mapping: Identifying Key Actors in the Coffee Supply Chain

The aim of the stakeholder mapping is to identify key stakeholders in the coffee supply chain that may hold an interest in the implementation of biodiversity credits and may be directly or indirectly affected by project activities. It is important to understand the concerns of the stakeholder groups, namely their rights and interests, their capacity to follow political processes, their structure and degree of organization and their current means of engagement in this type of project. For instance, in the state of Espirito Santo, the IPÊ (Instituto de Pesquisa Ecologica), an NGO that brings together scientists from different backgrounds, is articulating local stakeholders in agroforestry and restoration in coffee. The project is called *School, Landscape and Communities*, which, after presenting the economic and environmental benefits of engaging in restoration activities, jointly develop a dream map of where these activities will take place to improve landscape connectivity, coffee yield through pollination and pest control, and water quality. Engaging local communities is central to ensuring the long-term success of such projects and must be accompanied by capacity building (Pashkevich et al., 2022). The main relevant stakeholder groups can be identified as shown in Table 4.

Table 4. *Stakeholder groups with potential interest in participation in biodiversity credit projects and their potential roles.*

List of stakeholders	Roles and responsabilities
Private investors	Private investors and asset managers interested in sustainable coffee supply chains. They unlock the initial investment but they can also be the buyers of biodiversity credits which in turn can sell in the secondary market to other stakeholders, such as coffee buyers. Investors may determine the ESG indicators implemented in the project that are aligned them with their portfolios.
BRB Finance Coalition	Co-funding, facilitation and support. The BRB Finance Coalition's mission is to accelerate the conservation and restoration of Brazil's forests. Between the Coalition's goals is also carbon sequestration. Its primary objectives are to invest in key bioeconomy activities, such as low-emissions agriculture, forestry projects and land-use actions. The participation of BRB Finance Coalition is critical to attract private investment and ensure high integrity of the project.
Project developer	The project developer is interested in developing the project and issue biodiversity credits. It manages the implementation, budget, monitoring and contracting. Depending on the project developer services offering, it could also promote and advertise the project through its commercialization network. It needs high expertise and a strong level of oversight.
Local partners	Local partners can be cooperatives, NGOs and local governments interested in bringing forward the collective needs and demands from local farmers. They can be the facilitators to flow the communication between project developers and local farmers but also, they are key to coordinate smallholders in topics like training, inputs, finance and monitoring. The selected local partner must have extensive experience in the area and in engagement with Indigenous populations and local communities and it will lead the implementation activities
Technical experts	Technical experts or validators verifies the impact and the project implementation. It provides the needed technical know-how/training and/or equipment.
Local communities and farmers	Local communities and farmers are key to implementing conservation activities, monitoring progress and therefore receive results-based payments. Interested in generating revenue from their economic activities, they may be open to the implementation of activities that can deliver higher yields. Ultimate beneficiaries and co-investors through their own work, transferring carbon and biodiversity rights in exchange. They are the issuers of biodiversity credits.
Buyers	The buyers can be key stakeholders in the coffee supply chain. They can also be part of co-financing schemes with companies from coffee supply chains. In this case, these buyers can market their products as "biodiversity-friendly", enabling higher marketing value, compliant with deforestation regulation demands (e.g., EUDR compliant), and increasing the resilience of the supply chain. The buyers can also be the initial private investors, opening the posibility to resell them to stakeholders in the coffee supply chain.

Figure 9 depicts the administration and governance of the different participant stakeholders, as well as the investment in biodiversity credits flows. The private investors and the BRB Finance Coalition will finance the project through blended finance. The project developer and local partner would receive the funds through a special purpose vehicle (SPV), a legal entity created with the specific business purpose of financing the project for its duration. The project developer and local partner will implement the project through stakeholder engagement with local communities and will hire the technical experts to support implementation of ecological intensification practices and biodiversity conservation and restoration activities in the opt-in farms (for examples on local engagement projects see IPÊ, 2024 or Chazdon et al., 2020 or Pashkevic et al., 2022). The local farms will receive funding and technical expertise to implement new sustainability practices on the farm and biodiversity enhancements on the farm surroundings, which lead to increased productivity yields and claims for biodiversity credits and carbon credits. The local farms sell their improved coffee production to the coffee cooperatives with the biodiversity credits and/or carbon credits attached. The buyers can buy the coffee as a standalone product or with the biodiversity credit attached to it. Buying the biodiversity credit shows support and commitment with the project. While the turnover from the coffee is retained by the local farms, the profit from biodiversity credits and/or carbon credits remain in the cooperative to pay back the private investors and potentially reinvest in new projects at landscape level.

