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Environmental Impacts and Transitions across Illicit, Informal and Licit Economies in Colombia: Coca-Cocaine, Gold, and Cattle

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Acronyms

ANLA: National Environmental Licensing Authority (*Autoridad Nacional de Licencias Ambientales* in Spanish).

ANT: National Land Agency (*Agencia Nacional de Tierras* in Spanish).

AUC: United Self-Defense Forces of Colombia (*Autodefensas Unidas de Colombia* in Spanish).

COP: Colombian Peso.

EMC: Central Armed Command (*Estado Mayor Central* in Spanish).

FARC-EP: Revolutionary Armed Forces of Colombia – People's Army (*Fuerzas Armadas Revolucionarias de Colombia – Ejército del Pueblo* in Spanish).

FPA: Final Peace Agreement between Colombian Government and the FARC-EP. FINAGRO: Fund for the Financing of the Agricultural Sector.

GDP: Gross Domestic Product.

ICA: Colombian Agricultural Institute (*Instituto Colombiano Agropecuario* in Spanish).

JAC: Community Action Boards (*Juntas de Acción Comunal* in Spanish).

OAG: Organized Armed Groups.

PCIM: Comprehensive Consolidation Plan of La Macarena (*Plan Consolidación Integral de La Macarena* in Spanish).

PECIG: Program for the Eradication of Illicit Crops by Aerial Spraying of Glyphosate (*Programa de Erradicación de Cultivos Ilícitos mediante Aspersión Aérea de Glifosato* in Spanish).

PNIS: National Comprehensive Program for the Substitution of Illicit Crops (*Programa Nacional Integral de Sustitución de Cultivos de Uso Ilícito* in Spanish).

PNN: National Natural Parks of Colombia (*Parques Nacional Naturales de Colombia* in Spanish).

PES: Payments for Environmental Services.

SIMCI: The Integrated Illicit Crop Monitoring System UNODC: United Nations Office on Drugs and Crime.

ZME: Special Management Zones (*Zonas de Manejo Especial* in Spanish).

Glossary

Alluvial Gold: extraction of gold from river deposits using manual or mechanical methods that take advantage of the natural movement of water to separate gold from sediment (UNODC, 2016).

Alternative Development: approach in drug supply reduction programs aimed at preventing and eliminating illicit crops through voluntary substitution and addressing the structural causes that have led rural populations in the Global South to cultivate coca, poppy, and cannabis for subsistence (DNP, 2023, p. 26).

Adverse Possession: legal mechanism that enables a person to acquire land ownership after proving prolonged occupation of the property (Ministerio de Justicia, 2021).

AUC (*Autodefensas Unidas de Colombia* in Spanish): Colombian far-right paramilitary group which was active between 1997 and 2006.

Community Action Boards: according to Law 743 of 2002, a community action board (*Juntas de Acción Comunal*) is "a civic, social, and community organization of social management, non-profit, with legal status and its own assets, voluntarily integrated by the residents of a place who join efforts and resources to pursue integral, sustainable, and enduring development based on the exercise of participatory democracy [sic]" (Law 743, 2002, Art. 8).

Community Councils of Black Communities: legal entity representing a Black Community and exercising the highest authority in the internal administration of Black Communities' Lands, in accordance with constitutional mandates, Law 70 of 1993, Decree 1745 of 1995, and the community's own legal system (Decree 1745, 1995).

Collective Territories: areas legally recognized as collective property of indigenous peoples and Black communities, under the figures of Indigenous Reserves or Community Councils. Collective Territories are managed autonomously by their communities, with their own management plans in harmony with their culture and traditions, under criteria of environmental protection and sustainable land management (Mosquera, Tapia, and Tamayo, 2015).

Department: first-level territorial entity in Colombia with autonomy for the administration of sectional affairs, and the planning and promotion of economic and social development within its territory, in accordance with the terms established by the Constitution and laws (ANT, 2022, Political Constitution of Colombia of 1991).

Dual-purpose Cattle Farming: traditional livestock system focused on the simultaneous production of both meat and milk, using crossbred animals from breeds specialized in either meat or milk production (DANE, 2015).

EMC (*Estado Mayor Central* in Spanish): organized armed group of FARC-EP dissidents.

Extensive Cattle Ranching: traditional livestock model characterized by the occupation of large tracts of land with low animal density. The animals feed directly on the natural resources available on the land, without the use of pasture improvement techniques. It is also common not to use fences to enclose the entire pasture, allowing the animals to roam freely within designated areas (Mora Marín et al., 2017).

FARC-EP: former guerrilla group which demobilized in 2016 with Final Peace Agreement with Colombian Government.

FARC-EP Bloc: primary unit of the military structure of the FARC-EP, composed of several fronts. At the time of the Final Peace Agreement of 2016, the FARC-EP had seven blocs divided by region: i) Southern Bloc; ii) Eastern Bloc; iii) Western Bloc; iv) Middle Magdalena Bloc; v) Caribbean Bloc; vi) Northwestern Bloc; vii) Central Bloc.

FARC-EP Dissidents: former members of the FARC-EP who decided to form new armed factions after or during the Final Peace Agreement process (FIP, 2018a).

FARC-EP Front: formation of several guerrillas of the FARC-EP. These units make up the blocs and are located in specific regions of the country.

Forest Reserves of Law 2 of 1959: in situ conservation areas, integrated into the environmental planning of territories along with the protected areas of the National System of Protected Areas (SINAP), to promote the conservation of natural resources, regulated by Decree 2372 of 2010 and Decree 1076 of 2015 (Law 2, 1959). The zoning of the Forest Reserves under the Second Law, carried out by MADS, is adapted to environmental conditions. Zone Type A protects essential ecological processes and biological diversity. Zone Type B promotes sustainable management of forest resources and biodiversity, also integrating agricultural activities in the Central Forest Reserve due to its economic importance. Zone Type C allows productive activities such as agroforestry and silvopasture, as long as the natural forest is conserved.

Indigenous Reserves: areas recognized as "collective property of the indigenous communities for which they are established, and according to Articles 63 and 329 of the Political Constitution, they are inalienable, imprescriptible, and unseizable. [...] They are a legal and socio-political institution of a special nature, formed by one or more indigenous communities that, with a collective property title that enjoys the guarantees of private property, possess their territory and govern it and their internal life with autonomous organization protected by indigenous jurisdiction and their own legal system (Decree 2164, 1995, Art. 21). These are regulated by Law 89 of 1890, Law 21 of 1991, and Decree 2164 of 1995.

Intensive Cattle Ranching: livestock model focused on maximizing productivity by using technologies to supply markets with products such as meat, milk, hides, among others. One of its main features is that animals are raised in confined spaces, where temperature, light, and humidity conditions are controlled artificially to accelerate production processes (Mora Marín et al., 2017).

Local Moran's I (LISA): index used in spatial analysis to identify and visualize local spatial patterns. Unlike its global counterpart, LISA allows analyzing the relationship between the values of each pixel or area with its neighbors, detecting significant clusters. LISA analysis classifies these values into four main categories: High-High, Low-Low, High-Low, and Low- High, facilitating the interpretation of local spatial correlations and the identification of clusters or spatial anomalies.

Mixed Cattle Ranching: livestock model that combines periods in which animals are confined in barns with others where they are allowed to graze in pastures. Its aim is to optimize feeding during fattening and lactation phases, and it contributes to pasture renewal and animal welfare, as the animals experience less stress due to their freedom of movement, which consequently increases their productivity (Mora Marín et al., 2017).

Organized Armed Groups: according to Article 2 of Law 1908/18, the Organized Armed Groups (OAG) are those who, under the direction of a responsible command, exert sufficient control over a portion of the territory to conduct sustained and coordinated military operations. The OAGs are defined by the following criteria: i) the use of armed violence against the Military Forces, other State institutions, the civilian population, civilian property, or other armed groups; ii) the capacity to generate a level of armed violence that surpasses the intensity of riots or internal disturbances; iii) the existence of a structured organization and leadership capable of exerting control or direction over its members, enabling them to use violence against the civilian population, civilian property, or Military Forces within national territory (Law 1908, 2018, Art. 2).

Peasant Reserve Zones: rural areas recognized through Law 160 of 1994 as territories aimed at protecting the rights of peasants over land and preventing the concentration of rural property (Law 160, 1994). In addition to Law 160 of 1994, they are regulated by Decree 1777 of 1996.

Public Lands: property belonging to the Nation, located in rural areas, which generally must be granted to those who occupy it, provided they meet the requirements established by agrarian reform legislation, in cases where adjudication is possible (ANT, 2018).

***Vereda*:** territorial subdivision of Colombian municipalities, usually consisting of small rural communities.

Executive Summary[1]

Illicit economies have been related in complex ways to the armed conflict and criminal governance in Colombia (CEV, 2022; Rettberg, Cárdenas, Ortiz-Riomalo, 2017). The development of these activities, along with state responses to control them, have had significant consequences for local economies and have also impacted the environment (Brombacher, Garzón & Vélez, 2021; UNODC, 2022; UNODC, 2021; Rubiano, Vélez & Rueda, 2020). The aim of this report is to analyze the functioning of the coca, cocaine, and gold mining production markets in Colombia to assess their relationships with environmental damages, such as deforestation. In addition to the functioning of these markets, this research explores the interactions of these illicit activities with other productive sectors that also generate environmental costs, such as cattle ranching. This research was conducted using a mixed-methods approach, integrating quantitative, spatial, and qualitative data based on field work conducted in three field sites. Using quantitative and spatial methods, it presents a comprehensive analysis of national dynamics on how these economies drive deforestation, influence environmental degradation, and interact with local socio-economic dynamics. The report also includes a qualitative component with insights from case studies in Meta, Putumayo, and Nariño and a literature review of the state's responses to the economies under study.

Coca and Cocaine Economy

Colombia produces 70% of the world's cocaine (UNODC, 2019b) and is responsible for 71% of worldwide coca bush cultivation (UNODC, 2024). Coca cultivation has become concentrated in 15 productive enclaves, primarily in the Pacific region, and departments such as Putumayo, and Norte de Santander. Recent trends show a geographical shift towards border protected areas and regions with high ecological value, including Indigenous Reserves, Afro-descendant Community Councils, National Natural Parks, and Forest Reserve Zones. These areas now host 59% of coca cultivation (UNODC, 2023). The geographical concentration of coca cultivation in environmentally strategic areas further exacerbates threats to biodiversity and ecological stability.

[1] The authors would like to thank David Chaparro and Catalina Leal for their research assistance, as well as the local teams who supported the coordination of fieldwork activities. We are also grateful to GI-TOC for providing funding for this research.

The coca and cocaine economy could be a significant driver of environmental change in Colombia, with impacts extending beyond cultivation to broader land-use transformations. Previous studies suggest that while coca cultivation itself is not the primary cause of deforestation (Dávalos, 2021), it acts as a catalyst for other environmentally damaging activities, such as cattle ranching and infrastructural expansion (Gutiérrez, 2021; Marín-Llanes et al., 2024). These spillover effects have led to the conversion of forests into pastures and increased deforestation rates, particularly in regions like the Amazon.

For instance, the coca boom (2014-2019) in Colombia fueled a 302% increase in land conversion to pastures for cattle ranching and a 104% rise in deforestation in the Amazon region (Marín- Llanes et al., 2024). Econometric models conducted for this study indicate a modest direct association between coca density and deforestation rates: the density of coca crops in a previous year is associated with a 2.2% increase in the deforestation rate and a 1.5% higher likelihood of deforestation in the following period. However, a stronger correlation emerges when considering the presence of coca economy which captures also its associated economic impacts: when considering the presence of coca crops, we find a 15.8% higher deforestation rate and a 10.4% higher probability of deforestation. Results suggest that while the direct effect of coca crop cultivation on deforestation exists, it is limited in scale. In contrast, the presence of coca economy, along with the productive activities it fosters (indirect effects), plays a more significant role in driving deforestation.

Gold Mining

Gold mining in Colombia varies significantly in terms of scale, status of legality, and environmental impact. While some large-scale mining operations exist, much of the country's gold production remains small-scale and informal. Alluvial gold mining expanded from 78,939 hectares in 2014 to 100,752 hectares in 2020, with annual fluctuations between 94,733 and 100,752 hectares from 2019 to 2022, according to UNODC data. Antioquia, Chocó, Bolívar, Cauca, and Nariño concentrate most of the country's mining activity, with 57% of national production coming from Antioquia. These regions also encompass strategic environmental areas, such as Forest Reserve Zones (53-55% of mining activity), Indigenous Reserves (0.3-0.5%), and National Natural Parks (5-7%). The overlap between mining

activities and these zones highlights the increasing pressure on Colombia's most biodiverse ecosystems.

However, in most Colombian departments, there are no statistically significant relationships between gold mining and deforestation, as alluvial gold mining takes place in river areas, where gold is extracted from sediments through processes such as dredging or excavation. These activities are concentrated in riverbeds and their surroundings, so they do not require large-scale tree clearing, which explains their lower association with deforestation. Fieldwork suggests that the most significant environmental impacts of the activity are related to water pollution. However, this aspect was not analyzed at the national level and requires further research.

Interactions between gold mining and coca cultivation are important in several regions. In Putumayo, for instance, up to 30.8% of municipalities host both activities, while other regions like Chocó and Cauca show fluctuating overlaps. These dynamics underscore the need to address the environmental and socio-economic challenges posed by the coexistence of these illicit economies.

Cattle Ranching

Cattle ranching has emerged as the leading driver of deforestation in Colombia, particularly following the 2016 Final Peace Agreement (FCDS, 2024; IUCN, 2022; Murillo-Sandoval et al., 2023). According to our estimations, from 2015 to 2023, the national cattle herd grew by 32%, reaching 29.6 million. However, this expansion did not correspond to an increase in cattle-raising areas, suggesting intensified land use in regions such as Córdoba, northern Antioquia, Bolívar, Cesar, Caquetá, and Putumayo. Regarding the relationship between the cattle herd and illicit economies, the correlation analysis conducted for this report at the municipal level between the cattle herd and coca crops shows a low statistically significant association between the hectares of coca crops and the number of cattle, with a correlation of 0.03. The relationship between coca economy and cattle ranching is beyond the location of the crops and could capture complex phenomena such as money laundering, which is beyond the scope of this research.

Qualitative research highlights the transformation of coca cultivation areas into pastures as a key intersection between cattle ranching and coca economy. Some of the paths toward the transition from coca to cattle were identified in the fieldwork: i) soil degradation due to chemicals and toxins, which changed the land's value and use; ii) state substitution programs (alternative development) and cattle farming state-promotion; iii) the absence of restrictions on forest clearing after the FARC-EP's peace process; iv) regional characteristics of cattle farming that offset the opportunity cost of replacing coca; v) mass land purchases suggesting patterns of land grabbing.

Case Studies: Meta, Putumayo, and Nariño

Fieldwork in these departments illustrates the localized dynamics of illicit economies and their environmental impacts. Meta and Putumayo showcase the spillover effects of the coca economy, including land conversion for cattle ranching. Nariño and Putumayo highlight the coexistence of coca cultivation and gold mining, with both activities exerting significant environmental pressures. In places where coca production is concentrating, the coca economy reveals some shifting toward agro-industrial models that encompass production, processing, and trafficking of cocaine, with farmers participating marginally or as employees (UNODC, 2023a; UNODC, 2024).

