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Pricing Carbon for Shade-Grown Cacao Agroforestry

Carbon and biodiversity finance for smallholder agroforestry — Ecuador

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Introduction

The production of commodities continues to cause large-scale deforestation around the world, accounting for an estimated 27 percent of all forest disturbance from 2001 to 2015, higher than both forestry and wildfire disturbances (Curtis et al. 2018). One such commodity is chocolate, or cacao, over 90 percent of which is produced by smallholder farmers across tropical countries who own an average of three hectares of land (Middendorp et al. 2020). Cacao is a highly demanded product with the majority of the fine variety, genetically distinct cultivar grown in Ecuador (Middendorp et al. 2020).

While forest land is often lost to grow agricultural products, agroforestry systems offer a way for farmers to achieve crop yields while incorporating trees into agricultural land. Shade-grown cacao agroforestry systems are a critical practice to reduce deforestation, improve the health of ecosystems, and mitigate climate change (Rodríguez et al. 2022). Not only does shade-grown agroforestry reduce the growth of undesirable herbs, but these multi-strata systems allow for high biodiversity and carbon sequestration (Middendorp et al. 2020). Although more research is needed to definitively conclude, mid-level canopy shade has been found to protect cacao trees from the threat of drought while maintaining high production levels for farmers to achieve economic benefits from the incorporation of shade trees (Middendorp et al. 2020). Compared to traditional monoculture practices, cacao agroforestry systems increase above-ground biomass and conserve species diversity as well as habitat connectivity of forest ecosystems (Middendorp et al. 2018). Due to the variety of advantages offered by shade-grown cacao systems, many smallholder farmers prefer this more environmentally friendly option that regulates landscape health (Useche and Blare 2013). Conversely, there are also strong market drivers favoring monocropped systems that need to be contented with if shade-grown production practices are to be more widely adopted (Middendorp et al. 2018).

Despite an interest in agroforestry, it can be difficult for farmers to convert land and wait for trees to mature to production. Several payments for ecosystem service programs such as REDD+ have developed in tropical countries to support forest conservation and restoration while meeting the livelihood needs of local forest-dependent communities, but the integrity and scalability of these initiatives remain in need of vast improvement. Here, we offer a report of recommendations to propose insights into the feasibility of crediting systems on smallholder shade-grown cacao agroforestry landscapes to implement successful programs that allow for thriving ecosystems and communities in the long term.

Overview of Production Strategies and Carbon Yield

Cacao production can be considered along a gradient of intensification within five different typologies. Full-Sun Monocrop, Productive Shade (a monocrop productive canopy), Mixed Shade (a mix of productive and naturalized species), and Rustic or Cabruca Shade (minimal management of canopy recruitment). In a regional survey of Latin American shade-grown typologies, the typical operation included 40 to 80 different tree species, with an average of roughly 860 species per hectare. Of these, 545 were cacao, 120 banana, 96 timber, 52 fruit, and 47 palm (Somarriba et al., 2013). Landscape composition of different typologies varies regionally with some Latin American Countries consisting up to 80% in various mixed and productive shade strategies, and roughly 50% of Ecuadorian plantations in Full-Sun Monocrops (Perlin, 2022). While carbon yield increases with canopy cover, cacao yield decreases due both to the amount of cacao trees per acre, and the yield from an individual tree (Wade et al., 2010).

Though shade-grown cacao typologies can increase carbon yields when compared to full-sun plantations, they lead to a decrease in biomass when compared to uncultivated forest cover. Conversion from forest to even rustic cacao systems can lead to a significant decrease in carbon stock (Kotto-same et al., 1997). A typical mixed Mixed Shade operation in the Central American context yields 117 +/- 47 Mg ha-1, with Above Ground Biomass (AGB) accounting for 49+/- 35 Mg ha-1(Somarriba, 2013).

Carbon Crediting

Enabling the implementation of any carbon crediting development is predominantly a task of minimizing project costs. These costs can be understood in terms of Abatement and Transaction costs. Abatement cost corresponds to the opportunity cost of undertaking carbon projects rather than the most profitable alternative, including the alternative of moving from smallholder to large-holder plantations. Opportunity cost of labor is lower for smallholders. Additionally, large plantations are typically closer and more connected to markets, and in geographies better suited to agriculture. All these components lean toward the benefit of smallholders for carbon investment. Credit access however is typically more readily available for larger plantations. Intertwined with credit is the issue of tenure security, which is typically more tenuous for smallholders (Cacho et al., 2003). Transaction costs include the search, negotiation, approval, administration, monitoring, enforcement, and insurance. Fixed costs could be optimized through the pooling of multiple smallholders into a single project. Variable costs would mostly be associated with labor, and any tasks that could be passed to smallholders with adequate training could prove advantageous when considering their comparatively cheaper labor costs.

While current carbon project development has focused on largerholder operations, smallholder projects are not inherently adverse to carbon finance, and many features could be considered advantageous. An array of best-practices could be employed to minimize both Abatement and Transaction costs. This includes the dissemination of information on suitable and profitable production systems to smallholders which would decrease the search costs of starting a new project. Smallholders could also be trained in inventory methods for carbon measurements, and an efficient randomized auditing system could be designed to ensure inventory quality. This auditing could be paired with simplified baseline and monitoring methods for smallholders while still upholding similar levels of quality. Selecting cohesive communities, promoting tenure security, encouraging community self-regulation, and implementing participatory project design would minimize administration, enforcement, and insurance costs. The promotion of common property could facilitate the benefits of project bundling (Cacho et al., 2003).

Biodiversity crediting

Although a nascent field, the opportunity for organizations to contribute to biodiversity conservation is rapidly emerging toward the pace of carbon credit programs. Early offsetting schemes for endangered species habitat protection have been recorded in California in the early 2000s, and refined programs are now offered by a variety of companies that can use state-of-the-art monitoring methods such as remote sensing, bioacoustics, and eDNA depending on best practices for different indicator species (Tedersoo et al. 2024).