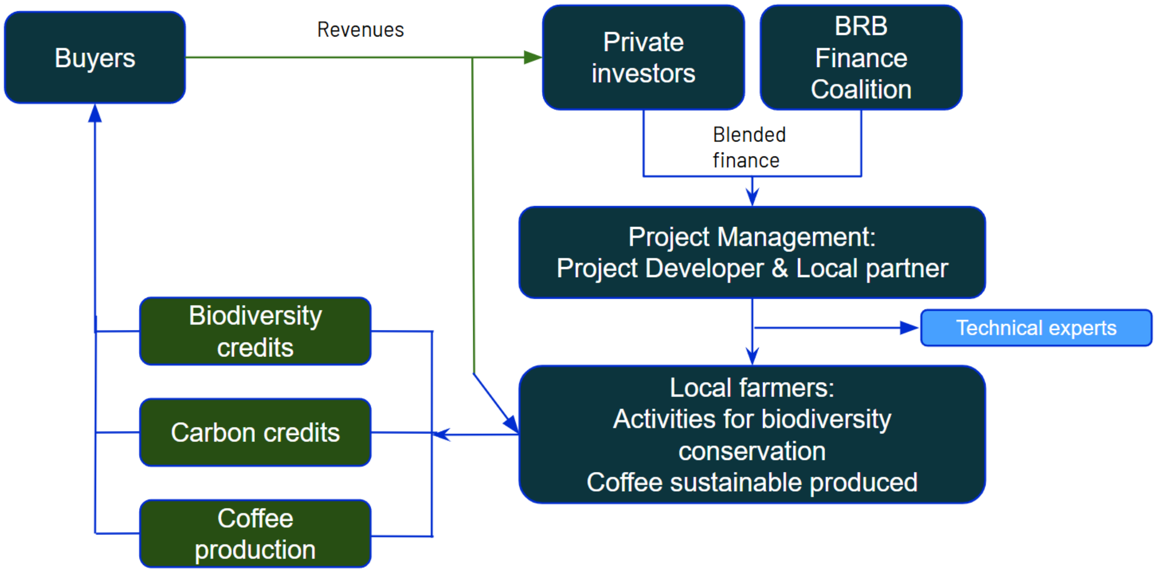

Figure 9. *Administration and governance in the issue of biodiversity credits***.** *BRB Finance Coalition stands for Brazil Restoration & Bioeconomy Finance Coalition.*

Identification of Activities or Potential Interventions

Consumers and companies' demands create opportunities for potential interventions because consumers are increasingly experiencing the adverse effects of climate change and becoming more aware of their climate impact. This awareness drives demand for climate technologies, products, and services that can address issues like drought, heat, flooding, and food insecurity, as well as for climate mitigation solutions (Oliveira da Silva et al., 2024). Similarly, companies are increasingly requiring technologies, products and services that help them prepare for, prevent, respond to, and recover from climate-related impacts (CIP, 2024).

Recent studies have shown that different methods of cultivating coffee strongly affect the biodiversity and carbon stocks of these plantations (Jawo et al., 2024, Verburg et al., 2019). Strategic planning can yield benefits from the restoration of natural vegetation to agricultural production through pollination services, with potential economic advantages even accounting for the costs of restoration (Lopez-Cubillos et al., 2023). For the Brazilian Atlantic Forest, production increases mediated by reforested areas within farms can offset the costs of restoration up to a limit of 25% forest cover (D'Albertas et al., 2024). Thus, there is potential for biodiversity conservation and numerous opportunities for biodiversity credits through the coffee supply chain.

For instance, shade coffee can serve as sanctuaries for wildlife and act as connecting corridors, while many other interventions can provide benefits for both, water and terrestrial environments (Verburg et al., 2019). The type of coffee processing, such as dry or wet, can impact or reduce pollution in watersheds. Wet coffee processing requires water to remove the pulp, which results in wastewater and organic pollution that can be harmful to water bodies and human health. Consequently, dry processing or water treatment can provide numerous benefits for watersheds (Ulsido et al., 2024).

These measures not only benefit farmers but also provide ecosystem services to a broader range of land and society. This is due to improvements in water quality, which is used downstream for numerous other purposes (Hunink et al., 2012), and enhancements in landscape connectivity favoring ecosystem services such as pollination (Aristizábal et al., 2025, Hohlenwerger et al. 2024). Therefore, there are several opportunities for management and biodiversity gains in coffee plantations across both aquatic and terrestrial environments (Table 5). Interventions should be selected from the list of potential options, allowing for adaptation to the reality of the area under process of certification and the dynamics in process within it.