One of the key findings of the qualitative research is the role of state driven forced eradication by aerial spraying in the transition from coca to cattle ranching. According to locals, aerial spraying damaged the soil, allowing only the cultivation of pastures. Besides the documented socio-environmental impacts of glyphosate (Rubiano et al., 2020), farmers reported that after spraying, soils were severely affected and could not be used for agriculture or forestry for six to eight years. The only viable use of the land was for pasture. After aerial spraying, several farmers converted these infertile, "intoxicated" soils into pastures.

Additionally, our findings highlight the governance structures imposed by OAG, where economic regulation takes precedence over broader aspects of social and family life. Unlike the former FARC-EP, whose territorial control was mediated through strict coexistence manuals, the current OAGs prioritize economic norms, particularly those governing illicit activities. These economic rules have direct

environmental consequences, such as deforestation. The armed conflict in Colombia has evolved into a struggle for territorial control, that contrasts with the revolutionary goals of the FARC-EP, aimed at taking over central state power (Trejos, 2025).

Also, qualitative insights underscore the socio-political complexities of these regions. Community actors emphasize the need for differentiated approaches to address illicit economies, recognizing the heterogeneity of rural livelihoods. Policies that indiscriminately label rural communities as criminal actors risk alienating these populations and undermining state legitimacy.

State Responses

According to our literature review, state interventions in these economies have yielded mixed outcomes and often unintended outcomes. Efforts to eradicate coca crops, formalize mining activities, and regulate cattle ranching often lack nuance, overlooking the socio-economic realities of rural communities. Criminalizing informal livelihoods exacerbates marginalization, fosters distrust in state institutions, and creates power vacuums that armed actors exploit. Also, these interventions have had environmental impacts on forest due to the displacement of coca crops (Rincón-Ruíz & Kallis, 2013) and on water sources and biodiversity in the case of aerial spraying (Rubiano et al., 2020).

Programs like the National Comprehensive Program for the Substitution of Illicit Crops (PNIS) have incentivized coca cultivation in anticipation of subsidies. Deforestation impacts were found in areas with PNIS beneficiaries (15.4%) and in neighboring zones (13.4% to 19.3%) (DNP, 2023; Londoño et al., 2024). Similarly, attempts to formalize artisanal mining face resistance from communities who perceive state regulations as unrealistic and exclusionary (Vélez et al., 2024). In the cattle sector, land-use policies fail to address the structural drivers of deforestation, such as land grabbing and speculative practices.

State policies must balance security efforts, environmental conservation and rural development. Integrating local perspectives into policy design and implementation is crucial to building trust, fostering legitimacy, and addressing the root causes of environmental harm.

1. Introduction

Illicit economies have been related to the armed conflict and criminal governance in Colombia (CEV, 2022; Rettberg, Cárdenas, Ortiz-Riomalo, 2017). The development of these activities, along with state responses to control them, have had significant consequences for local economies and have also impacted the environment (Brombacher, Garzón & Vélez, 2021; UNODC, 2022; UNODC, 2021; Rubiano, Vélez & Rueda, 2020). The aim of this report is to analyze the functioning of the coca, cocaine, and gold mining production markets in Colombia to assess their relationships with environmental damages, such as deforestation[1]. In addition to the functioning of these markets, this research explores the interactions of these illicit activities with other productive sectors that also generate environmental costs, such as cattle ranching.

Following this introduction, section 2 presents the methodology and data used for the report. Section 3 examines the complexities of the illicit economies under study, exploring the concepts of criminality, illegality, and informality. Sections 4, 5, 6 and 7 provide an in-depth analysis of the functioning and evolution of the coca economy, illegal gold mining, and cattle ranching, respectively, at the national level. Section 8 presents the spatial relationships between coca cultivation, gold mining, and deforestation, incorporating econometric estimates based on geospatial data to analyze their associations on a national scale. Section 9 delves into the environmental impacts of these illicit markets, the regulatory influence of armed actors, and their interactions with other local activities in the three study areas. Section 10 discusses state interventions in the coca economy, livestock farming, deforestation, and gold mining, assessing their effectiveness and impact on environmental degradation. Finally, the report concludes with a synthesis of the key findings and lessons learned, followed by policy recommendations aimed at addressing illicit economies and mitigating their environmental consequences.

[1] For this report we also explored the relationship between coca cultivation, gold mining and pollution. Pollution is defined as the concentration of fine particulate matter (PM2.5) in the atmosphere, measured in micrograms per cubic meter (μg/m^3). The data were obtained from the Atmospheric Composition Analysis Group's global PM2.5 dataset, which combines ground measurements, satellite observations, and models to estimate surface-level air pollution (Atmospheric Composition Analysis Group, 2023). Our results do not show strong associations between the illicit economies and pollution level. Because of that, those findings were not included in the report.

2. Methods: Quantitative, Spatial, and Qualitative Approaches

This research was conducted using a mixed-methods approach, integrating quantitative, spatial, and qualitative data based on field work conducted in three field sites. The **quantitative approach** employs a detailed spatial database with information spanning from 2000 to 2023 at a one-square-kilometer resolution at the national level. Regression analyses are based on data up to 2022, while spatial analyses extend to 2023. Quantitative approach uses satellite data from various sources to identify statistical correlations between the presence of these economies and deforestation, supported by econometric models that also account for exposure to illicit activities in neighboring areas. Simultaneously, the **qualitative component** includes case studies in three key municipalities, semi-structured interviews with local actors and experts, and social cartographies, allowing for a deeper exploration of the territorial and social dynamics related to these illicit economies. This mixed-methods approach offers a comprehensive view of both the statistical correlations and realities of the rural communities, thus providing a holistic analysis of the social, economic, and environmental impacts of the studied economies.

2.1 Quantitative and Spatial Component

The aim of the quantitative and spatial component is to determine statistical correlations between the presence and intensity of coca and gold mining economies with environmental damage, specifically deforestation at the national level. Variables from various sources were used to build a spatial database with information for most variables from 2000 to 2022 at a one-square- kilometer resolution.

This section presents the methodological foundations of the analysis and is structured into three key components. Section 1.2.1 (Data Sources) describes the datasets used to quantify coca cultivation and alluvial gold mining, as well as the validation process applied to ensure their reliability. Section 1.2.2 (Variable Definitions and Construction) outlines the key variables and their processing, with a focus on deforestation as the primary environmental impact indicator. Section 1.2.3 (Methodological Strategies) presents the econometric approach used to analyze the relationship between illicit economies and deforestation.

2.1.1 Data sources

For the coca crops we used the Integrated Illicit Crop Monitoring System (SIMCI for its Spanish acronym) of the United Nations Office on Drugs and Crime (UNODC) that tracks coca crop areas annually since 2001 using satellite data. Based on this information, the number of hectares of coca in each one-square-kilometer pixel is calculated. Additionally, we used gold data based on SIMCI that monitors alluvial gold mining in the country at the same spatial level, though this information is available only for 2014, 2016, and the period 2018-2023.

The analysis also incorporates land suitability data. Municipal-level data on cattle ranching were obtained from the Colombian Agricultural Institute (ICA) Cattle Census, allowing for a panel dataset from 2009 to 2023. The rest of the variables are georeferenced: the coordinates and transactions at gasoline sales points were obtained from the Ministry of Mines and Energy (2010-2024), and road maps from the National Planning Department (DNP). The sources used include UPRA (2024) for cattle ranching, SGC (2019) for gold mining, and Prem et al. (2023).

2.1.2 Variable definitions and construction

Regarding environmental damage, our main outcome variable is the deforestation rate. The deforestation rate was calculated using data from Hansen et al. (2013), which identifies, at a 30-by-30-meter aggregation level, the year when the greatest forest loss occurred within a given pixel. Based on this information, the deforestation rate at the one-square-kilometer pixel level was calculated by summing the 900-square-meter pixels where the greatest forest loss was found and dividing it by the forest cover in the year 2000.

With this information, two complementary exercises were conducted. First, we mapped and visualized the dynamics of each of the economies analyzed, along with deforestation patterns. Second, we run statistical correlations between the presence of these economies and deforestation, supported by econometric models that also consider exposure to illicit activities in neighboring areas. Throughout this work, "exposure" refers to information about the presence and intensity of a variable in neighboring areas. This variable is relevant because it reflects the prevalence in local economies and, therefore, the risk of "spillover" into the studied area.

To analyze the relationship with deforestation, a Moran index was constructed to categorize the territory based on the presence of each illicit economy, its exposure, and the intensity of deforestation. This categorization is shown for coca crops through differentiated colors in Figure 1. Based on this categorization, it is possible to determine the intensity level of the illicit economy in each pixel, the intensity level of deforestation in that same pixel, and the level of exposure to each of these variables in neighboring pixels.

Figure 1. *Spatial combinations matrix and Moran's categorization.*

DEFORESTATION	COCA CROPS: High-High (HH)	COCA CROPS: High-Low (HL)	COCA CROPS: Low-High (LH)	COCA CROPS: Low-Low (LL)
High-High (HH)	High presence of coca crops and high presence of deforestation	High presence of coca crops and high presence of deforestation, with low exposure	Low presence of coca crops and high presence of deforestation	Low presence of coca crops and high presence of deforestation
High-Low (HL)	High presence of coca crops and high presence of deforestation, with low exposure	High presence of coca crops and high presence of deforestation, with low exposure	Low presence of coca crops and high presence of deforestation	Low presence of coca crops and high presence of deforestation
Low-High (LH)	High presence of coca crops and low presence of deforestation	High presence of coca crops and low presence of deforestation	Low presence of coca crops and low presence of deforestation, with high exposure	Low presence of coca crops and low presence of deforestation, with high exposure
Low-Low (LL)	High presence of coca crops and low presence of deforestation	High presence of coca crops and low presence of deforestation	Low presence of coca crops and low presence of deforestation, with high exposure	Low presence of coca crops and low presence of deforestation

Therefore, the legend obtained is as follows:

- High presence of coca crops and high presence of deforestation, with high exposure
- High presence of coca crops and high presence of deforestation, with low exposure
- High presence of coca crops and low presence of deforestation
- Low presence of coca crops and high presence of deforestation
- Low presence of coca crops and low presence of deforestation, with high exposure
- Low presence of coca crops and low presence of deforestation, with low exposure
- Absence of both

Source: Own elaboration.

2.1.3 Methodological strategies

To provide insights into the aggregated associations between illicit economies and deforestation at the national level, econometric estimates were made using fixed-effects models. Specifically, the correlation between illicit economies and deforestation was estimated in the same one-square-kilometer pixel, controlling for regional trends and static differences between pixels.

Given that the distribution of the outcome variable is concentrated at zero, the models were estimated using the *poisson pseudo maximum likelihood* methodology, and the results of these models are reported as percentage changes in the outcome variable.

The spatial behaviors observed previously allowed us to determine the following key considerations. First, we estimate the direct relationship between illicit activities and future environmental harms at the grid cell level. Second, we control for unobservable time-invariant characteristics of the grid cell (e.g., cultural and religious institutions), specific yearly shocks that affect all grid cells in the sample (e.g., exchange rate), and unobservable characteristics varying linearly at the municipality level (e.g., population).

The main econometric equation is presented below:

$$E\left[Harms_{g,m,t} \mid Illicit_{g,m,t-1}, \delta_g, \delta_t, t_m\right] = \exp(\alpha_1 \cdot Illicit_{g,m,t-1} + \delta_g, + \delta_t, + t_m + \varepsilon_{g,m,t})$$

The subscripts *g,m,t* denote the grid cell *g* in municipality *m* and year *t*.

The results can be evaluated at the extensive (presence) and intensive (rate) margin.

- $Harms_{g,m,t}$: presence or rate of deforestation.
- $Illicit_{g,m,t-1}$: lagged presence or rate of coca crops / gold mining.
- δ_g y δ_t, : grid cell and year fixed effects, respectively.
- t_m : municipality-level linear trend.
- $\varepsilon_{g,m,t}$: error term clustered at the *vereda* level.

The spatial dynamics observed led to the following considerations for the model with buffers. First, we include the density of illicit activities in neighboring areas (strict neighbors, within a buffer of 5 and 10 km) to estimate its association with future environmental harms. Models also include the direct relationship at the grid cell level between illicit activities and future environmental harms. We evaluate whether the direct (inta-grid cell) relationship holds once we include neighboring patterns in the regression. Second, we control for unobservable time-invariant characteristics of the grid cell, specific yearly shocks that affect all grid cells in the sample, and unobservable characteristics varying linearly at the municipality level.

The econometric equations with buffers are presented below:

$$E\ [Y_{g,m,t} \mid X_{g,m,t-1}, ExpX1_{g,m,t-1}, \delta_g, \delta_t, t_m] = \exp(\beta_1 \cdot X_{g,m,t-1} + \gamma \cdot ExpX1_{g,m,t-1} + \delta_g + \delta_t + t_m + \varepsilon_{g,m,t})$$

The subscripts *g, m, t* denote the grid cell *g* in the municipality *m* in the year *t*.

- $Y_{g,m,t}$ Deforestation (rate or presence) in year t
- $X_{g,m,t-1}$: Coca Crops / Gold Mining (rate or presence) in year t − 1
- $ExpX1_{g,m,t-1}$:Three measures of Illicit Economies intensity (hectares of gold mining (std) in neighboring grid cells, in 5 km buffer, and 10 km buffer) in areas neighboring grid g, included in the models exclusively in year t − 1.
- δ_g, δ_t : Grid and year fixed effects, respectively
- t_m: Linear trend by municipality.
- $\varepsilon_{g,m,t}$: Error term clustered at the *vereda* level.

The estimated coefficients reflect percentage changes in deforestation, considering the presence and intensity of the illicit economies studied in this report.

In addition to establishing the statistical correlation between illicit economies and deforestation in the same one-square-kilometer pixel (i.e., exact geographical overlap), we included information on exposure to these economies in the models (i.e., the local influence of neighboring areas). These econometric equations are presented below:

$$E\ [Y_{g,m,t} \mid X_{g,m,t-1}, ExpX1_{g,m,t-1}, , \delta_g, \delta_t, t_m] = \exp(\beta_1 \cdot X_{g,m,t-1} + \gamma \cdot ExpX1_{g,m,t-1} + \delta_g + \delta_t + t_m + \varepsilon_{g,m,t})$$

The subscripts *g, m, t* denote the grid cell g in the municipality m in the year t.

- $Y_{g,m,t}$: Deforestation (rate or presence) in year *t*
- $X_{g,m,t-1}$: Coca Crops / Gold Mining (rate or presence) in year *t* – 1

- $ExpX1_{g,m,t-1}$: Three measures of Illicit Economies intensity (hectares of gold mining (std) in neighboring grid cells, in 5 km buffer, and 10 km buffer) in areas neighboring grid g, included in the models exclusively in year t − 1.
- δ_g, δ_t: Grid and year fixed effects, respectively.
- t_m: Linear trend by municipality.
- $\varepsilon_{g,m,t}$: Error term clustered at the *vereda* level.