One metric known as the Biodiversity Impact Credit connects population sizes to long term species survival in order to account for species longevity in the ecosystem beyond the initial crediting period (Rossberg et al. 2024). Another tool aims to reward climate-smart agriculture by combining ecological quality and spatial distribution of 32 factors known to enhance biodiversity specifically on farmland (Birrer et al. 2014).

Biodiversity crediting programs have significant global potential, yet certain limitations continue to challenge broader trust in their viability. Most importantly, it should be understood that biodiversity crediting is less effective than mitigating initial habitat loss and functions as a secondary resort. When damage has already taken place, biodiversity credits may then face issues related to compliance and transparency (Gonçalves et al. 2015). A major quantification challenge with any payment for ecosystem service programs is the accuracy of baselines. These values must be updated frequently and verified by unbiased parties (Gordon et al. 2015). In addition to proper baselines, if the biodiversity credit is marketed as an offset, the units need to fairly compensate for ecosystem-wide health and function (Gonçalves et al. 2015). In order to bolster the ecosystem to account for what is lost, the crediting project has to prove additionality in its development of increased biodiversity (Gonçalves et al. 2015). Further, these projects are at risk of placing the burden on concerned stakeholders beyond the entity causing ecosystem degradation. In some cases, the offset restoration project is carried out by volunteers who had nothing to do with the habitat loss (Gordon et al. 2015). To remedy this discrepancy, it is imperative for the people responsible for damage be held accountable to fully support the associated biodiversity crediting project.

Social Context of multi-use systems (Melo, 2013)

To evaluate opportunities for intervention within existing production regimes, a review of the agrarian context within Ecuador's Wet Tropical Forest, a region of high suitability for cacao agroforestry is provided. A gradient of land-use intensity runs North to South, with more forest fragments present in the north in parallel with distributed smallholders, and more extensive forest clearing in the south with larger more intensive production. The entire region however is synonymous with agrarian livelihood. Early settlement clearing was spurred by government incentives and expanding mobility infrastructure, reaching a peak of land clearing in the 1970s. Since the 1990s clearing for commodity production and semi-subsistence has been self-sustaining. Anthropogenic drought from areas of earlier deforestation has been a major driver of continued migration into the northern frontier.

A survey of smallholder communities in a remote portion of Esmeraldas Province records 90% of operations include cacao production. The average smallholder has 20 hectares of land, with 50% in cacao and the rest in cattle. The overwhelming majority of survey respondents had completely cleared their land of forest cover. More than half focused production on sun-grown hybrid varieties, and the share of farmers adopting these hybrids is increasing. Income from cacao averages $212, while household expenses are $193 for stables and utilities.

Previous systematic attempts at promoting and supporting shade-grown cacao with native heirloom varieties met with failure due to a swathe of logistic barriers that span local, regional, and international considerations. Alternative Food Networks were seen as a solution to counter unsustainable and unethical practices. The business case posited that a premium price for the niche market of higher quality nacional varieties would compensate for their lower productivity in shade-grown plantations. Additionally, it was figured that the elimination of exploitative middlemen would add more of the value chain to the pockets of smallholders. While high international commodity prices buoyed this scheme from 2004 to 2007, 2008 onward saw lower international cacao prices and undermined the high-quality market in particular. Certification alone was not enough to gain access to premium markets, and heirloom varieties were undervalued on the international market. Farmers had difficulty meeting quality standards for processing with middlemen eliminated from the value chain. Fundamentally, this approach does not avoid an inherent imbalance between the producers and consumers, where the former are dependent on this system for their livelihood but the latter benefit from optional participation. The contradiction between adequate payments to farmers and high quality products persisted. Today, many producers view shade-grown production with suspicion.

Monitoring, reporting, and verification

Any nature-based solution project must have some way to assess its progress toward goals that are outlined in planning and evaluation phases. Monitoring is essential for documenting data as well as informing subsequent management practices, and the best monitoring methods will depend on the objectives of the project. In this case, methods will need to address both carbon and biodiversity metrics.

Carbon monitoring

In order to receive carbon credits as a form of payment for forest conservation and restoration, it is important to effectively monitor and accurately report carbon stocks through scientifically viable methodologies. Standard practice using remote sensing to estimate carbon requires canopy height models and allometric equations (Chave et al. 2014). Given the species wood density, diameter at breast height, and tree height, biomass can be calculated which corresponds to carbon content.

Instead of recording tree height for each individual on the ground, the advent of remote sensing technology has allowed for the generation of canopy height models to map tree height across a landscape (Gyamfi-Ampadu and Gebreslasie 2021). Light Detection and Ranging (LiDAR) as well as Radio Detection and Ranging (RADAR) sensors offer researchers the ability to build structural models of landscapes, ranging from drone-based sensors to NASA's Global Ecosystem Dynamics Investigation (GEDI) which has global coverage available (He et al. 2024). There are also a variety of platforms to generate forest carbon and disturbance metrics in a given region. A new tool called REDD+AI by the nonprofit CTrees allows for users to input any region and receive metrics of forest loss as well as specific attribution including logging, roads, and fires at the five-meter resolution level. This can be used to monitor forest degradation and inform areas of need for sustainable agriculture, especially if agricultural land shifts from changing climate (Dalagnol et al. 2023).