Table 5. *Potential interventions for environmental improvements in coffee plantations according to Ulsido et al. (2024), Lopez-Cubillos et al. (2023), Verburg et al. (2019), and Hunink et al. (2012).*

Measure	Environment	Scale	Benefits
Shade system	Land	Farm	Reduces temperature and physiological stress; reduces runoff
Diversifying cropping systems	Land	Farm	Improve resilience to climate change and soil quality
Use of mulching	Land	Farm	Reduces soil evaporation and weed growth
Reduction of fertilizer and promotes biofertilizer	Water	Landscape	Reduction of downstream eutrophication
Reduction of pesticides and promotes of biosolutions	Land/Water	Farm	Improvements in soil quality and reduction of pollution downstream
Promote water recycling and the reuse of graywater	Water	Farm	Avoid depletion of natural water resources

Implementation of traceability mechanisms	Land/Water	Farm	Prevent deforestation and monitor biodiversity benefits along the supply chain
Implementation of regenerative agriculture, improving farming practices	Land	Farm	Rebuild soil organic matter and biodiversity, enhance and maintain ecosystem function and preserve native seeds
Lagoon based system treatment	Water	Farm	Reduces pollution and acidification on watershed
Dry processing	Water	Farm	Reduces water pollution and acidification, improving dissolved oxygen
Upstream terracing	Land/Water	Farm	Reduces erosion and runoff, protecting soil and watershed
Soil and water conservation	Land/Water	Farm	Diversity of native tree coverage protect soil from erosion and provides rich leaf litter
Forest cover/Restoration	Land/Water	Landscape	Pollination, pest control, temperature buffer, soil and water conservation, wind protection, carbon sequestration
Production of certified products following auditable protocols	Land/Water	Landscape	robust sustainability certifications confirming biodiversity and climate benefits

Methodology Selection, Local Stakeholder Engagement and Implementation of the Project

The complexity of biodiversity measures

A biodiversity credit must represent a measurable and evidence-based unit of positive biodiversity outcome, additional to what would have otherwise occurred, and sustainable. However, biodiversity is inherently complex and cannot be reduced to a single measure. As a result, multiple metrics will always be required for different purposes (Mace et al., 2012). This is why we propose to have at least one metric for different dimensions of positive biodiversity outcomes: One (1) that represents the conservation of endangered or endemic species, another (2) for species related to ecosystem services that benefit agriculture (e.g., bee species richness), and a third (3) that reflects broader societal benefits such as water-related biodiversity. Ultimately, the idea of the biodiversity credits is to enhance the resilience of commodity supply chains resulting from the enhancement of biodiversity, which is not limited to generalist species that provide ecosystem services (Kleijn et al., 2015).

Another major challenge that must be considered when issuing biodiversity credits, such as the possibility of leakage. Leakage occurs when an investment results in the displacement of threats rather than their reduction (Filewod & McCarney, 2023). For example, leakage can happen if a farmer shifts production to an undeveloped area after restoring previously productive land. Another form of leakage may be supply chain-mediated, such as when coffee prices rise due to decreased crop production, encouraging other producers to cultivate the same crop in places not part of the biodiversity credit scheme (Wauchope et al., 2024).

Framework for Stakeholder-Driven Biodiversity Gains

To ensure meaningful biodiversity gains while addressing these complexities and avoiding pitfalls (e.g., leakage), we propose an adapted framework based on Wauchope et al. (2024), in which we incorporate targeted metrics and a participatory approach (Figure 10).

1. Framing: Defining biodiversity credits and setting parameters

The first step is to determine what a credit represents. This step also involves determining the time period and spatial scale at which the credits will be calculated. Biodiversity credits are defined based on local ecological conditions to ensure that they are consistent with specific objectives for each project area.

2. Co-Design with local stakeholders and the community

To achieve both environmental and social success, scientists and local stakeholders such as farmers, conservationists and representatives of Indigenous communities will actively work together in a participatory project design:

- <u>Participation and knowledge exchange:</u> Dialogue with local stakeholders ensures that planned actions are both ecologically sound and socially meaningful. Local knowledge about the land and natural systems is crucial for designing interventions that reflect the unique ecological dynamics of the area.
- <u>Goal definition and design:</u> Biodiversity targets are set collaboratively to ensure that they are both realistic and effective. These targets will be tailored to the local ecosystem, with measurable targets for biodiversity outcomes. Biodiversity credits are then issued to document these positive changes.

3. Quantifying: Selecting and measuring biodiversity metrics

Selecting appropriate metrics is vital for ensuring that biodiversity changes are accurately measured. These metrics will be chosen based on the local ecological context and biodiversity priorities:

- <u>Metrics selection:</u> The metrics will be selected from a wide range of indicators, including species richness, and functional diversity, with special consideration for threatened species and habitats. The metrics address each of the three dimensions: (i) population dynamics of endangered species, (ii) community metrics (diversity of species richness) that provide information on pollinators, (iii) beta-diversity along the water basin where interventions occur. These metrics will be combined into a composite index to provide a holistic view of biodiversity change.

- Local adaptation: The selection of metrics will reflect both global biodiversity standards and local knowledge. For example, the region is known for the occurrence of endangered species of Muriquis (*Brachyteles hypoxanthus*) and sloth (Stier 2019, Santos et al. 2019), estimating the contribution to the recovery within the global context is crucial for the project visibility. In addition, Espírito Santo is the main producer of *C. canephora*, the coffee species, which is known to benefit fully from pollinators, but no studies have been carried out to describe the bee community in the Neotropics. Moreover, indigenous knowledge about specific plant species or habitat types may provide insights that complement scientific methods, ensuring that the metrics are culturally relevant and locally grounded.