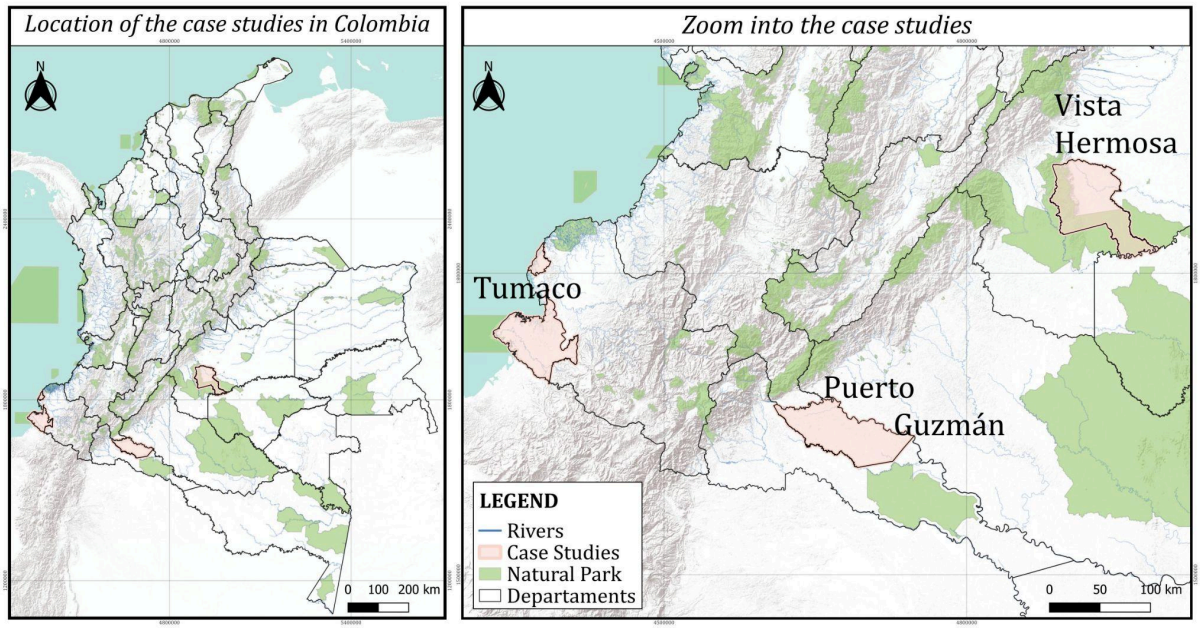
In practice, this involves incorporating data on the number of neighboring pixels with coca crops or gold mining, as well as the density of these activities in the strictly neighboring pixels and in areas 5 and 10 kilometers around the pixel, into the statistical model. This allows us to establish the correlation between exposure levels and deforestation, as well as to test whether the direct relationships found persist after including the exposure information. It is important to note that establishing causal relationships is beyond the scope of this document.

Previous studies and qualitative fieldwork have found other relevant variables that can help explain the interactions between these economies and environmental damage. Therefore, the econometric models included interactions with cattle ranching at the municipal level, transactions and gas sales points, and roads.

2.2 Qualitative Section

The selected case studies include three municipalities—Vistahermosa (Meta), Puerto Guzmán (Putumayo), and Tumaco and the Telembí Triangle area (Nariño), as shown in Figure 2. These locations not only feature economies centered on coca-cocaine production, gold mining, or livestock farming, but also currently offer conditions conducive to the relatively safe presence of academic research teams. However, the dynamics of conflict in these areas are currently fluid, reflecting the instability and uncertainty typical of the post-Agreement period with the Revolutionary Armed Forces of Colombia – People's Army (FARC-EP). This sometimes hindered the development of the research and implies that the collected data and subsequent analyses pertain to a particular time frame.

Figure 2. *Case studies.*



Source: Own elaboration.

From a methodological standpoint, we selected territories where coca crops are not primarily under the control or ownership of Organized Armed Groups (OAG), though they are adjacent to or part of productive enclaves[2], as characterized by the UNODC (2023a). This selection ensured the safety of the research teams and facilitated the successful development of fieldwork.

Interviews were conducted with national and regional experts, and in- depth case studies were carried out through field visits. These visits included meetings with actors involved in the productive activities analyzed, as well as with institutional representatives and local experts, allowing for a more detailed and contextualized understanding of the dynamics under study. Semi-structured individual interviews were conducted in each municipality with community actors involved in coca cultivation, cocaine production, gold mining, and/or cattle ranching economies. Additionally, social mapping exercises were carried out in groups of five to ten people in the rural areas visited.

[2] UNODC (2023a) defines a productive enclave as a "territory that has shown a highly significant concentration of coca crops (hectares planted per square kilometer) and where the persistence of the phenomenon has lasted for more than four of the five years analyzed" (p. 45).

The individual interviews, lasting approximately one hour, and the social mapping exercises, lasting between two and three hours, aimed to explore the value chain processes of coca cultivation, livestock farming, and mining, as well as the challenges and territorial impacts associated with these activities. Whenever security conditions and participants' preferences allowed, interviews were recorded; in all cases, field notes were taken to document each conversation. In each municipality, a local research facilitator supported the fieldwork by gathering information before and after the academic team's visit. Their role included establishing contacts, organizing meetings, and arranging spaces with the various participants involved in the research.

3. The complexities of the Economies Under Study

The concepts of "criminality" and "illegality" present significant challenges in understanding the social, political, and cultural dynamics that unfold on the margins of the state. In the economies of coca, cocaine, gold, and cattle ranching, distinguishing between these two categories is particularly complex due to the involvement of multiple actors and diverse socioeconomic contexts. Also, the binary categorization of legality and illegality is limited, as there are other intersecting categories that determine the status of an economic activity. To address this complexity, scholars studying illicit commodity markets have developed conceptual frameworks that provide a more nuanced and comprehensive understanding of these economies and the experiences of those engaged in their value chains (Beckert and Dewey, 2017; Cruz and Pereira, 2021). Distinctions between illegal, legal, grey, informal, and criminal markets offer valuable insights into the social diversity and heterogeneity within these economies (see Figure 3).

Figure 3. *Distinctions among legal status.*

Source: Own elaboration.

The concept of a *grey market* or *grey zones* emerged to challenge or critique the binarism legality/illegality and it describes the vast number of transactions occurring at the intersection of legal/regulated frameworks and illegal/illicit ones (Hartnett and Dawdy, 2013; Damonte and Schorr, 2022). Also, other authors use the category of informality to highlight these intersections. Stemming from economic studies on unregulated and untaxed activities, we use the concept of informal market for defining the economic practices, in particular mining, that occur without all the state requirements but are not fully illegal and not criminal. In other words, we use the category of informal for describing the economic activities carried out by communities without state permits, lacking social or labor security and without environmental licenses, or are in the process of obtaining them (Vélez and Rodríguez, 2020). Then grey areas and informality are categories that overlap for illustrating the intersections between legal and illegal social spheres, as shown in figure 3.

In addition, the criminal status in economic activities is related to ownership, economic regulation, or control carried out by organized armed groups or organizations. These groups often impose their own norms, such as illegal taxation and may profit from facilitating illegal transactions, aligning with economic actors to manipulate regulatory frameworks in their favor, or attempt to monopolize

market control. These actors mediate access to markets, establish social orders, and impose economic, political, and social rules on territories and populations. In some cases, armed groups limit their interference to taxation and basic public order, while in others, they expand their control to all aspects of social and economic life, including also environmental norms and rules (Arjona, 2016). This latter scenario enables criminal actors to consolidate power and extend their influence beyond economic exploitation, shifting toward direct political and social control. Thus, over time, some informal markets may become criminalized, as criminal actors use them for financial and strategic purposes, exerting governance over local populations.

However, this does not imply that informal actors in illegal markets are comparable to members of criminal organizations or part of their structures. Defining small scale mining and coca economies as criminal can lead to stigmatization and justification for police and military interventions in territories where traditional or informal livelihoods are prevalent (Rubiano, Vélez, and Rueda, 2020). For example, miners operating without legal permits should not be classified alongside organized armed groups (OAGs) that extract and dispute rents from these economies. Similarly, small and medium-scale coca growers or ranchers should not be conflated with criminal intermediaries or frontmen (Rubiano, Vélez, and Rueda, 2020). These economies operate at different scales, involve varying levels of engagement with armed actors, and often contain segments primarily driven by rural communities.

The blurred boundaries between informality, grey markets, illegality, and criminality arise because actors operating under different logics participate in the same value chains. Criminal organizations may own the machinery rented by informal miners, coca farmers may sell their processed product to OAGs, and farmers may lease land for livestock financed through drug trafficking. Additionally, the inputs required for these economies—such as machinery and chemicals—are often sourced through contraband rather than legal suppliers (Damonte and Schorr, 2022). These interconnections complicate governmental interventions, including environmental rules, as the same supply chains may link legal, informal, and illicit actors.

A key challenge in public policy is the lack of clear criteria to distinguish between these categories. It remains unclear whether the state should differentiate actors based on land size—as in debates over differential penal treatment for small-scale coca farmers and distinctions between peasant livestock and narco-livestock (Devine et al., 2020; Devine et al., 2021; Tellman et al., 2020)—or on the type of machinery used, as in the distinction between artisanal and small-scale mining, or on how the rents are utilized. Without such clarity, criminalization becomes the default response, pushing informal actors toward illegal regulatory regimes and increasing the likelihood of informality being co-opted by criminal networks.

State legitimacy is at stake in these territories. Treating rural mining or coca-growing communities indiscriminately as criminal actors can deepen marginalization, undermine trust in state institutions, and lead to resistance against state interventions. When enforcement actions are perceived as criminalizing traditional livelihoods rather than as legitimate measures to protect public order and the environment, rural communities may oppose state presence, creating power vacuums that armed actors exploit (Ciro, 2020). Excessive use of force or aggressive state policies may further weaken social cohesion, escalate local conflicts, and ultimately hinder efforts to establish effective and sustainable governance. As figure 3 illustrates, these interdependencies reveal both points of convergence and distinction in the economies under study. Ultimately, policy responses must develop nuanced approaches that address the structural conditions fostering informality while limiting opportunities for illicit actors to exert control.

4. Spatial Distribution of Coca Cultivation, Gold Mining, and Cattle Ranching: Land Suitability Analysis

To contextualize the spatial distribution of coca cultivation, gold mining, and cattle ranching, an analysis of land suitability was conducted. Assessing land suitability for these activities offers a general perspective on the geographic, environmental, and economic factors associated with their distribution (Figure 4).

The suitability of land for different activities is defined through methodologies that integrate physical, socioeconomic, and ecosystemic criteria, tailored to the specific requirements of each use. For cattle ranching, UPRA (2024) classifies areas into suitability categories (High, Medium, Low, Not Suitable, and Legal Exclusion), considering factors such as topography, climate, soil quality, water availability, market access, and compatibility with environmental conservation. These categories assess the potential of an area for pasture-based beef production, taking into account physical, socio-ecosystemic, and socioeconomic limitations, as well as the investments required for its development.

For gold, the suitability assessment follows the guidelines of SGC (2019), which are based on the identification of geochemical anomalies and potential zones for mineral exploration and exploitation. These zones are evaluated using weighted parameters such as proximity, adjacency, and area of influence to classify them into High, Medium, and Low potential categories.

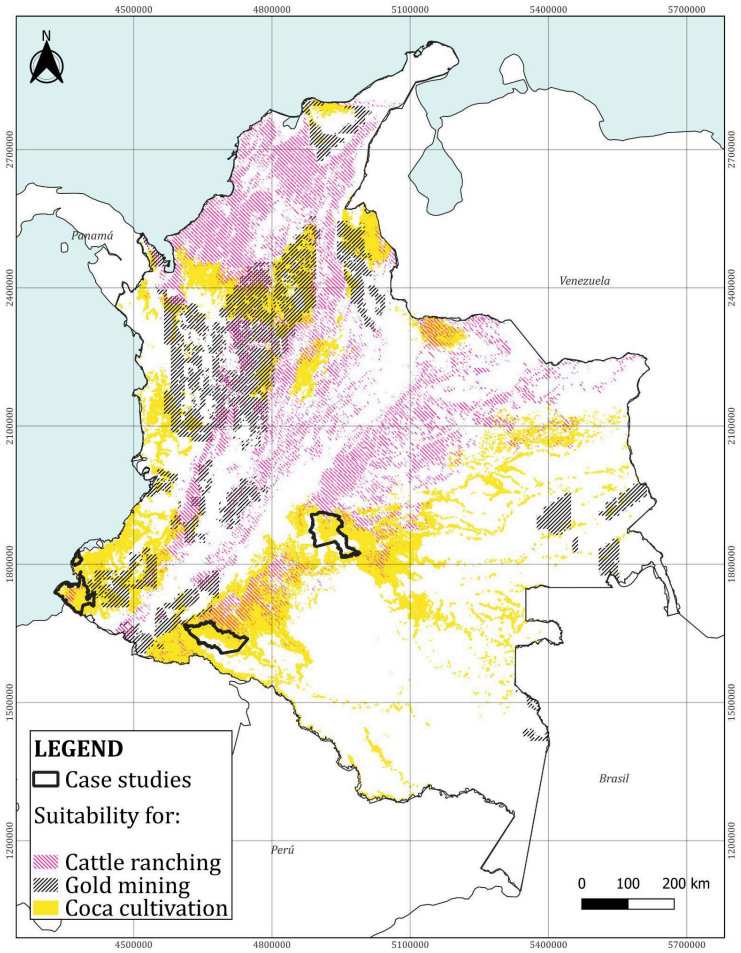
Finally, for coca crops, land suitability is related to factors such as altitude, agroecological characteristics of the terrain, and access to illegal markets, as described in the study by Prem et al. (2023). This approach highlights how economic and geographical conditions influence the persistence of illicit crops, showing that land suitability depends not only on physical characteristics but also on socioeconomic dynamics. However, external factors such as law enforcement, state presence, and conflict dynamics significantly influence whether coca is actually cultivated in areas deemed suitable.

Note that suitability does not necessarily translate into actual activity. While this assessment provides insights into where coca cultivation, gold mining, and cattle ranching could theoretically take place based on environmental and socioeconomic factors, observed land use is also shaped, among other factors, by market forces, governance, conflict dynamics, and policy interventions. For example, the interaction between suitability and actual land use is shaped by institutional presence, land tenure security, enforcement actions, and economic incentives. In some cases, state regulations, land access constraints, or market fluctuations may prevent land from being used for its most suitable economic activity. Conversely, in regions with weak governance, illicit economies may expand

even in areas where conditions are only moderately suitable. This underscores the need to interpret suitability maps not as deterministic predictors of land use, but as indicative of potential under specific enabling conditions.

Furthermore, the relationship between suitability and actual land use is dynamic, meaning land that is currently unsuitable for an activity may become viable due to environmental change, infrastructure development, or shifts in economic incentives. For example, increased road connectivity may turn previously remote areas into viable sites for agriculture or extraction activities. Similarly, armed group control can influence whether an area is used for coca cultivation, despite its agroecological characteristics.

Figure 4. *Suitability Map for Cattle Ranching, Gold Mining, and Coca Cultivation in Colombia.*



Source: Own elaboration.

5. Coca and Cocaine Economy at National Level

The primary input to produce cocaine hydrochloride is the coca leaf. These crops, originally associated with ancestral practices of Andean-Amazonian indigenous communities, became one of the plants controlled by the United Nations since they are part of the transformation process to produce cocaine hydrochloride (see figure 5) (Gootenberg, 2009). The cultivation of coca crops for cocaine requires agrochemicals for a continuous growing, leading to groundwater and soil contamination (see Figure 5, right side, for the multiple environmental impacts of cocaine processing) . In Colombia, these crops mostly belong to peasant families on small properties located in 19 departments across the country, as shown in Figure 7 for 2023[3]. According to SIMCI, the average size of coca plots in 2018 was 1.07 hectares (UNODC, 2019). However, according to the characterization of National Comprehensive Program for the Substitution of Illicit Crops (PNIS for its Spanish acronym) for beneficiary households in coca-growing areas, the average size of family-owned coca plots was 0.5 hectares (FIP, 2018b, p. 12).