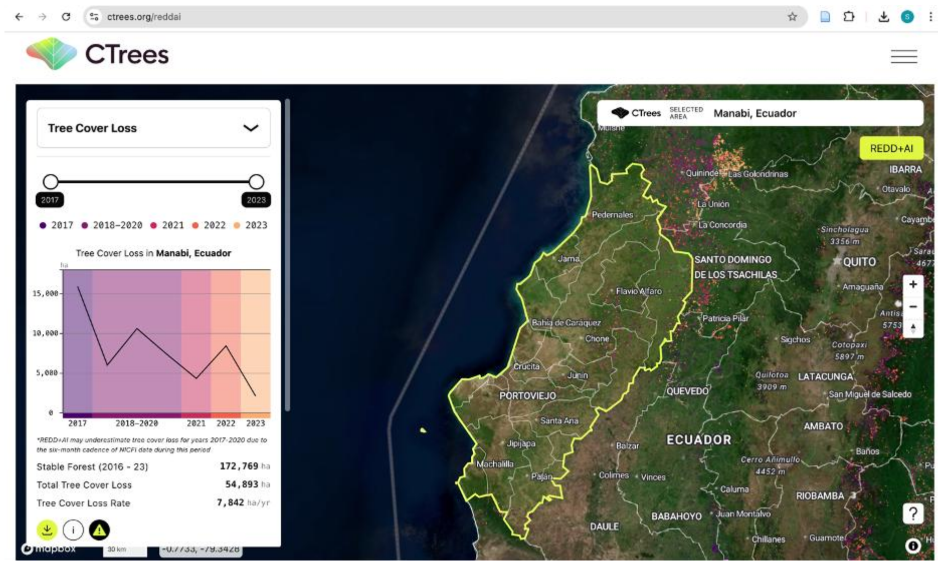


Figure 1: A view of the REDD+AI web-based platform to track forest cover and degradation.

Biodiversity monitoring

While carbon is a widely implemented community financing mechanism, this single metric alone does not meet the many other needs of a healthy forest ecosystem. One other way to assess the integrity of a forest landscape is the monitoring of biological diversity in that space. Approaches to recording biodiversity should be centered around the widely regarded Essential Biodiversity Variables that refer to a set of parameters to measure change in biodiversity (Mulatu et al. 2017). These variables should be centered around species metrics and can include information about species traits, populations, community composition, ecosystem function, and structure. All of these classes are measurable through a variety of methods, many of which fall into field-based or remotely sensed categories.

Remote sensing offers an opportunity to efficiently monitor ecosystems at the landscape scale. High spatial and spectral resolution sensors have made large advances in recent years to provide key insights into biodiversity monitoring. In addition to the improvement of available imagery, the combination of remote sensing with machine learning allows for habitat suitability and classification models (Reddy et al. 2024). Further, sensors with LiDAR and RADAR allow for structural insights that indicate suitable habitat for certain species (Bae et al. 2019). When structural information is combined with optical imagery, it is possible to map functional diversity across scales (Schneider et al. 2017). One platform to map biodiversity is Bioflore. This web-based application created by scientists in Brazil allows users to upload imagery and generate species classification predictions. Beyond ecological metrics from technological monitoring, it is also very important to incorporate traditional ecological knowledge when possible (Reddy et al. 2024). Especially in regard to biodiversity, there is a lot to be learned from ecological memory about an ecosystem, especially when documenting conservation and restoration of species.

Challenges and opportunities in scaling up

Cacao agroforestry systems are a promising solution to the loss of tropical forests while providing financial stability for local communities. However, certain challenges remain obstacles to scaling crediting programs in this land use type. Land tenure is an ever-present issue across geographies that causes turnover in management of natural resources (Enrique et al. 2020). This is also a gender equality issue in most countries where cacao is produced since women do not have as much access to farmland as men, and women are not as connected to leadership positions or certification services that allow for strategic financing (Fountain & Hütz-Adams 2020).

In addition to social conditions, there are ecological threats to increasing the scale of cacao agroforestry. In a study that applied climate models through 2050 to the West African cacao belt, it was found that maximum dry season temperatures may severely limit dry season cacao production beyond water availability (Schroth et al. 2016). Climatic changes are set to affect growing conditions in the tropics such that production sites may be forced to shift, leading to further deforestation and new land conversion. For example, a simulated drought study in Sulawesi, Indonesia found that soil respiration decreased due to changes in root activity and lower decomposition rates (van Straaten et al. 2010). Increased conversion of healthy forest ecosystems highlights a challenge with the “land sharing” as opposed to “land sparing” philosophy with threatened species at higher risk of population declines when the land is managed for agriculture (Fischer et al. 2008). In addition to biodiversity beyond the farming crops, many Theobroma varieties such as Copoazu (*Theobroma grandiflorum*) and Macambo (*Theobroma bicolor*) do not get chosen for growing due to government funding for mainstream cacao crops (Lagneaux et al. 2021).