4. Detecting: Assessing biodiversity change, including a peer review process

Monitoring biodiversity changes against a baseline is key to tracking the success of the project:

- Evaluating positive changes and avoided losses: Positive changes in biodiversity or avoided losses compared to the baseline will result in the issuance of biodiversity credits. Credits will only be issued if changes fall within a specified tolerance range (e.g., ±10%). This ensures that small fluctuations are accounted for, but only measurable, significant changes are rewarded.
- Ongoing data collection: Continuous monitoring will ensure that the project is on track and that biodiversity outcomes are being achieved. Data will be collected through field surveys, remote sensing, and community input.
- Peer-Review: A robust and open peer-review process will be established, allowing independent experts to assess the project's progress and outcomes. This third-party evaluation ensures that the results are credible, transparent, and objective.

5. Adjusting: Addressing external factors and leakage

It is essential to account for leakage and external influences that may affect biodiversity outcomes:

- Addressing leakage: We will apply a leakage accounting process that adjusts biodiversity credits to account for potential negative impacts caused by external factors. For example, if a project in one area results in agricultural expansion elsewhere, credits may be adjusted accordingly to reflect the true biodiversity impact.
- Transparency in adjustments: To build trust, the process of leakage adjustment will be transparent and publicly accessible. Stakeholders will have visibility into how adjustments are calculated and how they influence credit issuance. This ensures fairness and credibility.

If the project fails to achieve positive biodiversity outcomes over an extended period, a "Plug-Out" system will be triggered. This system is designed to reassess the project's goals and interventions, making adjustments or even discontinuing the issuance of biodiversity credits if additional biodiversity gains cannot be demonstrated.

- Review and adjustment: The "Plug-Out" system includes a structured review process where the project's methodologies, assumptions, and interventions are re-evaluated. If necessary, corrective measures will be implemented to steer the project back on track.

This comprehensive approach, grounded in the principles of co-design, transparency, and local engagement, ensures that biodiversity credits reflect meaningful, additional, and sustainable biodiversity gains. By addressing complexities like leakage and involving local stakeholders at every step, the project aims to foster long-term ecological and social benefits. The proposed framework not only accounts for biodiversity metrics but also integrates social dynamics and Indigenous knowledge, making it a robust, adaptive model for biodiversity credit issuance.

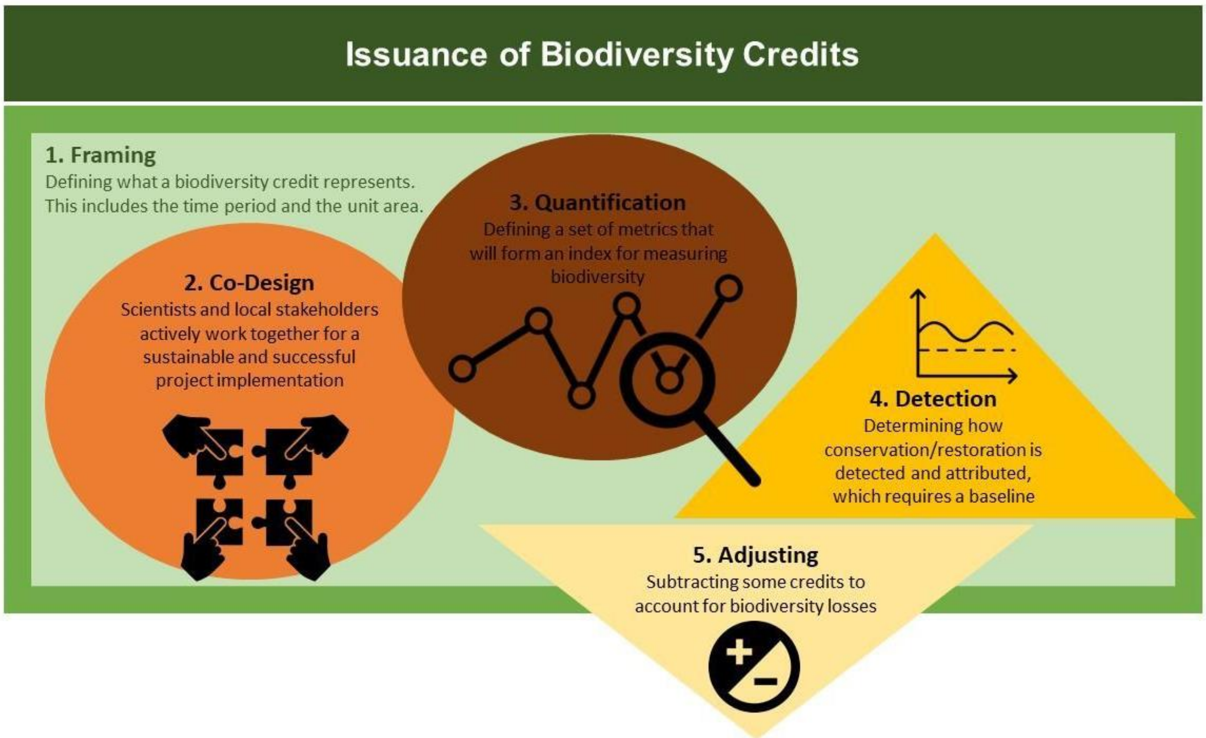

Figure 10. *Schematic representation of the framework based on Wauchope et al. (2024) for the definition, measurement and issuance of biodiversity credits.*