Once cultivated, coca leaves are harvested by laborers commonly referred to as *raspachines*. According to estimates by the UNODC (2004), in the coca-growing area of the Guaviare department, for example, four to five workers may be hired for the task of harvesting leaves per hectare of cultivated coca (UNODC, 2024). According to Ciro (2020), the wages are usually paid per *arroba* (11.5 kg) harvested, and a "good *raspachín* can gather around eighteen *arrobas* a day" (authors' own translation, p. 132). Since 2020, a single hectare of coca can produce 6.4 tons of fresh leaf annually (see Figure 5) (UNODC, 2023a). All of this suggests that coca leaf harvesting is labor-intensive but not land-intensive: a single hectare of coca produces high yields and requires significant labor.

The harvested coca leaves are chopped and moistened with liquid residues from previous alkaloid extraction processes. The chopped leaves are then subjected to various chemical compounds such as cement, gasoline, ammonia, and caustic soda (sodium hydroxide) to extract the alkaloid, using also large amounts of water

[3] The departments with coca cultivation in 2023 were: Amazonas, Antioquia, Bolívar, Boyacá, Caquetá, Cauca, Chocó, Córdoba, Guainía, Guaviare, Magdalena, Meta, Nariño, Norte de Santander, Putumayo, Santander, Valle del Cauca, Vaupés and Vichada (UNODC, 2025).

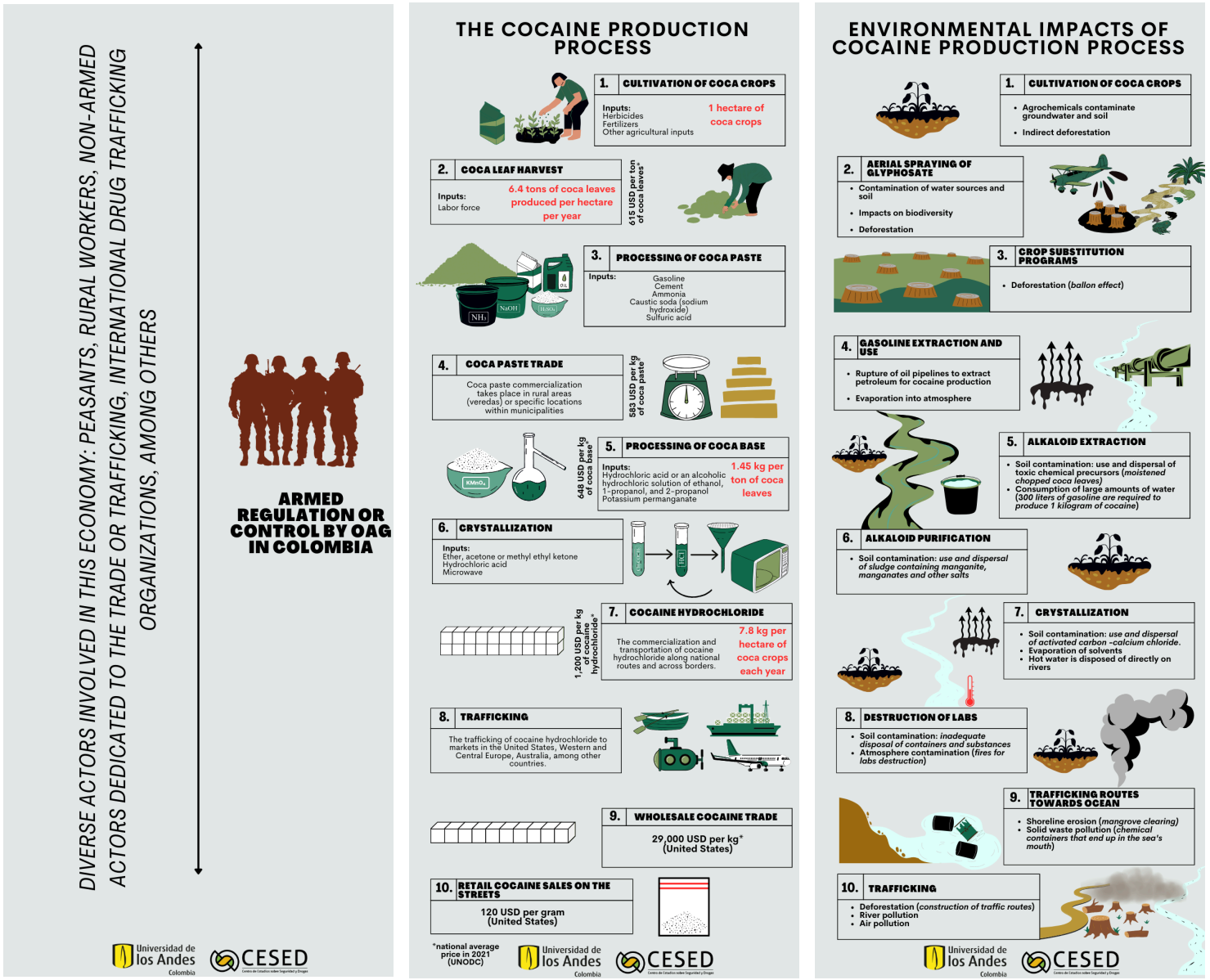
(300 liters of gasoline are required to produce 1 kilogram of cocaine) (UNODC, 2009; UNODC, 2023b). The alkaloid extraction process is as follows. First, the leaves are alkalized with cement and moistened with water and other liquids. Then, a large volume of solvents, commonly gasoline, is added to large buckets or drums. After a chemical process of decantation and precipitation of the alkaloid using sulfuric acid and ammonia, filtration takes place, resulting in coca paste (UNODC, 2009; UNODC, 2023b). The disposal and dispersal of these chemical precursors during the alkaloid extraction process results in soil contamination (UNODC, 2023b).

Next, a refinement process is carried out by dissolving the coca paste in an acidic solution (hydrochloric acid or an alcoholic hydrochloric solution) (UNODC, 2023b). Additionally, potassium permanganate is often used for the oxidation of the cocaine base (UNODC, 2009; UNODC, 2023b). In some cases, the cocaine base can be obtained without passing through the coca paste production phase via a more efficient method in terms of chemical use (UNODC, 2009). This alkaloid purification process, as cultivation and alkaloid extraction, generates soil contamination because of the use and disposal of the resulting sludge.

Finally, the crystallization process occurs, where the cocaine base is dissolved in organic solvents and acidified, usually with hydrochloric acid (UNODC, 2009; UNODC, 2023b). The final crystallization is achieved through evaporation or cooling, and in many cases, a microwave oven is used to accelerate the drying of the cocaine hydrochloride crystals after crystallization (Bermúdez, February 1, 2018). This product is then transported and sold, which increases the average price per kilogram. This process also leads to soil contamination, but also to air pollution and river degradation as hot water is disposed directly into them.

As mentioned earlier, diverse actors participate in this economy (see Figure 5, left side). At the base of the value chain, the population primarily consists of peasants involved in the cultivation, harvesting, and processing of coca leaves into coca paste. However, recent reports suggest a growing involvement of OAG in both cultivation and processing. Various OAG are involved in controlling and/or regulating coca crops at the local level and in the commercialization of coca paste, along with non-armed actors dedicated to the trade or trafficking of coca-based products (UNODC, 2023b).

Figure 5. *Cocaine production process and environmental impacts.*

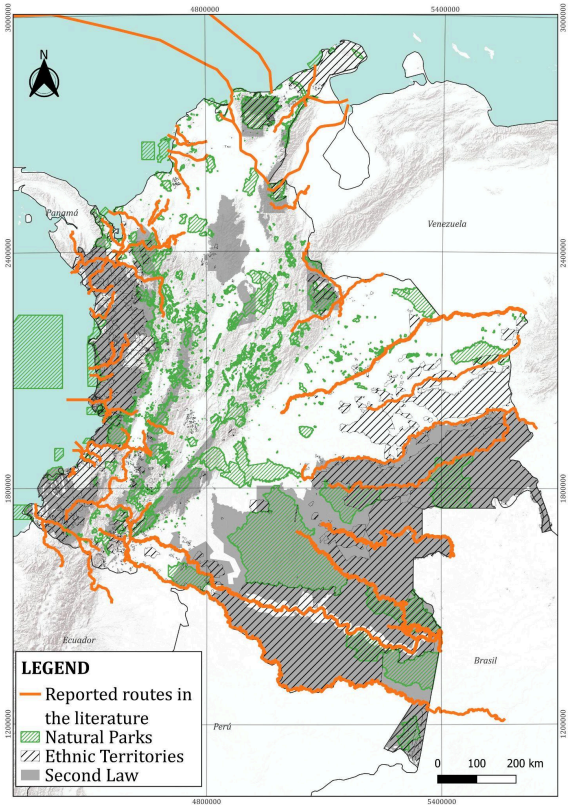


Source: own elaboration based on UNODC (2023a; 2023b) and UNODC (2009).

Several national and international drug trafficking organizations are involved in the transit and trade of cocaine hydrochloride from Colombia, Brazil, Peru, Ecuador, and Bolivia to major markets in the United States, Western and Central Europe, Oceania, and other countries in Africa and Asia that have increased demand in recent years (UNODC, 2022; UNODC, 2023b). For the European case, it has been suggested that the main entry points for cocaine are in Belgium, the Netherlands, and Spain (European Monitoring Centre for Drugs and Drug Addiction, 2023). The map in

figure 6 was constructed using available qualitative information (not georeferenced data) to provide an overview of transit dynamics based on reported patterns. These routes, highlighted in the map, illustrate pathways within Colombia that facilitate this transit, many of which intersect with protected areas and natural parks, emphasizing the strategic and ecological implications of these illicit activities.

Figure 6. *Reported routes in the literature.*



Source: Own elaboration based on UNODC (2019), Policía Nacional (2021), Comisión de la Verdad (2022), UNODC (2023a), and UNODC (2023b).

Since the 1990s, the coca and cocaine economy was regulated mainly by the FARC-EP in its cultivation, processing, and commercialization segments throughout its controlled territory in regions such as Caquetá, Meta, Guaviare, and Putumayo, among others. The FARC- EP taxed both paramilitaries and buyers of coca paste (Ramírez, 2001). Before that decade, the FARC-EP had no direct involvement in this economy and saw it as a source of conflict with peasants, intermediaries, among other actors (Vélez, 2001; Jaramillo et al., 1989).

With the 2016 FPA and the withdrawal of FARC-EP from coca-producing territories, a reconfiguration of this economy has occurred, which has resulted in long periods of uncertainty primarily affecting the peasant population (Ciro, 2023). At the same time, new conflict scenarios have emerged between dissident FARC-EP groups and other OAG competing for territorial and economic control, which also generates alarms, violence, and human rights violations against the civilian population. As mentioned earlier, this market reconfiguration includes signs that some OAG are directly involved in coca cultivation and processing.

5.1 Dynamics at National Level

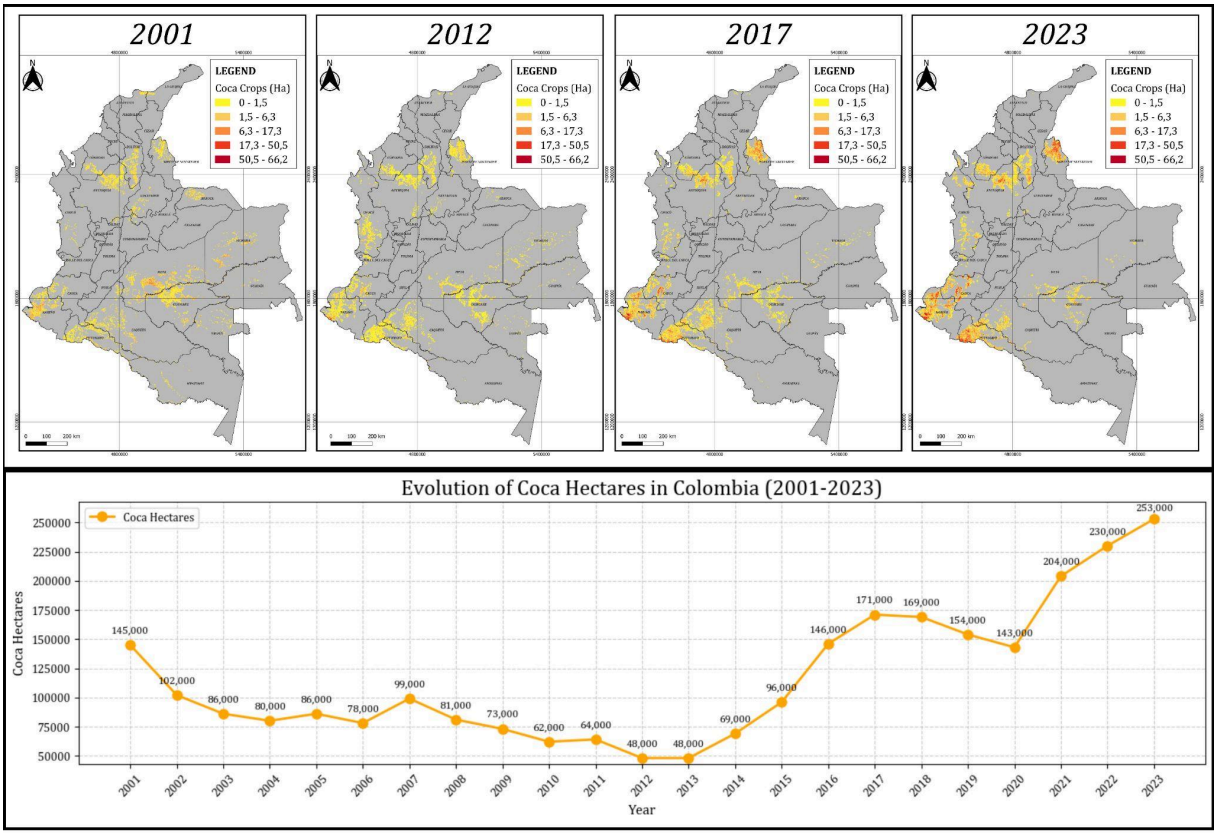
Colombia, since the late 20th century, has been one of the leading producers of coca leaves and cocaine hydrochloride worldwide. According to UNODC, Colombia produces 70% of the world's cocaine (UNODC, 2019b) and is responsible for 71% of worldwide coca bush cultivation (UNODC, 2024). Additionally, the country currently has fifteen coca productive enclaves[4] that concentrate 39% of the total potential coca leaf production, primarily located in the Pacific region and the departments of Putumayo and Norte de Santander (UNODC, 2025). While there have been some changes in coca cultivation in the country due to aerial eradication strategies (Abadie et al., 2015), the main production areas have remained constant over time. However, in recent years, there has been a shift towards border regions, as illustrated in Figure 7. Therefore, as suggested by UNODC, this phenomenon has not expanded across the territory; on the contrary, it has become more spatially concentrated. For example, the national increase in cultivation between 2021 and 2022 is explained by a 77% rise in coca cultivation in Putumayo (UNODC, 2023a). Other departments, such as Guaviare and Caquetá, have not registered a high density of coca crops in recent years, even though they played a significant role in the past.