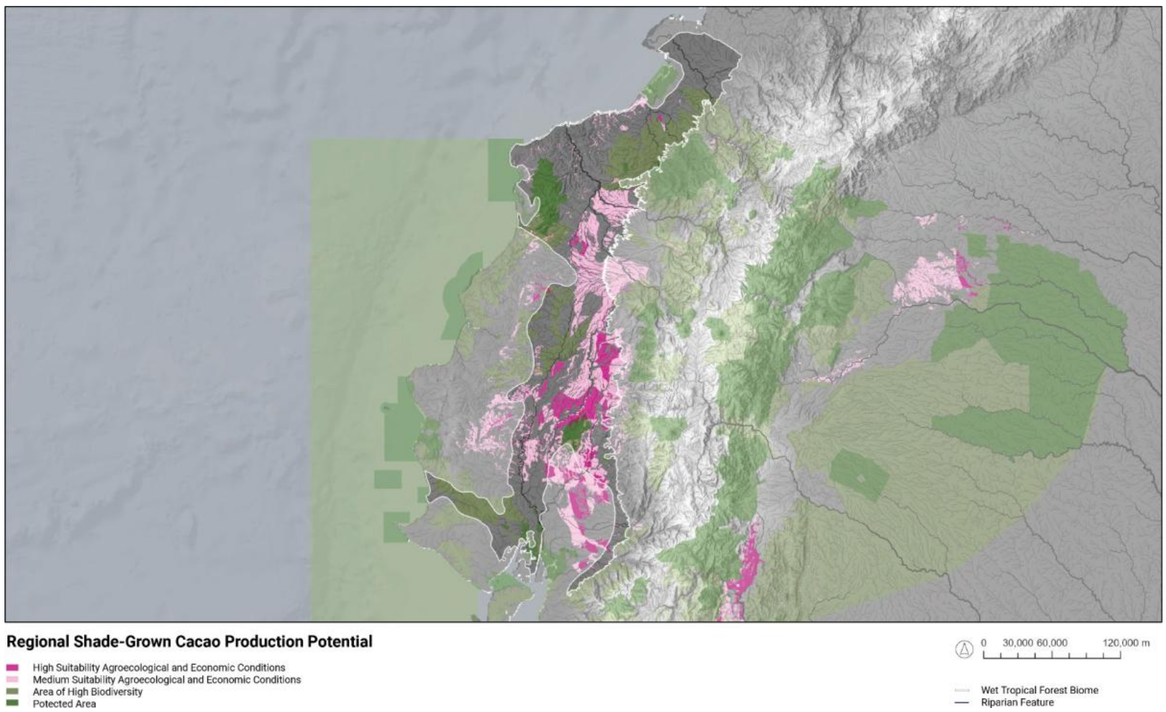
When scaling multi-strata agroforestry systems, it is important for farmers to have decision-making power in setting purchase prices. Currently, this is a point of struggle for many farmers (Kroeger et al. 2017), but there are opportunities to improve the flow of products from the farm to the store. It has been found that smallholder farmers involved in direct trade were able to secure higher prices for sales and had greater support in agricultural training as well as social networks. There are many positive externalities of farmers engaged in direct trade such as mitigated pesticide use with a correlation of direct trade and organic certifications (Middendorp et al. 2020). It is very important for farmers to have access to cooperatives and connections to supportive organizations as much as possible. This is why nonprofits like Third Millennium Alliance that mobilize funding from larger organizations like USAID to ensure that farmers have robust payment programs to establish agroforestry systems with leadership from within the local community. When creating economic models for larger scale organization of agroforestry, it is crucial to account for production decisions besides strictly monetized components such as farm geography and household demographic information (Useche and Blare 2013). Ultimately, cacao is a high-export product out of several tropical countries in West Africa, Southeast Asia, and Amazon countries (Enrique et al. 2020). With such high supply and demand of this commodity, certifications such as the European Union Deforestation Regulation could be a path to sustainable production, but these certifications must ensure stakeholder engagement from all involved countries. To ensure true positive impact and adaptation, scaling must include influence of political systems and support from impactful organizations, never losing sight of local needs and values.

Critical thresholds in the price of carbon can influence the logic of shade-grown systems. Studies show that at $5/Ton, which reflects the domestic carbon price of many South American markets, intensive cacao with 40% land-sparing yields twice the economic return as equivalent acreage in shade-grown operations, even when considering a price premium for heirloom varieties (Middendorf, 2018). $30/ton presents a tier that would reliably make shade-grown operations a 2-4x higher investment. These figures do not consider additional income streams from canopy fruit or timber harvest, and other PES.

Geospatial analysis:

To put these report findings into practice, we conducted several geospatial analyses to understand how shade-grown cacao could be integrated within opportunities for carbon and biodiversity benefits. All analyses include protected areas and a dataset of Key Biodiversity Areas as defined under the International Union for Conservation of Nature Red List of Threatened Ecosystems or as ecosystems where there is globally outstanding ecological integrity (BirdLife International 2024).

Shade-Grown Cacao Production Potential



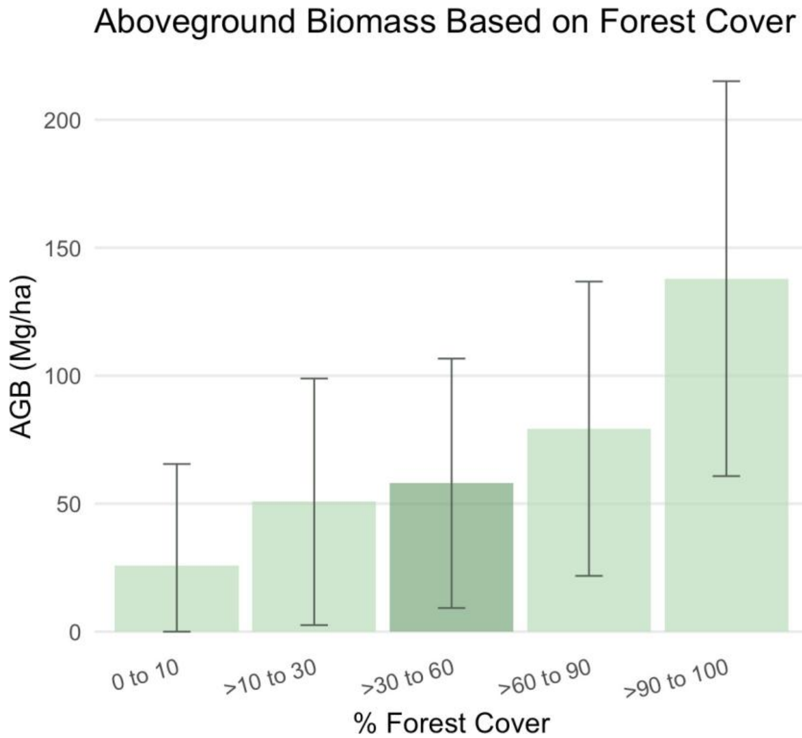
Here, we identified areas with high biophysical and economic potential for shade-grown cacao agroforestry by overlaying protected areas, key biodiversity areas, and cacao economic agro ecological zones from Ecuador's Food and Agriculture Ministry (area that comprises geographic spaces that integrate similar biophysical characteristics of soil, physiography and climate, with the economic conditions of infrastructure and support services for the production of cocoa crops).