Monitoring, Reporting and Verification

One of the most common questions in the discussion about monitoring is, obviously, how to measure progress and ensure biodiversity conservation in a consistent way (Antonelli et al., 2024). To ensure biodiversity conservation, we need verifiable criteria (Clayton et al., 2024). According to Ford et al. (2024), methods for monitoring biodiversity credits must be *scalable*, meaning they should be available and efficient on a global scale; *accessible*, thus not prohibitive by cost or demanding of experts; *granular*, i.e., available in sufficiently fine resolution considering spatial, temporal and taxonomic dimensions; and *evidenceable*, meaning that the records of organisms provided by the method could be audited by a third-party verification. Thus, for now, we aim to reconcile methods for aquatic and terrestrial sampling that are minimally invasive to biodiversity, cost effective, standardized to allow comparisons between samples, and obviously effective for sampling biodiversity in aquatic and terrestrial environments of Atlantic Forest.

Emerging Biodiversity Monitoring Techniques: Camera Traps, Acoustic Monitoring, and Environmental DNA

We choose to focus on emerging biodiversity monitoring techniques: passive acoustic monitoring, camera traps and eDNA - three modern, non-invasive and cost-effective methods that have been proposed in the literature as effective for biodiversity monitoring (Tedersoo et al., 2024, Ford et al., 2024). If the use of these modern tools is not possible, traditional sample methods (e.g., hand-nets for fishes and/or observation for bees and birds) should be used.

Camera Traps. Due to their low intrusiveness and costs, as well as temporal flexibility that allows them to remain in the field for variable periods, suitability for a range of habitats, and verifiable records, camera traps have been popular. Their advantages also include the ability to detect rare or elusive animals, often making them recommended over traditional methods (Trolliet et al., 2014). However, while there are experiments using camera traps in aquatic environments (Bilodeau et al., 2022) their use is significantly rarer than in terrestrial environments. This is due to the fact that any type of visual sensing in aquatic environments relies on clear water, which is not always available in freshwater environments.

Passive acoustic monitoring. Passive acoustic monitoring has emerged as a low cost, temporary flexible (for the same reason as camera traps), and easy to deploy tool for monitoring the biodiversity of sound-emitting species (Hill et al., 2018), such as frogs, birds, bats and marine species. Acoustic monitoring allows for both, the identification of species and creation of acoustic diversity index, which is being used to infer biodiversity recovery associated with tropical forest recovery (Müller et al. 2023). Technologies are still emerging overcoming identification issues trying to assess the biodiversity beyond vertebrate biodiversity to identify arthropods in all land uses and in agricultural landscape (Doohan et al., 2019, Van Klink et al., 2022, Van Klink et al., 2024). Similar to camera traps, although there are researchers and results concerning the identification and behavior study of neotropical freshwater fishes using acoustic monitoring (Godinho et al., 2017, Raick et al. 2020), it is still in the initial stages of development and does not yet allow for comprehensive monitoring of aquatic biodiversity.

Environmental DNA (eDNA). Trace-DNA from specimens can be collected from water, soil or air using a modern sampling tool kit. New techniques have enabled the identification of multiple species from bulk samples by comparing the sequence of a standardized DNA region to a reference database of pre-identified specimens (Taberlet et al., 2012). eDNA sampling allows for surveying rare species (Sales et al., 2021) without the need for euthanizing individuals or any other intrusive action in the environment. It also facilitates the identification of specimens regardless of their life stage (Cheng et al., 2013). However, this tool relies on a known reference DNA sequence database, which limits its widespread use in some environments, especially for neotropical fish fauna (Dal Pont et al., 2021).

Despite these disadvantages, eDNA sampling has proven to be more efficient than traditional methods for vertebrates (Carvalho et al., 2022). Additionally, even in the absence of matching reference-sequences, biodiversity can be quantified as Operational Taxonomic Units (OTUs). These OTUs sequences can be stored in databases and, if matching sequences become available in the future, will allow for retrospective identification. Soil eDNA samples are especially important, as this biota provides a good indicator of environmental health (Tedersoo et al., 2024), and is of special interest to farmers, as well as bees, the main pollinators of coffee plantations (Aristizábal et al., 2025). The use of water eDNA samples could be very useful as it allows for the identification of both terrestrial and aquatic species from the same sample (Polanco et al., 2021).