[4] The productive enclaves in the Pacific region are ten: El Charco-Olaya Herrera, Frontera Tumaco, Roberto Payán-Isagualpi, Telembí-Cristal, Policarpa-Patía, El Charco-El Turbio, Argelia-El Tambo, Timbiquí-Saija, El Naya, and Timba-Jamundí-Buenos Aires. In the department of Putumayo, two enclaves are located: Orito-Vides and Frontera Putumayo. In Norte de Santander, the productive enclave of Catatumbo is found, and finally, in the Central-South region of Bolívar, the enclaves of Valdivia-Tarazá-Cáceres and San Pablo-Taracú are consolidated.

During the 21st century production levels and market dynamics have fluctuated. In 2000, 163,000 hectares of coca were found in Colombia. From that point, the UNODC reported a steady annual decline, with coca crops dropping to 48,000 hectares by 2012 and 2013. However, this trend reversed in 2014, as coca cultivation began rising systematically, reaching 230,000 hectares by 2022 and 253,000 by 2023 according to the latest UNODC report (Figure 7).

Academic research indicates that the increase after 2014 cannot be attributed to the suspension of aerial spraying in 2015. Instead, it is linked to the announcement of the PNIS crop substitution program, introduced as part of the FPA between the Colombian government and the FARC-EP, which incentivized the expansion of coca cultivation (Marín Llanes et al., 2024; Prem et al., 2023).

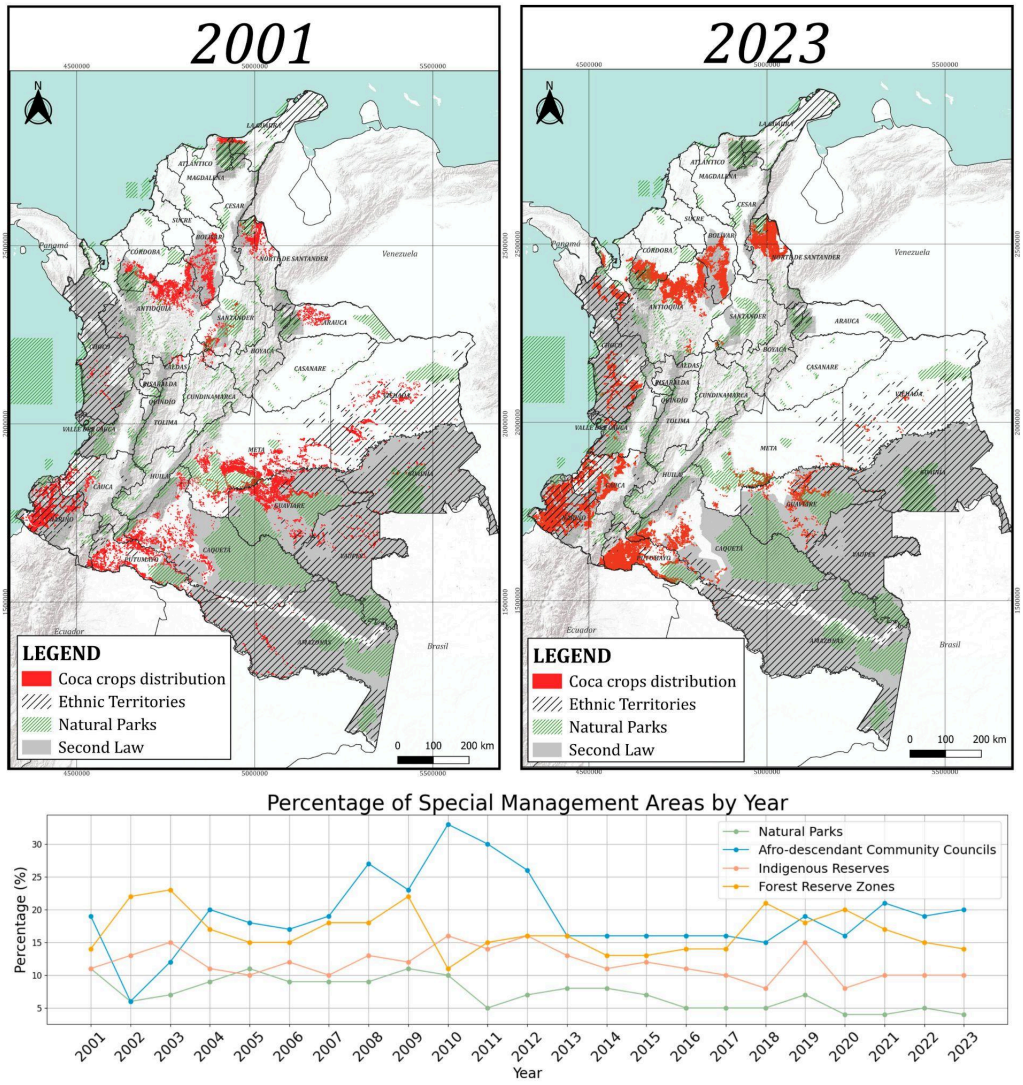
Figure 7. *Coca crops distribution.*



Source: Own elaboration with data from UNODC.

A large proportion of coca crops are currently found in environmentally strategic areas, defined by administrative categories such as Indigenous Reserves, Afro-descendant Community Councils, National Natural Parks, and Forest Reserve Zones under Law 2, posing significant threats to biodiversity and environmental sustainability. In 2001, 55% of coca cultivation (79,724 hectares) was concentrated in these areas, with 11% in Parks, 19% in Afro-descendant Communities, 11% in Indigenous Reserves, and 14% in Forest Reserve Zones. By 2023, the share of coca crops in these areas increased to 48%, covering 121,440 hectares, with a similar distribution: 4% in Parks, 20% in Afro-descendant Community Councils, 10% in Indigenous Reserves, and 14% in Forest Reserve Zones, as shown in Figures 8.

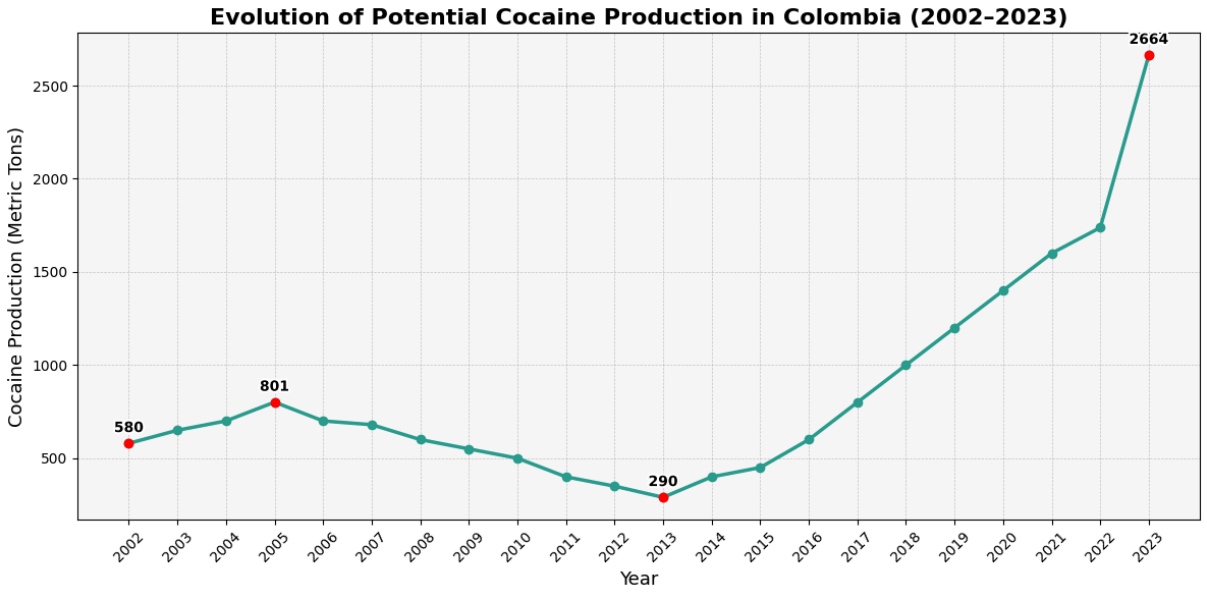
Figure 8. *Coca crops distribution in Strategic Environmental Management Areas.*



Source: Own elaboration with data from UNODC and SINAP.

UNODC estimates that Colombia produced 580 metric tons (t) of cocaine in 2002. Production peaked at 801 t in 2005 but fell to 290 t in 2013. However, from 2014 onward, production increased systematically, reaching 2,664 t in 2023 (see Figure 9).

Figure 9. *Evolution of Potential Cocaine Production in Colombia (2002-2023).*



Source: Own elaboration with data from UNODC.

UNODC also tracks prices across the cocaine supply chain and regions (see Table 1). Between 2005 and 2021, coca leaf prices showed limited fluctuation over time, with more notable differences across regions than across years. Coca paste prices followed a generally downward trend, with the Amazon region recording the lowest averages and Orinoquía maintaining comparatively higher levels. Cocaine base prices remained relatively stable, although some regional and temporal peaks were observed. In contrast, cocaine hydrochloride prices showed minimal variation both over time and across regions, suggesting a greater degree of standardization in the final stages of the supply chain.

Table 1. Price Variation in the Cocaine Supply Chain in Colombia (2005-2021).

Product	Lowest Price (COP - USD)	Highest Price (COP - USD)	Lowest Regional Average	Highest Regional Average (COP)
Coca Leaf	2,000 COP (1.07 USD) - 2013	3,000 COP (1.09 USD) - 2015	1,852.9 - 1,870.6 COP *(Sierra Nevada, Orinoquía, Meta-Guaviare)*	2,861.8 COP *(Pacific)*
Coca Paste	1,575,800 COP (428 USD) - 2020	2,534,100 COP (1,092 USD) - 2005	1,776,859 COP *(Amazon)*	2,063,677 COP *(Orinoquía)*
Cocaine Base	2,279,300 COP (772 USD) - 2017	2,824,700 COP (1,436 USD) - 2008	2,387,047 COP *(Putumayo-Caquetá)*	2,612,059 COP *(Central)*
Cocaine Hydrochloride	4,155,500 COP (1,634 USD) - 2006	4,984,600 COP (1,762 USD) - 2016	4,185,635 COP *(Putumayo-Caquetá)*	4,994,117 COP *(Orinoquía)*

Source: Own elaboration with data from UNODC.

6. Gold Mining at National Level

Gold mining in Colombia has been a major economic activity since colonial times, particularly in Antioquia and the Pacific region (Bonet, 2007; Leal, 2016). During the 19th and early 20th centuries, gold mining in the Colombian Pacific was characterized by low mechanization and limited productivity (Leal, 2016; Bonet, 2007). In the 20th century, the arrival of foreign mining companies restricted the local population's access to gold deposits and introduced large-scale, mechanized extraction (Leal, 2018; Castillo and Rubiano, 2019). By the late 20th century, the relationship between gold mining, armed conflict, and criminality intensified and diversified (Rettberg, Cárdenas, Ortiz-Riomalo, 2017).

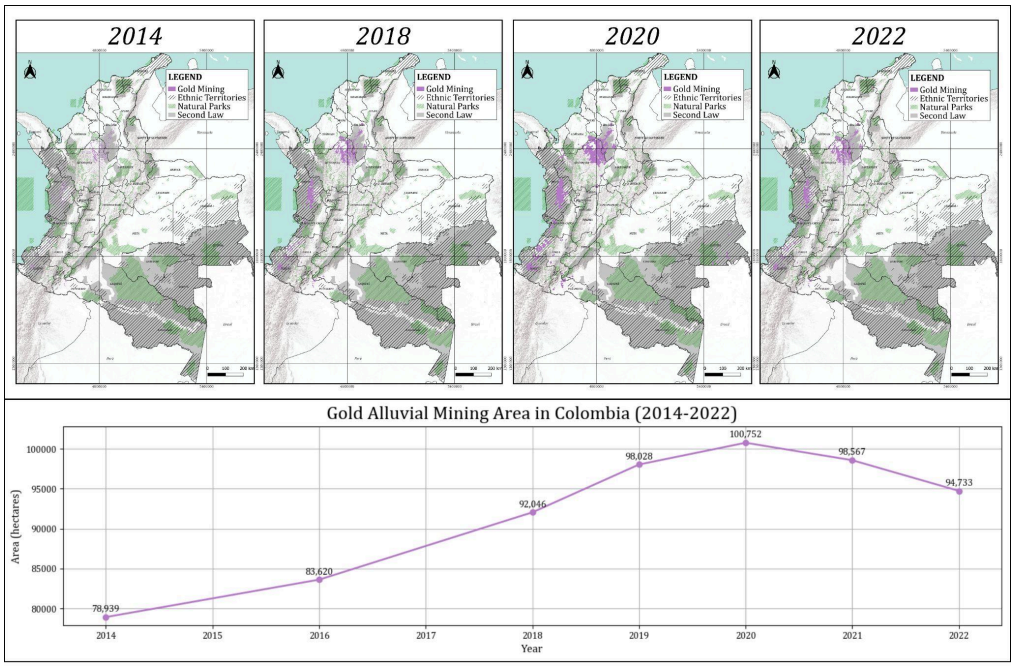
Today, gold mining in Colombia varies significantly in terms of scale, legality, and environmental impact. While some large-scale mining operations exist, much of the country's gold production remains small-scale and informal. Additionally, in some regions, alluvial gold mining has expanded under the influence of organized armed groups (OAGs) and criminal networks, particularly in Antioquia, Chocó, Bolívar, Cauca, and Nariño. This type of mining—often carried out with dredges, backhoes, and motor pumps along river systems—allows for rapid, large-scale extraction but has also been associated with illegal taxation, territorial control, and severe environmental degradation (Valencia & Rasmussen, 2018; Rettberg & Ortíz-Riomalo, 2018).

Gold mining in Colombia can be classified according to scale and extraction methods. Surface alluvial mining involves shallow excavations up to three meters deep, followed by sediment washing, while deep alluvial mining involves digging pits between seven and twelve meters deep using mechanized equipment. In contrast, hard rock or primary mining consists of underground tunnel extraction, requiring explosives to reach gold veins (Machácek, 2019). Although all three forms exist in Colombia, alluvial mining is the most widespread, particularly in riverine regions where deposits can be accessed without significant infrastructure investment. The Colombian Mining Code (Law 685 of 2001) further differentiates mining based on legal status: legal mining is fully permitted and regulated by the National Mining Agency and ANLA; artisanal mining is limited to small-scale *barequeo* (manual panning of sediment), which does not require a mining title but

registration at municipalites; illegal mining refers to any extraction without legal authorization; and informal mining involves small-scale operations by rural communities without mining titles or environmental licenses but not necessarily linked to criminal organizations (Vélez & Rodríguez, 2020). Despite these distinctions, in practice, informal, illegal, and criminally influenced mining often coexist in the same territories, involving a variety of actors, including independent miners, local entrepreneurs, intermediaries, and armed groups.