This map has implications for cacao agroforestry suitability strategies and land use planning. By highlighting areas with the highest suitability, this analysis shows where interventions could be prioritized, reducing deforestation, and optimizing cacao yields based on economic practicality. These insights can guide organizations to focus on regions with the greatest potential for agroforestry programs. Connecting back to the report, this map serves as a spatially explicit example of how integrating multiple ecosystem services (e.g., key biodiversity areas) can support agroforestry systems that align with REDD+ or other PES programs.

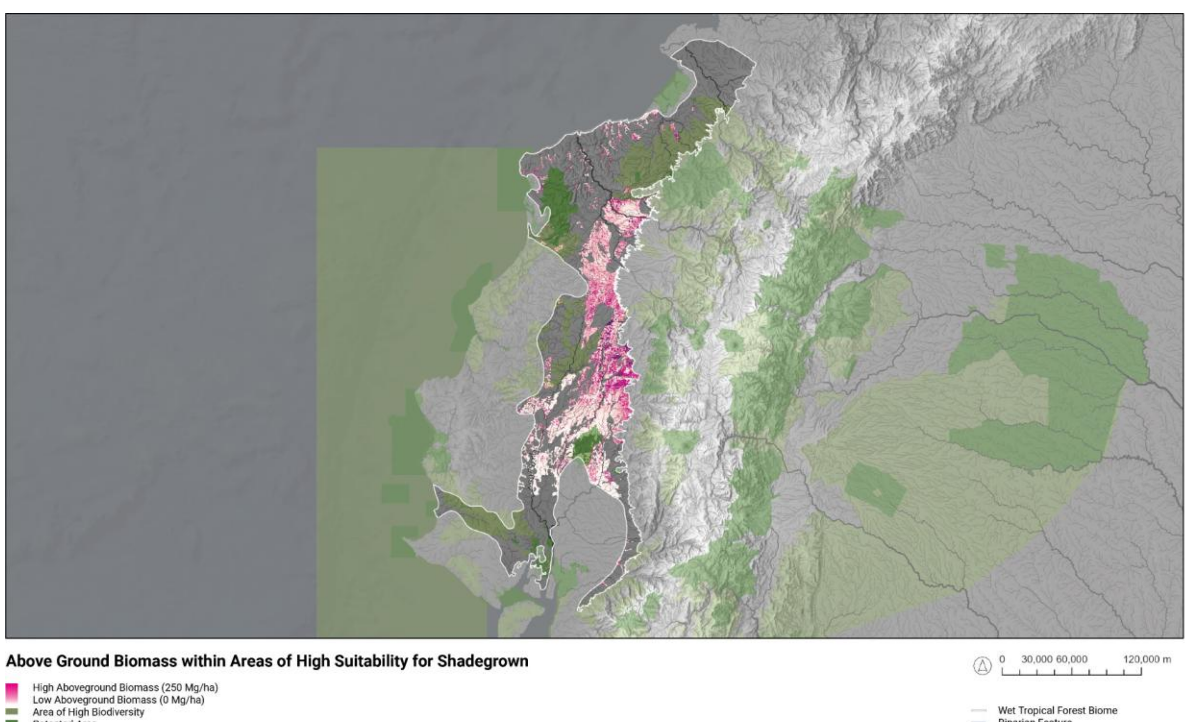
A qualitative finding from this region of high suitability for shade-grown cacao production is its strategic potential as a connective matrix between many protected areas and high-biodiversity areas. To align with this potential, management practices that meet thresholds for high-quality matrix habitat could be implemented to promote connectivity between areas of key biodiversity while making reasonable concessions to income-generating land use. These regions could align with opportunities for additional income streams from timber and fruit canopy species en-liu of prioritization for more rigorous practices focused exclusively on biodiversity. High-suitable cacao areas also fall within areas of high biodiversity, which would align with a management approach that weights income from biodiversity and carbon credits over maximization of cacao yields. The distinction between high and medium economic and agroecological suitability for shade-grown cacao could also inform levels of production scale and intensity with consideration to alignment with abatement and transaction costs. For example, areas of high-economic suitability benefit from mobility infrastructure and connection to markets, which would point to higher potential opportunity cost for decreased productivity and a higher suitability for more intensive and larger-scale production. Regions of lower economic suitability may be more appropriate for lower intensity small-holder operations that rely more on subsidies from carbon and biodiversity crediting.

Relationship between Aboveground Biomass and Forest Cover

Within Ecuador's Wet Tropical Forest biome, the relationship between forest cover and above ground biomass was analyzed. This offers a rough estimate of the amount of carbon financing available for shade-grown systems. A typical shade-grown cacao operation provides approximately 30% forest cover, which in this bioregion yields around 50Mg/ha of AGB. These statistics are in-line with broader regional surveys for aboveground biomass in shade-grown cacao plantations (Somirriba, 2013). These figures also provide a sense for the upper bound of biomass that would be available for carbon financing if additional forest cover was prioritized.