Given the advantages and disadvantages of each sampling technique, and given the particularities of each farmland and the diversity of species to be sampled, such requirements could inevitably lead to the need to reconcile more than one method. In addition, there are some peculiarities to be considered in terms of sample accuracy when using these new techniques. For instance, a special concern arises when considering water eDNA, as DNA fragments can drift with the water flow, and both degradation time and detection distance can vary greatly among environments, mainly depending on water velocity and temperature (Deiner & Altermatt, 2014, Penaluna et al., 2021). In such cases, detected biodiversity could originate from upstream farms if distances are not carefully monitored. For this reason, the location of the sampling station needs to be carefully evaluated beforehand.

Index of Biotic Integrity (IBI) as a Tool for Biodiversity Credit Issuance and Environmental Assessment

From biodiversity data, the Index Biotic Integrity (IBI) can be composed for each biodiversity dimension defined above. The index originally designed for management of water basins used for human consumption, merges a variety of biodiversity metrics to assess environmental health. Although it was initially developed based on the attributes of fish fauna (Karr, 1981), it can be applied to both aquatic (Casatti et al., 2009) and terrestrial environments (Alexandrino et al., 2017). Assessing aquatic habitat offers the advantage of serving as a proxy of overall (terrestrial & aquatic) environmental health, since landscape use and conservation directly reflects on the quality of in-stream habitat variables and fish assemblage (Brejão et al., 2018, Peressin & Cetra, 2014, Cruz et al., 2013). Therefore, the IBI approach provides a measurable and comparable single value that can be easily used for issuance of biodiversity credits. The Index of Biotic Integrity is also useful for another important reason in the context of biodiversity credits issuance: It enables comparison of biodiversity integrity across properties within the same landscape. This comparison reveals whether the biodiversity of a property is above, below or at the expected average. Consequently, by providing a reference biodiversity status, the relative gain can be estimated in terms of the aimed community integrity. For instance, coffee flowers have been registered to receive visits from up to 50 species per site, in places with high forest cover, out of a 116 species found in the region (Medeiros et al. 2019). Therefore, an IBI focused on bee species could be set at 40 species, if an average only 10 species at initial stages of the project, for every two species (1%) increments that can be attributed the interventions (restoration or agroforestry) a credit could be issued. In this sense IBI should be issued for endangered or endemic species and for water quality associated species.

As highlighted above, each method brings its own set of shortcomings and advantages, which can change over time. However, it is critical to never forget the comparability of data, since the principle of biodiversity credits issuance is biodiversity net gain. Hence, having positive and negative control (reference systems) to measure how much of what is being recovered has been achieved (positive control), or the negative reference to an area without management to understand how biodiversity would remain if no intervention had taken place is crucial for estimating the positive impacts and the issuing of biodiversity credits. The comparability of biodiversity data for each property must always be maintained, regardless of the geographic location and monitoring methods chosen. At this moment, we propose that after the initial baseline, monitoring assessments must be performed every 5 years to evaluate the biodiversity gains resulting from interventions (Tedersoo et al., 2024). Monitoring must demonstrate that the results occurred due to the project, more than what would have happened without the project (Antonelli et al., 2024).

A note for the future: Other technologies may become more accessible or acquire better resolution in the future. Thus, it is important to monitor their evolution to potentially utilize these new technologies for monitoring and issuing biodiversity credits. For instance, satellite remote sensing (SRS) technology provides opportunities for fine-scale mapping of habitats worldwide but is yet costly (Sozzi et al., 2018). Additionally, unoccupied aerial vehicles (UAVs) allow monitoring areas up to hundreds of km^2, which is an appropriate scale for biodiversity credits. UAVs can also collect data at a finer resolution than SRS; for example, they can use thermal sensors for animal detection (Seymour et al., 2017).

Peer-review process with a security plug system: Biodiversity credits must be issued according to measurable criteria. For now, based on Wauchope et al. (2024), we suggest that an increase of 1% in IBI values could equate to 1 biodiversity credits. Certification schemes could also help ensure that biodiversity credits are ethical and trustworthy, as various media reports suggest that some certification systems have failed to protect either biodiversity or Indigenous people (Antonelli et al., 2024). To solve this problem and ensure an auditable process, we also suggest a peer-review system, similar to that used for publishing scientific papers, aiming to create a more scientific process as possible. In this system, recognized researchers would be invited to analyze and review the monitoring project and the results of the monitoring. The scientific peer review model allows to ensure that the project has a real possibility for biodiversity net gain from a rigorous analysis of the monitoring process. This peer-review model should be connected to a plug system, which if the monitoring shows no biodiversity net gain after 15 years, the project will cease activities.