Gold mining remains concentrated in a few key regions, with relatively stable spatial patterns over the past decade (Figure 10). According to UNODC satellite monitoring, the total area of alluvial gold mining increased from 78,939 hectares in 2014 to 100,752 hectares in 2020, fluctuating between 94,733 and 100,752 hectares annually between 2019 and 2022. The regions with the highest concentration of alluvial gold mining include Northeast Antioquia (Remedios, Segovia), Bajo Cauca (El Bagre, Cáceres, Caucasia, Nechí, Zaragoza), the Pacific region (Chocó, Cauca, Nariño), and Southern Bolívar. Antioquia remains Colombia's largest gold-producing department, contributing approximately 57% of national production through a mix of formal underground mining and large-scale alluvial extraction.

Figure 10. *Gold Alluvial Mining Area in Colombia (2014-2022).*



Source: Own elaboration with data from UNODC and SINAP.

According to UNODC reports, between 2019 and 2022, only between 21% and 29% of alluvial mining exploitation had technical and environmental permits. Therefore, this measurement, though imperfect, provides an approximation of the intensity of illegal gold mining in Colombia, its location, and its potential consequences. Illegal alluvial mining remains widespread, particularly in Bajo Cauca and Northeast Antioquia, where OAGs have historically financed their operations through gold taxation and control of machinery, fuel supplies, and trade networks (Rettberg & Ortíz-Riomalo, 2018).

Table 2 presents the prevalence of alluvial gold mining in special management areas. Although the number of hectares varies each year, the distribution across regions does not show significant changes. Between 2014 and 2022, the Forest Reserve Zones under Law 2 concentrated between 53.3% and 54.8% of gold mining. In Indigenous Reserves, this percentage ranged between 0.27% and 0.53%. For the Community Councils of Black Communities, the ranges were between 10.4% and 14.1%; for National Natural Parks, between 5.2% and 6.8%; and outside these areas of environmental interest, between 20.5% and 28.1%.

Table 2. *Gold Mining categories by year.*

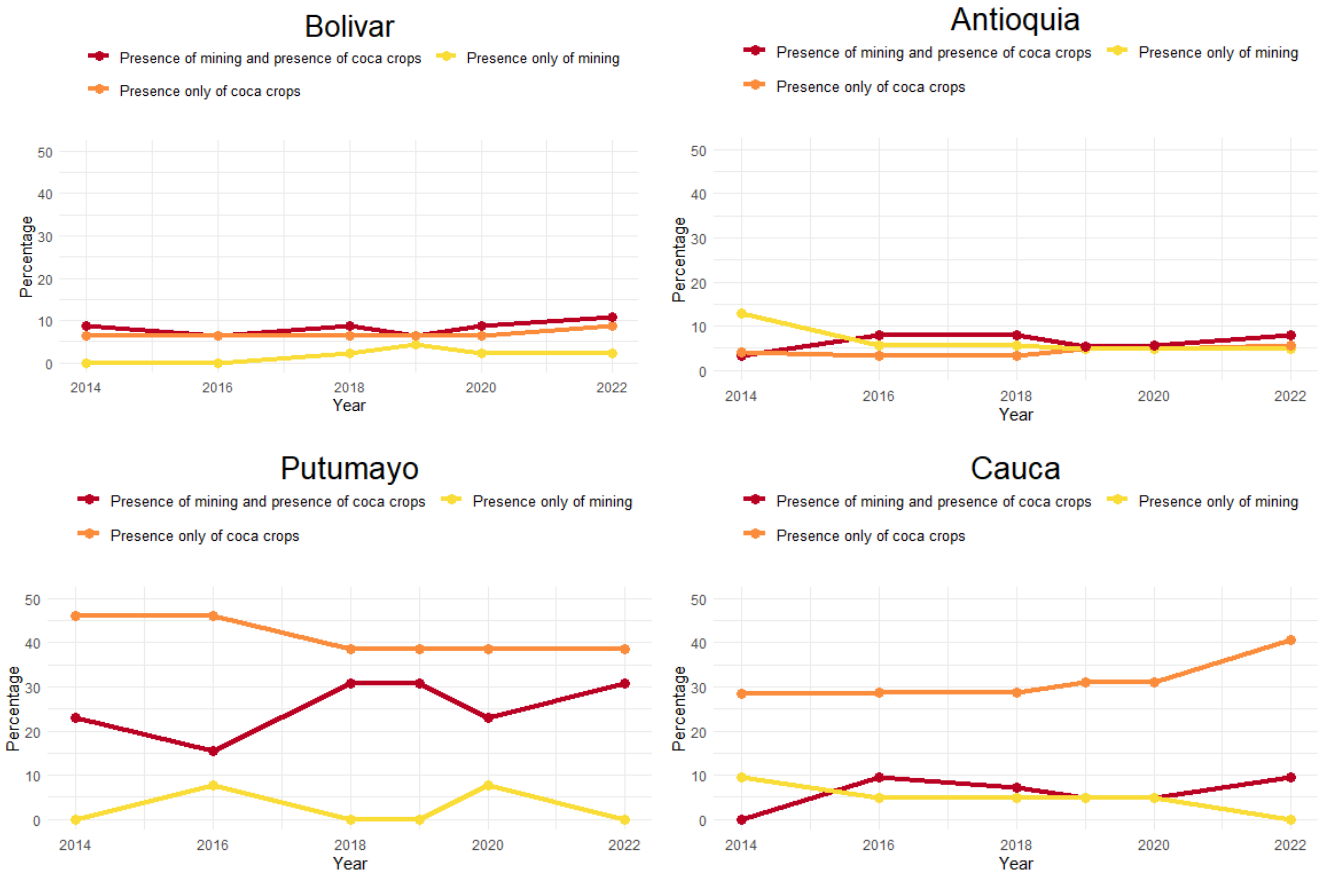
Year	Forest Reserve		Indigenous Reserves		Community Councils		Natural Parks		Overlap		Without Restrictions	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
2014	46,543	53.3	355	0.41	12,332	14.12	5,310	6.08	2,074	2.38	20,711	23.72
2016	49,596	53.83	487	0.53	11,477	12.46	5,019	5.45	1,153	1.25	24,398	26.48
2018	54,203	53.45	508	0.5	11,790	11.63	5,291	5.22	1,168	1.15	28,446	28.05
2019	57,901	53.8	411	0.38	11,167	10.38	6,740	6.26	793	0.74	21,015	21.44
2020	59,577	53.82	417	0.38	11,536	10.42	6,982	6.31	864	0.78	20,670	20.52
2021	59,718	54.79	333	0.31	11,878	10.9	6,482	5.95	795	0.73	20,189	20.48
2022	56,214	53.65	279	0.27	11,106	10.6	7,118	6.79	801	0.76	20,578	21.72

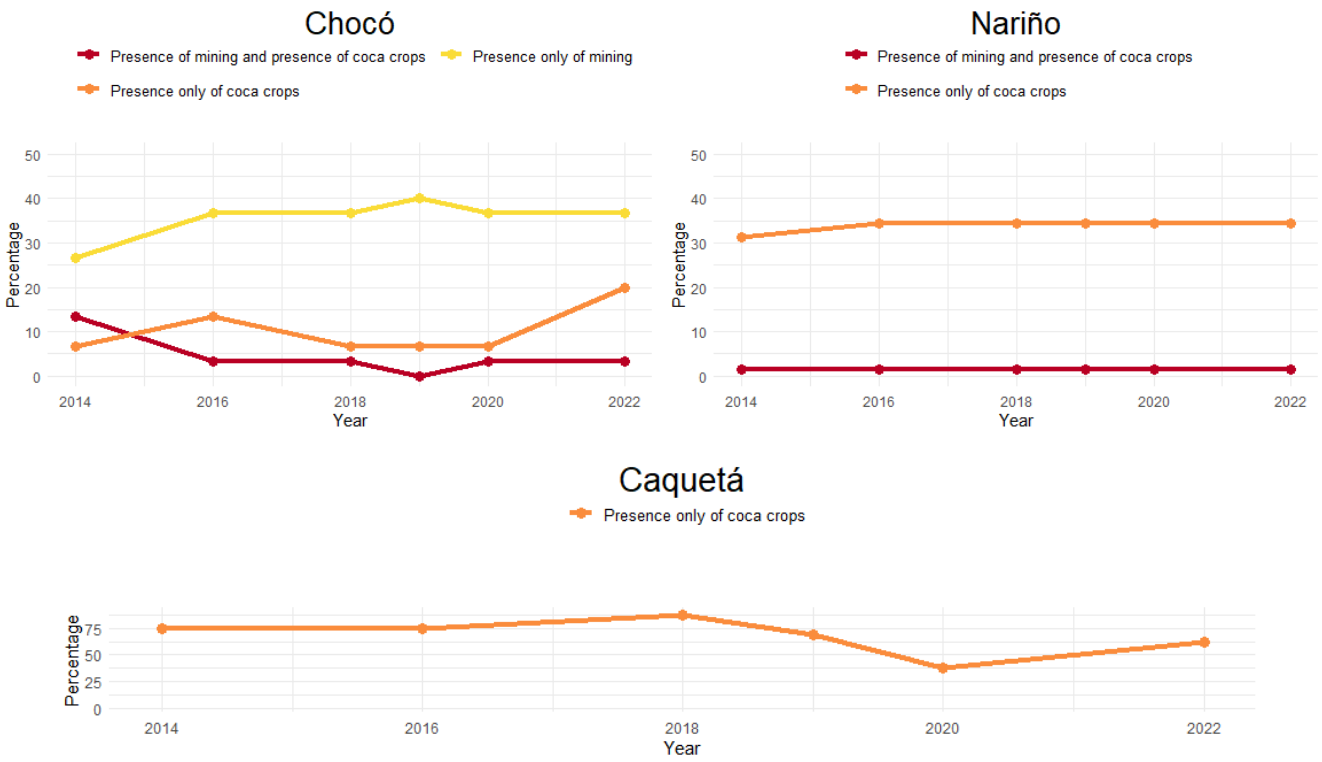
Source: Own elaboration with data from UNODC and SINAP.

These percentages highlight the growing pressure on strategic environmental areas, especially in National Natural Parks, where mining directly threatens biodiversity and the stability of unique ecosystems.

Additionally, previous studies have shown that gold mining, mainly informal and illegal, may be linked to other illicit activities such as coca leaf cultivation and its transformation into derivatives (Ortiz-Riomalo and Rettberg, 2018; Rettberg, Cárdenas, Ortiz-Riomalo, 2017). Figure 11 shows overlap between the presence of coca crops and gold mining at the municipal level by departments. The simultaneous presence of coca crops and gold mining occurs in Putumayo, Nariño, Cauca, Choco, Antioquia and Córdoba, however, only in Antioquia and Bolívar have both activities coexisted more stably, which may be related to land suitability. In contrast, while other regions also contain both coca cultivation and gold mining, both activities simultaneously are less common. As a result, the overlap between these illicit economies is limited, and in these departments, coca cultivation and gold mining are more often found in separate areas.-

Figure 11. *Percentage of municipalities with presence of coca crops and mining.*





Source: Own elaboration with data from EVOA.

Gold mining has far-reaching environmental consequences, particularly in relation to water systems and soil degradation. Alluvial mining directly affects river ecosystems, causing erosion, sedimentation, and instability in riverbanks, which in turn reduces water quality and availability for local communities (Gutiérrez-Mosquera et al., 2020). Mercury contamination is another critical issue, persisting in ecosystems decades after mining activities have ceased. Mercury exposure in mining regions has been found to exceed safe levels by up to six times, leading to severe neurological effects and long-term chronic health risks (Crespo-Lopez et al., 2021). A study in Chocó found high concentrations of total mercury (THg) and methylmercury (MeHg) in sediments from abandoned mining ponds, affecting bioaccumulation and toxicity in aquatic ecosystems (Gutiérrez-Mosquera et al., 2020).

In the Amazon region, 30% of fish samples exceeded permitted mercury limits, with carnivorous fish the most contaminated due to bioaccumulation (Nuñez-Avellaneda et al., SINCHI, 2020). The Cotuhé River, which crosses Amacayacu National Natural Park, is in the department of Amazonas, Colombia has suffered from illegal mining, leading to a drastic decline in fish populations and water pollution that threatens Indigenous communities' food security (Pinilla & Santos, 2014). This issue extends beyond Colombia, as Ecuador and Peru have also documented widespread contamination from alluvial gold mining, including lead, mercury, manganese, and cyanide, with mercury posing the most serious long-term risk (Vilela, 2020; CEJIS, 2022). It is estimated that 60% of mercury used in illegal mining settles in soil, while 40% is directly discharged into rivers, leading to bioaccumulation in aquatic food chains (WWF, Gaia Amazonas, UN, 2019). Despite these risks, biomonitoring remains insufficient, with only 10% of reviewed studies comprehensively assessing water quality and human health effects (Alcala-Orozco et al., 2020; Crespo-Lopez et al., 2021).

Beyond mercury contamination, deforestation and habitat destruction are also environmental concerns. In Chocó and the Amazon, forest clearing for mining operations has led to biodiversity loss, while the destruction of riparian vegetation intensifies sedimentation and river pollution. The disruption of these ecosystems reduces water filtration capacity and increases the risk of flooding. Mining ponds create standing water bodies that serve as breeding grounds for malaria and dengue, further exacerbating public health risks (SPDA, 2015). Without effective control and surveillance, alluvial gold mining will remain a persistent source of contamination, further degrading aquatic ecosystems and harming the health of local populations. Given the long-term ecological damage and bioaccumulation effects, addressing this issue requires integrated environmental monitoring, strengthened enforcement, and alternative economic opportunities for mining-dependent communities.

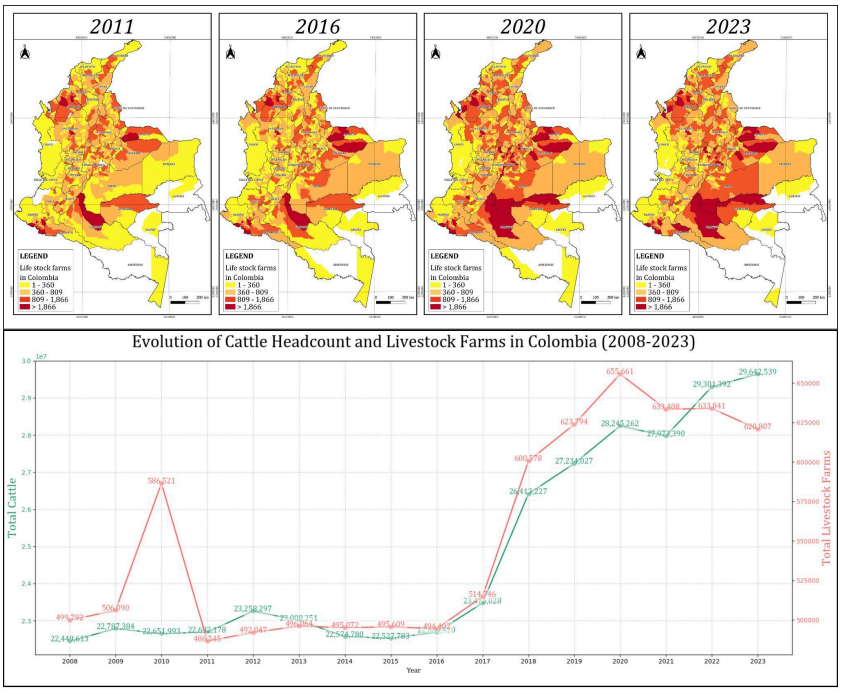
Gold mining in Colombia continues to be a complex and evolving sector. While it remains a key economic activity, it is also a major environmental and governance challenge, particularly where alluvial mining overlaps with criminal economies.