Aboveground Biomass Estimates in High-Suitability Areas



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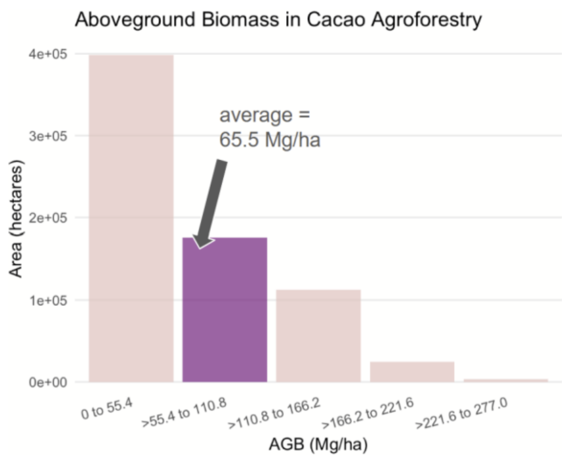
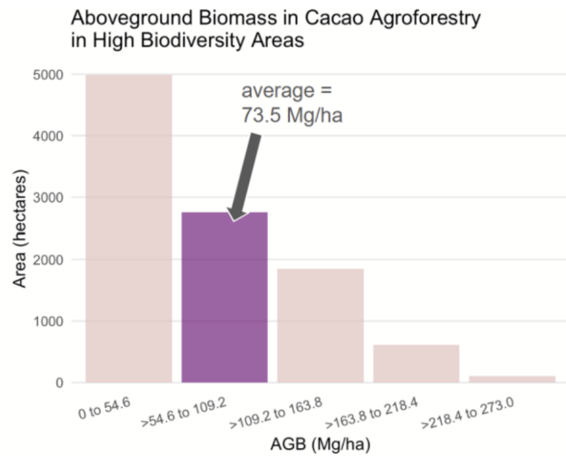


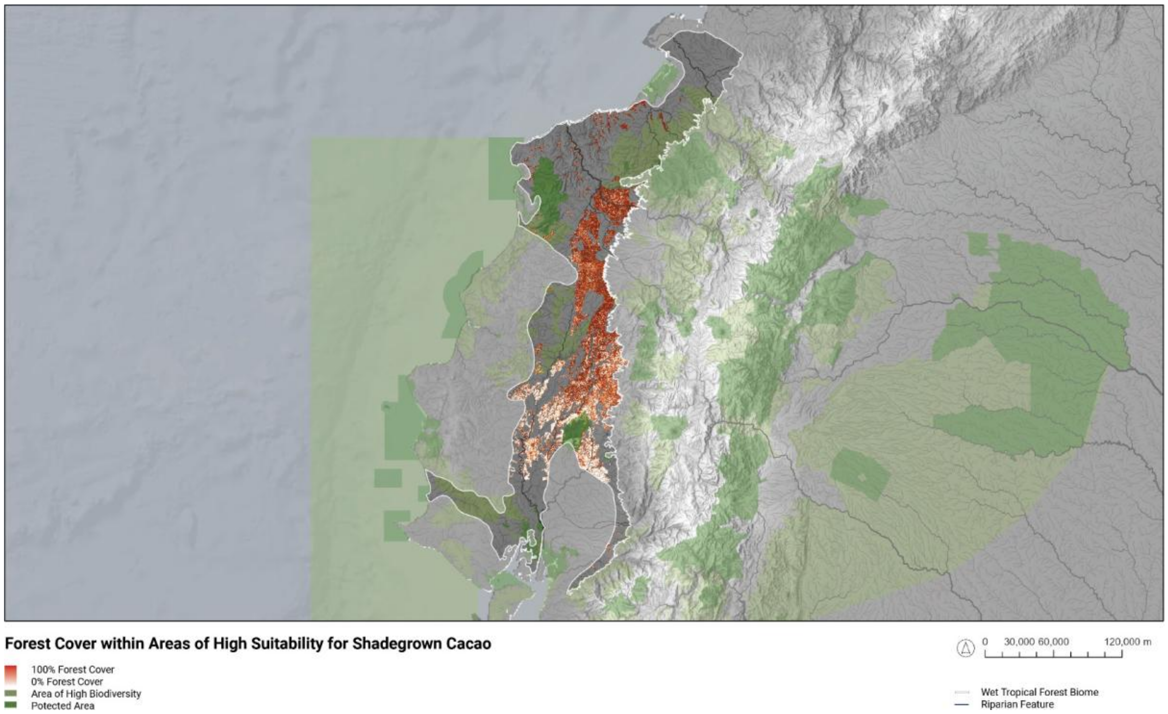


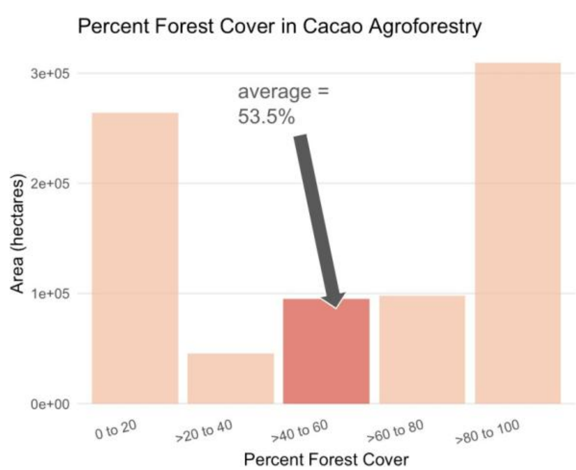
We quantified aboveground biomass (AGB) within areas suitable for shade-grown cacao and viewed distribution across various intervals, including a focus on high biodiversity areas. These biomass estimates are provided by the European Space Agency Biomass Density Dataset from 2021 (Santoro et al. 2024).