Issuance of Biodiversity Credits

Biodiversity credits represent a compelling economic solution for financing forest conservation and restoration, particularly in coffee-growing regions where the relationship between forest cover and agricultural productivity is well-documented. Research in the Brazilian Atlantic Forest demonstrates that strategic forest restoration can create a win-win scenario for both biodiversity and coffee yields. Studies show that coffee fields within 200 meters of forested areas experience 15-20.8% higher yields, when compared with areas without forest fragments nearby (Latini et al., 2020), moreover beyond 200 meters the richness of bee species is reduced by half (González-Chaves et al. 2020), highlighting the direct economic value of forest proximity. This economic advantage becomes particularly evident over a 20-year timeline, where restoration costs (including direct implementation, opportunity costs, and initial production changes) can be fully offset by increased coffee productivity, especially when farms maintain existing forest cover above 10% and target restoration of up to 25% of their land (D'Albertas et al., 2024). By implementing activities that enhance the ecosystem, the population of pollinators could increase, leading to crop productivity. Animal pollination services contribute between US$235-577 billion annually to global crop output (Lautenback et al., 2012). In the United States alone, pollinators contribute more than 24 billion dollars to its economy, of which honey bees account for more than 15 billion dollars through their vital role in keeping fruits, nuts, and vegetables in our diets (The White House, 2014). Moreover, relying on a single managed species is less resilient and, in many cases, wild pollinators are better at enhancing yield (Garibaldi et al., 2013). These are reasons why projects promoting honeybees' production with only one or two species to ensure coffee yields (Nespresso Initiative, 2024) is the opposite of promoting resilient agroecosystem (Tscharntke et al., 2012). According to research performed in the Atlantic Forest, higher coffee yields are associated with the municipalities that have historically protected at least 20% of old-grown forest, although currently more than half of the municipalities (over 300 coffee-producing municipalities), have less than 15% of forest cover surrounding the coffee fields (González-Chaves et al. 2022). Being both species of coffee, and especially Robusta, directly impacted by pollination, it seems critical to boost and preserve the pollination diversity in the coffee cultivated areas. Biodiversity credits can effectively bridge the financing gap for restoration projects while generating tangible returns through improved agricultural yields, creating a sustainable economic model that benefits both farmers and ecosystem services. The price for biodiversity credits could be estimated taking into consideration the costs displayed in Table 6, which encompasses direct costs related to biodiversity enhancements, opportunity costs, costs related to changes in land management practices. These different costs need to be modelled and analyzed under the lens of future potential scenarios to render sound estimations.

Table 6. *Costs that could be covered by biodiversity credits.*

Type of costs	Description	Example
Direct costs related to biodiversity enhancements	Costs related to interventions to conserve and restore adjacent forest patches to the farm.	**E.g.,** tree planting, introduction of native species
Opportunity costs	"Opportunity cost" refers specifically to the value of the next best alternative you give up when making a decision.	**E.g.,** in relation to increased deforestation due to the expansion of farmland. Intensive farming practices lead to soil erosion and low productivity, forcing farmers to expand land to maintain production volumes.
Costs related to changes in production/land management practices	Introduction of new practices that can increase ecosystem services, like increase soil	**E.g.,** fertilizer management, cover crops, no tillage, agroforestry.

	quality and water supply.	
Cost of inaction	"Cost of inaction" encompasses all the potential negative impacts, including financial loss, missed opportunities, and reputational damage, that arise from simply not taking any action at all.	**E.g.,** Costs related to the decrease in the number of pollinators. **E.g.,** Costs related to the social license to operate

Discussion

The long-term resilience of the coffee supply chain is now inextricably linked to the health and well-being of the ecosystems it depends upon. With consumers facing higher coffee prices and companies grappling with escalating risks, from climate variability and regulatory compliance to social license to operate and potential supply chain disruptions, a proactive, integrated approach is essential. Our roadmap leads into ecological restoration, funded through the innovative mechanism of biodiversity credits, as a means of building this crucial resilience. While ecological restoration is recognized as a highly effective strategy, its implementation is often hampered by high costs (D'Albertas et al, 2024), placing a disproportionate burden on farmers and local communities, whose primary focus may be on crop productivity rather than ecological enhancements (Gastauer et al., 2021). We are also proposing to democratize this process by placing farmers, local communities, and Indigenous populations at the center of a biodiversity credit scheme, ensuring that their active participation is integral to its success (Chazdon et al. 2020). Biodiversity credits must be priced to fairly incentivize farmers (through capacity building) to adopt sustainable farming strategies and implement biodiversity enhancement actions (Pashkevich et al., 2022). These strategies and farming strategies can revolve around two targets:

1. Target biodiversity soil by implementing sustainable practices related to agroecological intensification (for instance agroforestry or cover crops), that can reduce the use of synthetic fertilizers and pesticides boosting soil health.
2. Target biodiversity in the adjacent forest patches, with activities directed to increase habitat connectivity, species diversity and ecological restoration at landscape level. These activities can have a positive impact on pollination services, and therefore on coffee productivity.