7. Cattle Ranching at National Level

Recent studies (FCDS, 2024; IUCN, 2022; Murillo-Sandoval et al., 2023) identify cattle ranching as the leading driver of deforestation in Colombia, particularly in the period following the 2016 Final Peace Agreement (FPA) (see Figure 13). Moreover, as documented in previous research (Murillo-Sandoval et al., 2023; Dávalos et al., 2011, 2016, 2021; Rettberg, Cárdenas, Ortiz-Riomalo, 2017; Ortiz-Riomalo & Rettberg, 2018), cattle ranching interacts closely with the illicit economies of coca cultivation and illegal gold mining, further shaping patterns of land use and environmental degradation.

Using geospatial data from the Colombian Agricultural Institute (ICA, for its Spanish acronym) on cattle distribution, this section provides a descriptive analysis of the sector's expansion. Figure 12 presents the temporal evolution of Colombia's cattle population, showing a stable trend between 2009 and 2015, when the number of cattle fluctuated between 22.5 and 23.3 million. However, from 2016 onward, the cattle population began to rise steadily, reaching 28.2 million in 2020 and 29.6 million by 2023—an overall increase of 32% between 2015 and 2023.

Figure 12. *Evolution of total livestock farms in Colombia (2008-2023).*



Source: Own elaboration with data from ICA.

This expansion aligns with the land suitability analysis discussed earlier, which highlights regions with favorable conditions for cattle ranching, particularly in Córdoba, Sucre, Magdalena, Santander, Arauca, Casanare, and Meta, where cattle population growth corresponds with areas identified as suitable. However, the data also indicates significant expansion in Caquetá, Guaviare, Vichada, and Putumayo, regions not classified as suitable for cattle ranching, raising concerns about land use conflicts and deforestation in these areas. The growth of the sector reflects the combined influence of geographic and environmental factors, alongside broader economic and institutional dynamics that have shaped land use decisions in the post-FPA period.

Although there has been an increase in the number of cattle in the country, there is no increase in cattle-raising areas. Systematically, it is shown that cattle density has increased in the following areas: Córdoba, northern Antioquia, Bolívar, Cesar, the eastern plains, Caquetá, and Putumayo. These descriptive results do not indicate any variations in the spatial distribution of the cattle herd over the past 15 years.

Based on ICA data, it is possible to analyze the evolution of the number of cattle farms and the share of farms by different size categories. Figure 12 shows that between 2011 and 2016, the number of cattle farms varied between 486,545 and 496,064. From 2017 onward, a significant change was observed in the number of cattle farms in the country, rising to 655,661 in 2020.

Studies such as Murillo et al. (2023) argue that, following the 2016 FPA, cattle ranching expanded as a result of the demobilization of the FARC-EP and the lack of governmental presence. This situation allowed other armed groups and land speculators to contest control over these territories, facilitating the informal appropriation of land as a strategy for legalization and money laundering. Moreover, many of the lands previously occupied by the FARC-EP became available, thereby promoting the expansion of cattle ranching in an already fully occupied agricultural frontier (Murillo et al., 2023). The authors also emphasize that, while not all cattle ranching is illegal or criminal, the practices aimed at land accumulation, speculation, and money laundering have been key drivers of deforestation, contributing to the growth of the illegal land market and the erosion of environmental governance. The primary environmental impact of the expansion

of cattle ranching has been the conversion of forests into pastures, which has become the leading cause of forest cover loss.

Regarding the distribution of farms by cattle herd size, the largest proportion is found in farms with fewer than 50 head of cattle per farm. Between 2011 and 2017, there were between 392,785 and 412,829 farms with fewer than 50 cattle per farm. In 2020, the number of farms in this group reached 537,032, a growth that explains the variation in the total number of cattle farms in the country. For farms with 51 to 100 cattle and 101 to 500 cattle, their share of the total number of farms is similar and remains constant over time. Between 2009 and 2023, the number of farms with 51 to 100 head of cattle ranged from 44,117 to 62,237, and those with 101 to 500 head of cattle ranged from 39,991 to 56,239. The largest farms, those with more than 500 cattle, have the lowest share of total farms in the country. However, since 2016, this number has systematically increased. In 2016, 5,233 farms with more than 500 head of cattle were recorded, and by 2023, this category had reached 7,178 farms. Although the share of these farms in the national total is small, this growth represents a 37.2% increase, mainly occurring in the departments of Guaviare, Atlántico, Caquetá, Bolívar, Sucre, Norte de Santander, Boyacá, Putumayo, and Quindío.

Regarding the relationship between the cattle herd and illicit economies, for this report, we conducted a correlation analysis at the municipal level between the cattle herd and coca crops. We found that when including all municipalities in the country, there is a statistically significant association between the hectares of coca crops and the number of cattle, with a correlation of 0.03. Therefore, while this statistical association is found, its magnitude is low. When associating these two variables only in coca-producing municipalities, the correlation coefficient is -0.02 but not statistically different from zero. We also conducted this analysis for gold mining and found no statistically significant associations at the national level (-0.004) or when limiting the sample to municipalities with gold mining (0.09). Therefore, these results suggest that at the municipal level, the illicit activities studied at the first stage of the value chain (cultivation and exploitation) do not correlate with the size of the cattle herd in Colombia.

However, related studies explore the relationship between the regional dynamics of the coca economy and the transformation of land into pastures for cattle ranching. Marín-Llanes et al. (2024) found that the coca boom increased economic activity in municipalities (municipal GDP) by between 2.8% and 10.5%. In addition, the authors show that other economic activities were boosted by the boom. Specifically, for the Amazon region of Colombia, Marín-Llanes et al. (2024) found that the coca boom increased the deforestation rate in Colombia by 104% and increased pastures for cattle ranching by 302%. However, the results of this research suggest that the coca boom did not affect the effective number of cattle. Therefore, while a significant and large-scale change was found in the transformation of coca fields into pastures, there is no evidence that the cattle herd grew due to changes in coca cultivation.

These results could be linked to a land grabbing phenomena, as documented by FCDS (2022; 2024) and consistent with similar patterns in Central America (Devine et al., 2020; Devine et al., 2021; Tellman et al., 2020). Land grabbing implies the concentration of land in the hands of a few owners without necessarily increasing the cattle which not only impacts the environment and the equitable distribution of resources but also generates social and economic tensions, affecting small and medium-sized producers. According to Devine et al. (2020), the absence of cattle on large parcels suggests that they are not actively being used for cattle production, but rather for land speculation or as a form of money laundering, which they term "narco-deforestation" to differentiate it from deforestation explained by land use by small rural owners.

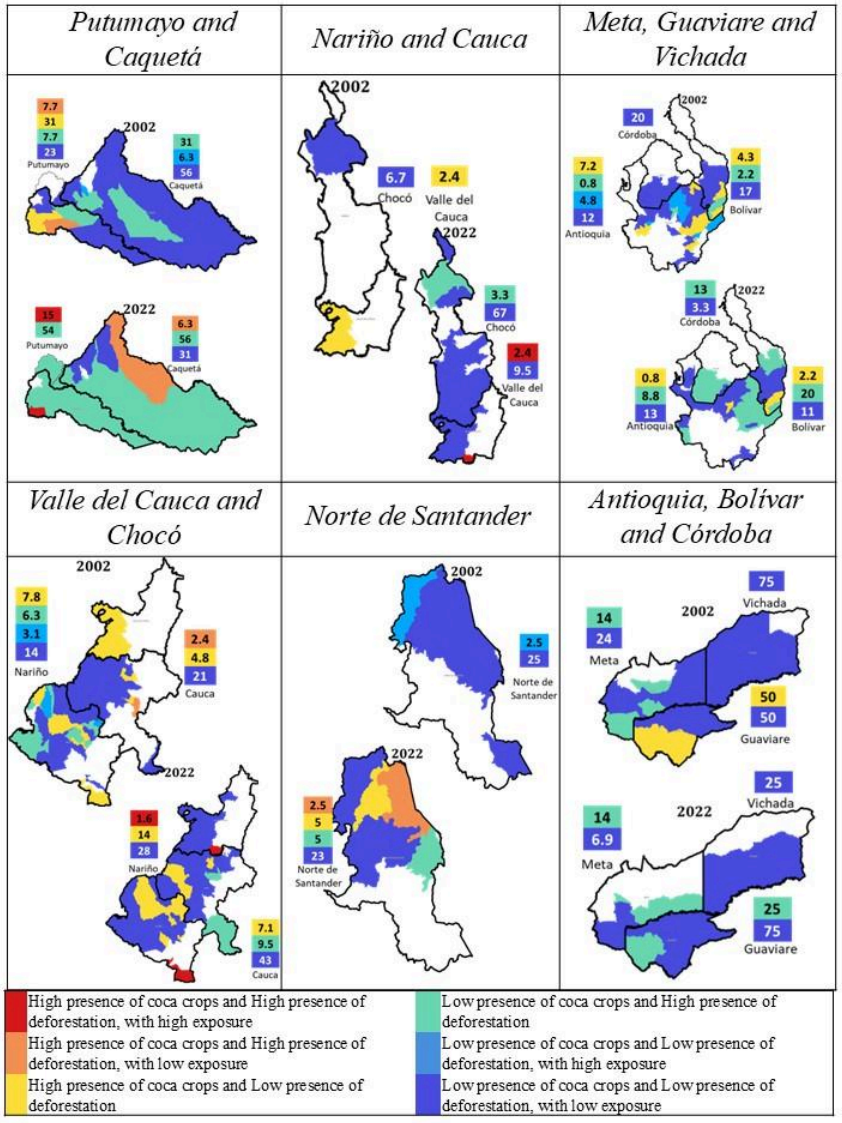
8. Environmental Impacts at National Level

8.1 Coca and Deforestation

To analyze the relationship between coca crops and deforestation, we first present statistical correlations between their presence in coca-growing regions, following the methodologies outlined in section 2.1. Specifically, we use the deforestation rate calculated from Hansen et al. (2013) and spatial analysis techniques to examine how coca cultivation correlates with forest loss. To capture spatial dependencies, we employ Moran's Index, which categorizes areas based on the presence of coca crops, their exposure in neighboring regions, and the intensity of deforestation.

Figure 13 illustrates these spatial patterns, showing the percentage of municipalities in each category and different years. The colors indicate varying levels of coca cultivation and deforestation, with orange and red tones highlighting regions where both variables are highly concentrated. In 2022, this pattern is present in Putumayo, Caquetá, Nariño, and Valle del Cauca, where coca cultivation and deforestation appear to be strongly linked in particular areas.

Figure 13. *Moran's relationship between coca and deforestation (2002-2022).*



Source: Own elaboration.

Table 3 shows the percentages of municipalities in each department, highlighting the three most frequent categories in all regions: “High presence of coca crops and Low presence of deforestation (HPC-LPD)”, “Low presence of coca crops and High presence of deforestation (LPC-HPD)”, and “Low presence of coca crops and Low presence of deforestation, with Low exposure (LPC-LPD-LE)”.

The general trend across all departments highlights 2005, when municipalities with "Low presence of coca crops and Low presence of deforestation, with Low exposure" predominated. This trend continues until 2010, when there is an increase in the categories of "High presence of coca crops and Low presence of deforestation" and "Low presence of coca crops and High presence of deforestation", alternating between the two.

In the departments of Caquetá and Putumayo, there is a predominance of low presence of coca and high deforestation. However, in Putumayo, high levels of coca crops and deforestation are observed in certain areas, particularly from 2013 onward. In Putumayo 8% of its municipalities categorized as “High presence of coca crops and High presence of deforestation (HPC-HPD)” in 2013, 2015, 2016, 2017, and from 2019 to 2022[5]. In Meta, the categories of low presence and exposure of both variables and high presence of coca crops with deforestation predominate. The latter category is highlighted as predominant in the department of Nariño.

These results suggest that spatial correlations vary among departments, so national trends cannot be generalized from these findings. Additionally, it is noted that in most departments analyzed, the correlation between coca and deforestation is low since the predominant categories are low presence and exposure of both variables, or high presence in one variable and low in the other.

[5] The percentages of municipalities in the category High Presence of Coca Crops and High Presence of Deforestation (HPC-HPD) is low and intermittent across different years. Specifically, in Antioquia, only 1% of the municipalities fell into this category in 2004 and 2008. In Chocó, the percentage was 3% in 2010 and 2012, while in Nariño, it was 3% in 2004 and decreased to 2% in 2010 and 2022. In Norte de Santander, 3% of the municipalities were classified as HPC-HPD from 2016 to 2021. In Valle del Cauca, this percentage was 2% in 2010, 2017, 2021, and 2022.

Table 3. *Percentage of municipalities in the representative Moran categories for coca-deforestation.*

Department	Index Category	2005	2010	2015	2018	2022
Antioquia	HPC-LPD	2	5	1	2	1
	LPC-HPD	2	2	4	8	9
	LPC-LPD-LE	12	11	11	10	13
Bolívar	HPC-LPD	0	2	0	0	2
	LPC-HPD	2	9	9	13	20
	LPC-LPD-LE	28	17	17	9	11
Caquetá	HPC-LPD	0	0	6	0	0
	LPC-HPD	81	38	13	44	56
	LPC-LPD-LE	19	56	81	56	31
Cauca	HPC-LPD	0	7	5	2	7
	LPC-HPD	7	2	2	2	10
	LPC-LPD-LE	21	26	40	40	43
Córdoba	HPC-LPD	3	0	0	0	0
	LPC-HPD	0	10	3	10	13
	LPC-LPD-LE	7	3	13	7	3
Chocó	HPC-LPD	3	13	0	0	0
	LPC-HPD	0	13	3	0	3
	LPC-LPD-LE	40	33	60	53	67
Meta	HPC-LPD	14	10	0	0	0
	LPC-HPD	3	10	7	14	14
	LPC-LPD-LE	14	10	21	17	7
Nariño	HPC-LPD	13	17	5	11	14
	LPC-HPD	0	0	0	0	0
	LPC-LPD-LE	22	22	38	31	28
Norte de Santander	HPC-LPD	0	0	5	10	5
	LPC-HPD	3	15	10	5	5
	LPC-LPD-LE	15	10	18	20	23
Valle del Cauca	HPC-LPD	0	2	0	0	0
	LPC-HPD	0	0	0	0	0

Department	Index Category	2005	2010	2015	2018	2022
	LPC-LPD-LE	0	2	10	12	10
Putumayo	HPC-LPD	8	0	0	0	0
	LPC-HPD	8	8	38	31	54
	LPC-LPD-LE	54	62	15	31	0
Guaviare	HPC-LPD	25	25	0	0	0
	LPC-HPD	0	75	25	75	25
	LPC-LPD-LE	75	0	75	25	75
Vichada	HPC-LPD	25	25	0	0	0
	LPC-HPD	0	0	0	0	0
	LPC-LPD-LE	50	50	25	25	25
Legend for Acronyms						
HPC-LPD	High presence of coca crops and Low presence of deforestation					
LPC-HPD	Low presence of coca crops and High presence of deforestation					
LPC-LPD-LE	Low presence of coca crops and Low presence of deforestation, with Low exposure					

Source: Own elaboration.