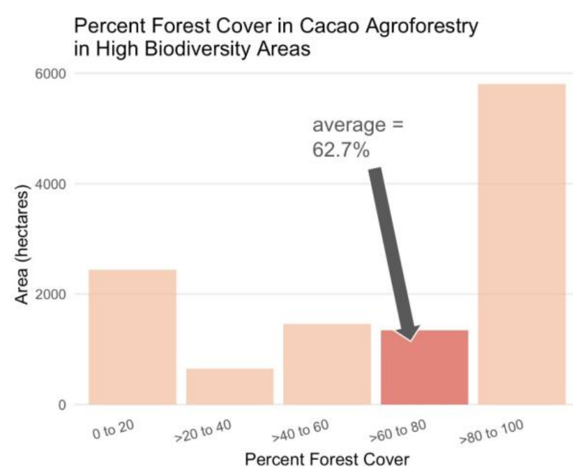
Generating AGB estimates helps to demonstrate the carbon storage potential of cacao agroforestry systems as a climate change mitigation strategy. This analysis reinforces the possibility of shade-grown cacao systems achieving both production goals and carbon yield to maximize sustainable economic pathways for farmers. Focusing on higher AGB in biodiversity-rich areas also helps to emphasize the dual benefits of preserving biodiversity and enhancing carbon sequestration.

Roughly 40,000 hectares have biomass values below the yield of an average shade-grown cacao plantation. Given a modest improvement of 25Mg/ha using shade-grown methods, there is a potential for 1 million Mg/ha of additional carbon storage. Within high biodiversity areas, roughly 5,000 hectares could be targeted for improvement.

Forest Cover Estimates in High-Suitability Areas







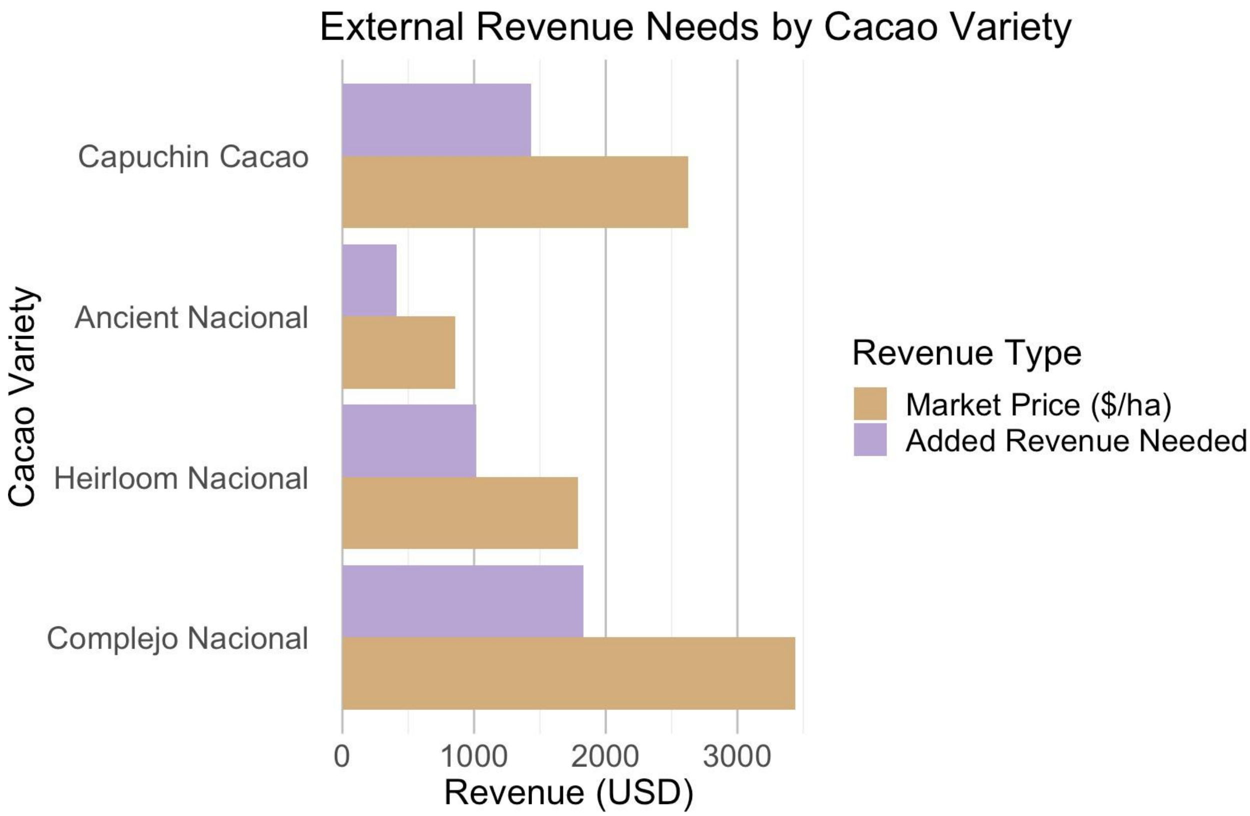
For this analysis, we measured forest cover in areas suitable for shade-grown cacao and in biodiversity-rich areas, categorizing the data into bins and providing averages. Forest cover data are from Global Forest Watch platform (Global Forest Watch 2014).

These findings demonstrate how shade-grown cacao systems can be implemented without compromising existing forest cover, allowing high-integrity forest cover to be conserved while still meeting local livelihood needs. Roughly 25,000 hectares of deforested land have the potential for conversion to shade-grown practices given a target of 30% forest cover.