Rather than merely imposing new requirements on farmers, we envision a system where technical experts verify the generated biodiversity enhancements and where the burden of certification shifts from the individual farmer to the entire supply chain. By purchasing verified biodiversity credits, coffee buyers can secure a claim on positive environmental attributes, ensure compliance with evolving regulations such as the EU Deforestation Regulation, and proactively contribute to the long-term sustainability of their supply base.

For this concept to have high integrity and scalability, three caveats need to be in order: the first (1) is good governance and blended financial mechanism. We propose BRB Finance Coalition as investment partner, since its participation can increase investors' confidence. The second (2) is to provide a benchmark to define the integrity of biodiversity credits and their results to ensure they are used to generate value in the same supply chain. BCA and IAPB's guidelines can support this action ensuring integrity along the way, although it is possible that it will have to adapt after future iterations as the biodiversity credits market achieves maturity. The third (3) is to develop system level governance, with specific criteria to assess impacts and benefits for local people (ISS, 2024), and ecological integrity. These are some systems that could be included to be more strategic and make our value claim more efficient.

At the cooperative level, we propose a transparent mechanism where profits from biodiversity credits are channeled back to repay for the investor's initial investment by securing the supply chain and into biodiversity enhancements at landscape level, engaging with local communities and Indigenous populations. Importantly, it creates an active, collaborative model where success is not just driven by the isolated efforts of a single farmer but is supported by robust value chains that are rewarded by verifiable improvements in their biodiversity in terms of increased productivity, biodiversity, and water quality. The strategic direction is to be forward looking, and generate future resilience. This prompts the question: Can biodiversity credits go even further, functioning as guarantees of future supply, similar to commodity futures contracts? Potentially, the existence of biodiversity credits bought and owned by a coffee buyer could even be traded into new biodiversity credit schemes, within the same supply chain. We consider the limitation of the same supply chain important to avoid speculation from external traders without a real interest in the improvement of the supply chain. Most importantly, trading biodiversity credits as guarantees of future supply could resolve the problem of timing due to nature recovery time, with a model that benefits for improved productivity, biodiversity, and water quality, for both local and global users, and can ensure a competitive return on investment. We recognize that it will take time to propel transformational change, especially overcoming reluctance for new practices and new partnerships, but we believe that well-connected coffee supply chains with farmers and local communities at the heart of it operating in a symbiotic environment can foster efficiency and productivity and biodiversity protection and conservation.

Conclusion

In Brazil, the intersection of coffee production, biodiversity conservation and Indigenous rights presents both immense challenges and unparalleled opportunities. As the world's largest coffee exporter, the supply chain faces escalating, operational, reputational and regulatory risks, also physical stemming primarily from climate change vulnerability and integrity of critical ecosystems, and especially the Atlantic Forest biodiversity hotspot. However, it is this very convergence of challenges that makes Brazil an ideal landscape for innovation. Guided by the principles of biodiversity-production mutualism, where functions with biodiversity could contribute to agricultural production (Maney et al., 2024), this roadmap presented here offers a spatially explicit, data-driven framework for prioritizing interventions, engaging local stakeholders, and harnessing the power of biodiversity credits to incentivize sustainable practices. This approach has high comparability at global scale and can lead to positive change in coffee production, with its potential scalability in similar commodities. As the world prepares for COP30 in 2025, Brazil has a unique opportunity to lead the way by embracing biodiversity credits, promoting transparent and verifiable monitoring, and fostering collaboration between governments, businesses, and local communities. By seizing this moment, Brazil can unlock the full potential of biodiversity credits to build a more resilient, equitable, and nature-positive economy, not only securing the future of its coffee industry but also setting a powerful example for the world.

Abbreviation Glossary

Note: *This list contains the abbreviations used in this document along with their meanings.*

BCA – Biodiversity Credit Alliance

BRB Finance Coalition – Brazil Restoration & Bioeconomy Finance Coalition

eDNA – Environmental DNA

EUDR – European Union Deforestation Regulation

GBF – Global Biodiversity Framework

GIS – Geographic Information Systems

GDP – Gross Domestic Product

IAPB – International Advisory Panel on *Biodiversity* Credits

IBI – Index for Biotic Integrity

IPÊ – Instituto de Pesquisa Ecologica, Institute for Ecological Research

IUCN – International Union for Conservation of Nature

NbS – Nature-based Solutions

NGO – Non-Governmental Organization

OTUs – Operational Taxonomic Units

PES – Payment for Ecosystem Services

PLANAVEG – National Plan for Native Vegetation Recovery

SPV– Special Purpose Vehicle

SRS – Satellite Remote Sensing

UNEP – United Nations Environment Programme

UNEP FI – United Nations Environment Programme Finance Initiative

WCMC – World Conservation Monitoring Centre

UNDP – United Nations Development Programme

WPA – World Protected Areas

WDPA – World Database on Protected Areas

UAVs– Unmanned Aerial Vehicles

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