Market Price and Revenue Shortfalls

		Yield (kg/ha)		Revenue ($/ha)		Revenue Shortfall ($/ha)		Carbon Price to Meet Shortfall		Additional Revenue given a $5 Carbon Price	
Cacao Variety	Shade Level	Wet Cacao	Dry Cacao	Market Price	Capuchin Price	Shortfall to Capuchin Price	Shortfall to Market CCN-51	Carbon Price to Meet Shortfall	Carbon Price to match CCN-51	Shortfall to Capuchin Price	Shortfall to Market CCN-51
CCN-51	Full Sun	5,600	2,000	$4,074	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nacional	Full Sun	3,080	1,100	$2,241	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nacioanl	30-40% Shade	2,520	900	$1,833	$5,554	$3,721	$2,241	$33.22	$20.01	$3,151	$1,671
Nacional	30-40% Shade	1,400	500	$1,019	$3,086	$2,067	$3,055	$18.46	$27.28	$1,497	$2,485
Nacional	30-40% Shade	700	240	$409	$1,543	$1,134	$3,665	$10.13	$32.72	$564	$3,095
Cacao	30-40% Shade	1,967	703	$1,431	$4,336	$2,905	$2,643	$25.94	$23.60	$2,335	$2,073

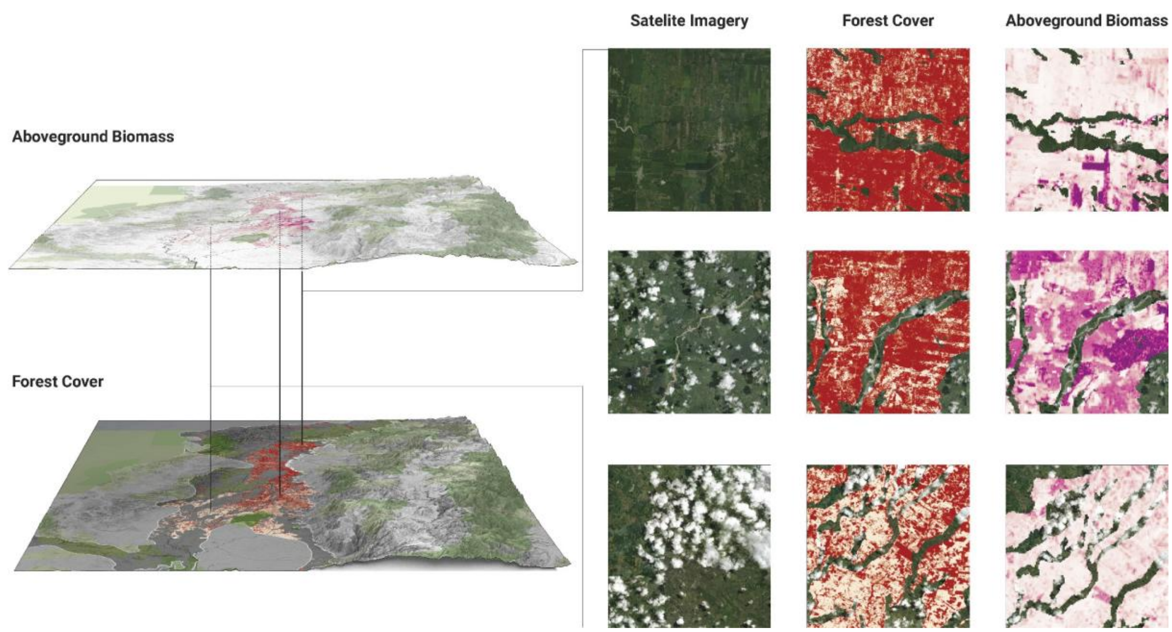
In this economic analysis, we compared market prices for different cacao varieties to full-sun varieties for both market-rate and subsidized prices as informed by the operations of the Third Millennium Alliance, a Non-Profit working to promote adoption of shade-grown cacao practices. We then calculated shortfalls and the amount of revenue needed from fruit, timber, and other agroforestry products beyond cacao to supplement income assuming that farmers could also generate revenue from carbon credits matching prices of neighboring regions. We then charted the difference in current prices and revenue needs to see how the discrepancy compares across shade-grown cacao varieties. With a carbon price between $20 and $30 per Mg, most shade-grown operations could match the market rate for sun-grown varieties, as well as the premium subsidy offered by TMA. These findings are in alignment with other studies, that identify a rough threshold of $30 Mg/Ha to incentivise adoption of shade-grown systems (Middendorp et al., 2018). In a more modest scenario for $5/Mg, which is in alignment with the domestic carbon price of neighboring countries in South America, additional revenue ranging from $1500 to $3000 per hectare would be needed to match the sun-grown market rate per hectare.



This table highlights the financial barriers that prevent smallholders from transitioning to shade-grown cacao while addressing potential to supplement income from cacao alone. All shade-grown cacao varieties had similar proportional needs of about double what they currently offer farmers to provide financial stability

Knowledge Gaps

A more accurate spatial mapping of existing LULC within Ecuador's wet tropical forest bioregion would offer a more precise analysis. Several datasets purport to provide LULC for Ecuador and the broader South American context, but the classifications are too generalized for crop-based analyses, and also exhibit misclassifications at the site-scale. This data gap prevents our analysis from understanding the location and extents of existing cacao production. Such a dataset would provide a basis for scenario planning that could include spatially-explicit variations in revenue, gains in carbon, and benefits to biodiversity given a range of interventions. Available datasets for forest-cover also lack the accuracy and resolution for a region-specific analysis, though workflows have been developed to provide bespoke high-resolution forest-cover data for specific areas of interest (Browne). Lack of accuracy in forest cover mapping leads to an obscured relationship between forest cover and above ground biomass. Without additional quality control, it is not apparent whether variation in aboveground biomass is due to differences in biomass between different forest regions, or due to difference in forest cover. A cursory visual comparison between the two datasets is provided below in which inconsistency is readily apparen



Conclusions

The adoption of shade-grown practices in cacao agroforestry presents an opportunity for climate mitigation and the implementation of landscape-scale conservation planning while sustaining agrarian livelihoods. Financial barriers to adoption of these techniques may be partially mitigated by carbon and biodiversity financing, as well as supplemental revenue from fruit and timber of canopy species. The price of carbon and biodiversity credits have a substantial impact on the feasibility of adoption. Large scale implementation will necessitate adopting these strategies to small-holder operations. Improvements in geospatial products can facilitate planning for these interventions and provide a more accurate estimate of the potential impacts for mitigation uplift and regional economic impact.

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