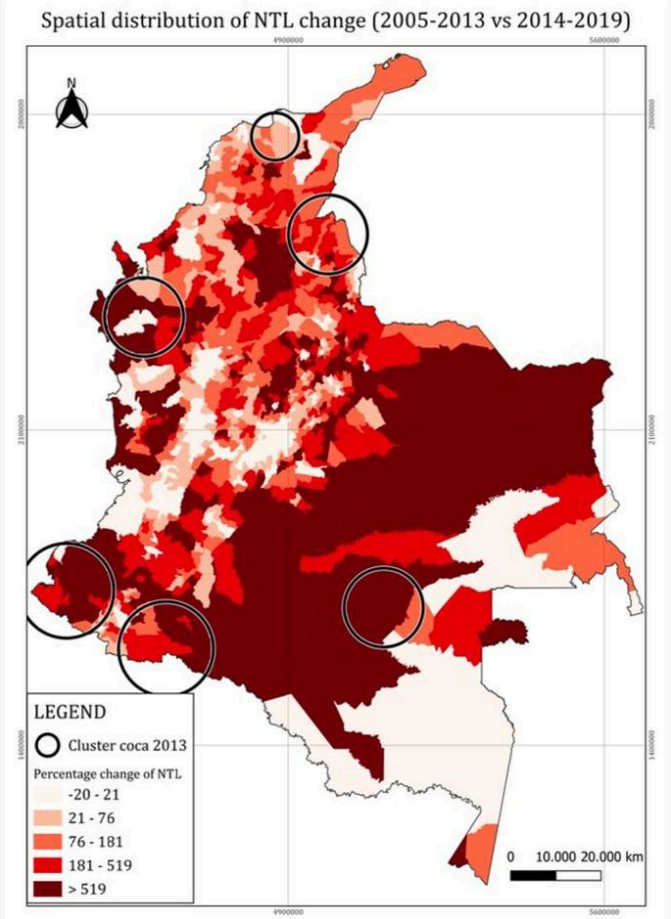
These descriptive results suggest that areas where we can identify associations between coca crops and deforestation are limited in the country. However, these analyses help identify areas, particularly in some regions of the country and after the 2016 FPA, where changes in deforestation patterns occurred.

In the remainder of this section, we present the results of econometric analyses that allow us to control intertemporal effects as well as spatial heterogeneities. In our econometric analyses, we examine the correlations between the density and presence of coca crops from the previous year (t-1) and deforestation patterns at the grid-cell level. Equation 3 extends the analysis with 5 km and 10 km buffers to evaluate the influence of neighboring illicit activities.

Coca crops density is used to assess the direct relationship between changes in the extent of cultivation and deforestation patterns, while coca crop presence captures also the potential spillover effects and productive transformations associated with

the coca economy. Previous research has highlighted that coca crops are not the most important driver of deforestation in the country (Murillo-Sandoval et al., 2023; Dávalos et al., 2021; Erasso & Vélez, 2020; Brombacher, Garzón & Vélez, 2021; Quiroga et al., 2022; Dávalos et al., 2011). However, the coca economy has been identified as a catalyst for other productive and agricultural sectors in regions where coca cultivation occurs which in turn can have environmental impacts (Ciro, 2020; Dávalos, 2021; Gutiérrez, 2021; Marín-Llanes et al., 2024). Ccoca crops cultivation could promote the regional economy which in turn could generate deforestation. For example, Marín-Llanes et al. (2024) using nighttime lights (NTL) as proxy of economic activity, found that the income derived from the recent coca boom in Colombia from 2014 to 2019 fueled other economic activities. Figure 14 illustrates this dynamic by showing significant increases in nighttime lights between 2005–2013 and 2014–2019, particularly in regions historically associated with coca cultivation, suggesting a broader economic expansion linked to the coca boom.

Figure 14. *Spatial distribution of NTL change (2005-2013 vs 2014-2019).*



Source: Marin-Llanes et al. (2024).

In our preferred models, which include municipality-level linear trends (see columns 2 and 4, Table 4), **the density of coca crops in the previous year is associated with a 2.2% increase in the deforestation rate and a 1.5% higher likelihood of deforestation in the following period.** While these associations are modest, they are consistent with previous studies suggesting that coca crops are not the primary direct driver of deforestation in Colombia (Murillo-Sandoval et al., 2023; Dávalos et al., 2021).

Thus, deforestation to cultivate coca, that is a direct effect, does not seem to be the most important effect. However, the presence of this economy, which also serves as catalyst for other economies seems to be a most important effect. **When considering the presence of coca crops, we find a 15.8% higher deforestation rate and a 10.4% higher probability of deforestation.** The coefficients related to coca crop presence also capture the broader economic and productive transformations that exacerbate deforestation beyond the cultivation itself. These magnitudes are larger than those associated with coca crop density, as this measure captures only the direct association. Thus, our results suggest that while the direct effect of coca crop cultivation on deforestation exists, it is limited in scale. In contrast, the coca economy, along with the productive activities it fosters, plays a more significant role in driving deforestation (Marín-Llanes et al., 2024).

Table 4. *Relationship between Coca Crops and Deforestation.*

	Dep. Var. : Deforestation			
	(1)	(2)	(3)	(4)
Panel (a): Deforestation Rate				
Coca Presence	0.2643***	0.1575***		
	(0.0842)	(0.0608)		
Coca Std. Density			0.0306***	0.0215**
			(0.0078)	(0.0090)
Mean	2.829	2.829	2.829	2.829
Panel (b): Deforestation Presence				
Coca Presence	0.1063***	0.1042***		
	(0.0073)	(0.0076)		
Coca Std. Density			0.0165***	0.0147***
			(0.0009)	(0.0010)
Mean	0.302	0.302	0.302	0.302
N	7,620,270	7,620,270	7,620,270	7,620,270

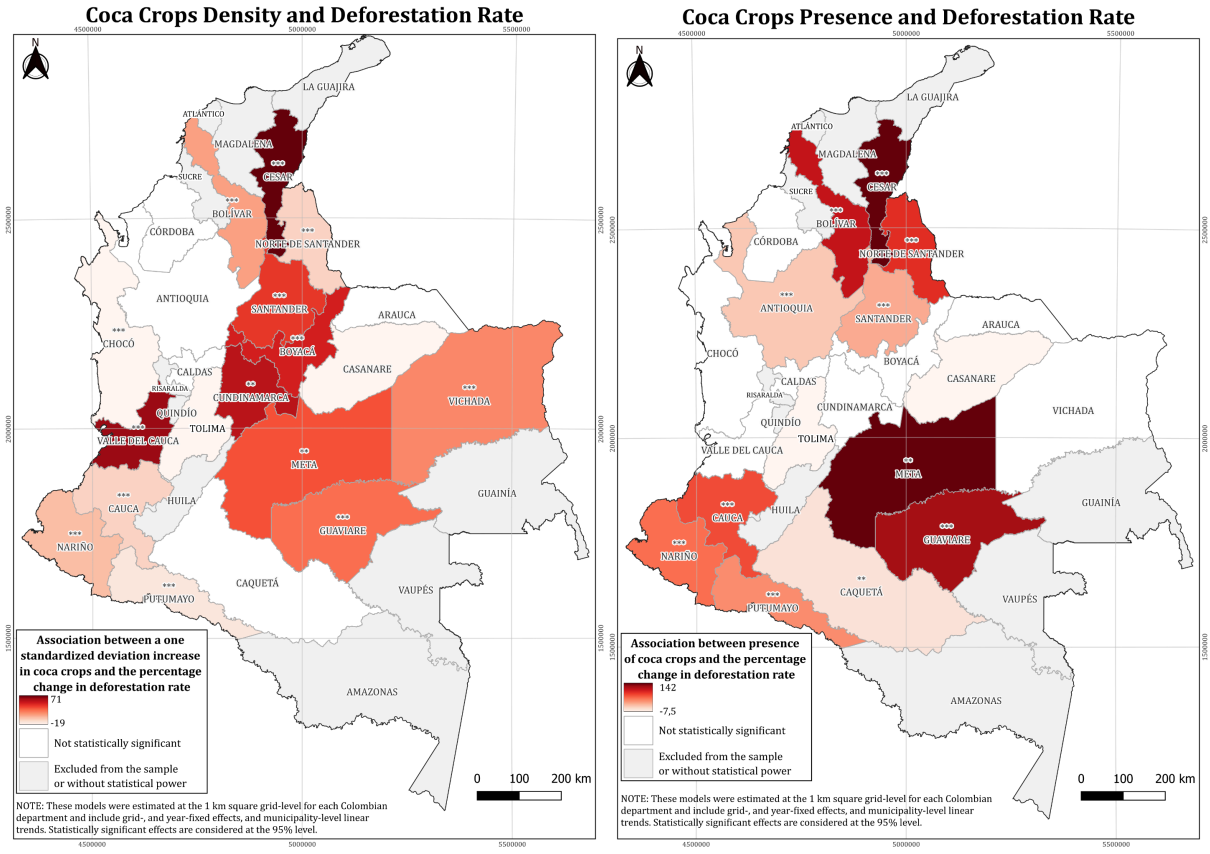
Grid FE	✔	✔	✔	✔
Year FE	✔	✔	✔	✔
Depto X Year FE	✔		✔	
Mun X Year FE		✔		✔
***1% **5% *10%				

Notes: Standard errors are clustered at the vereda level. Models were estimated using Poisson pseudo-maximun likelihood regressions.The reported coefficients correspond to percentage changes obtained by transforming the estimates with $e^{\beta} - 1$

Source: Own elaboration.

We further investigate whether these associations hold consistently across all Colombian regions or if significant regional differences exist. Figure 15 presents department-level models that examine the relationship between coca cultivation (both presence and density) and deforestation in each department. Our results suggest notable regional variations: while we observe positive and statistically significant associations in Meta, Nariño, and Putumayo—where our case studies are concentrated—such associations are absent or even negative in other departments. Beyond our case study departments, we find consistent positive and statistically significant correlations between coca crop density and presence and deforestation in Bolívar, Cauca, Cesar, Guaviare, and Norte de Santander. Coca crop density is linked to deforestation in Valle del Cauca and Vichada, while coca cultivation presence is associated with deforestation in Antioquia and Caquetá. However, in various models exploring the department-level associations between coca cultivation (presence and density) and deforestation (both the likelihood of deforestation and its intensity), we find no statistical relationship in Chocó, Caldas, Córdoba, Cundinamarca, Boyacá, and Arauca. In Tolima and Casanare, we even observe negative associations between these variables. These differences may be explained by factors such as variations in state presence, property regimes, the regulation of illicit markets, the presence of armed actors, and the interaction between the coca economy and other drivers of deforestation, such as land grabbing and cattle ranching or the presence of other economies such as gold mining.

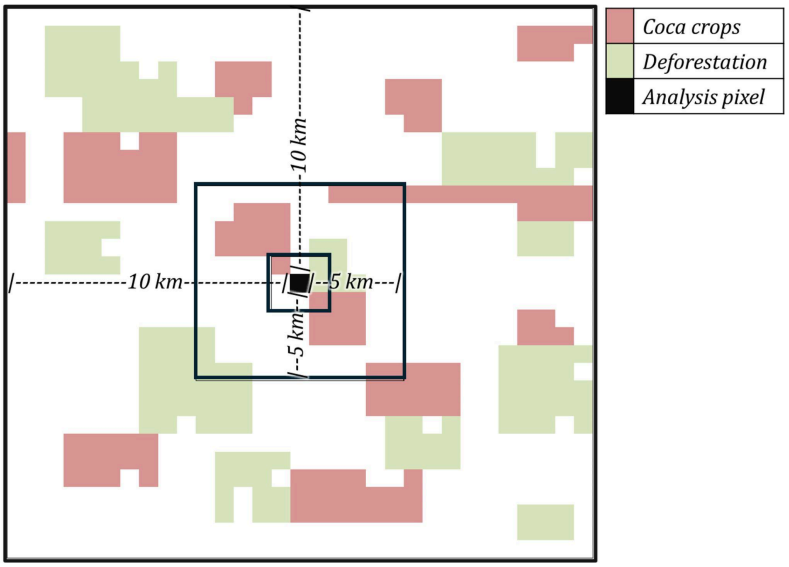
Figure 15. *Deforestation Rate at the Department Level.*



Source: Own elaboration.

We also incorporate a spatial dimension by considering the number of neighboring grid cells with coca crops and the density of coca crops in neighboring areas, defined by immediate neighbors and buffers of 5 and 10 kilometers. Figure 16 presents an example of this association with the buffers. Our results suggest that exposure to the coca economy predicts the presence of deforestation in the following year but does not account for the intensity of deforestation. In models using the probability of deforestation as the dependent variable, both the number of neighbors and the density of coca crops in neighboring grid cells are positively associated with the probability of deforestation in the subsequent period. The likelihood of deforestation increases linearly from 5.4% to 20.1% as the number of neighboring cells with coca crops increases from 1 to 8. Similarly, a one standard deviation increase in coca density in neighboring areas is associated with a 1.4% to 2.2% increase in the probability of deforestation. In these models, the inclusion of exposure to coca crops reduces the estimated association of coca crop presence and density in the same grid cell by approximately 20% and 50%, respectively.

Figure 16. *Example Illustration of the Spatial Distribution of Coca Crops and Their Influence on Neighboring Areas within 5 km and 10 km Buffers.*



Source: Own elaboration.

For models using the deforestation rate as the dependent variable, neither the number of neighbors with coca crops nor the density of coca crops in neighboring areas predicts future deforestation. In these cases, the estimates for coca crops within the same grid cell remain qualitatively unchanged.

These findings suggest that while there are spatial correlations between coca cultivation and deforestation patterns, their relevance is not central in the Colombian context. In addition to the regional heterogeneities found, our results indicate that while exposure to coca cultivation can predict deforestation in the following period, it does not explain its intensity. These conclusions align with previous research (Quiroga et al, 2022; Murillo-Sandoval et al., 2023) suggesting that while the presence of the coca economy can impact productive activities that contribute to deforestation, other factors associated with the broad coca economy could also play significant roles.

As mentioned before, certain variables—such as road development and cattle ranching—have been identified as drivers of deforestation. To test the robustness of our findings, we include these variables in our estimations. In other words, if road development or cattle ranching were the only reason why coca crops and deforestation are associated in the data, the relationship between coca and

deforestation would disappear when adjusting for these potential drivers. Our results suggest that the symbiosis between the coca economy and deforestation is more complex than that. Specifically, as shown in Tables 5 and 6, when incorporating road density and cattle ranching (measured per hectare at the municipal level), we find that the estimated associations between coca cultivation and deforestation remain unchanged. These results do not suggest that there is not relationship between road density or cattle ranching with deforestation. Instead, our findings reveal that when comparing grid-cells with similar levels of road density and cattle ranching, the association between coca crops and deforestation persists.

We also include gasoline consumption outliers in the econometric models as a proxy to identify transformation areas from coca leaves to coca paste and we do not find consistent differential associations between coca crops and deforestation. Therefore, the relationship between coca crops and deforestation does not change when we include road density, cattle ranching, or areas where coca transformation takes place in our analysis.

Table 5. *Relationship between Coca Crops and Deforestation: road density heterogeneous effect.*

	Dep. Var.: Deforestation			
	(1)	(2)	(3)	(4)
Panel (a): Deforestation Rate				
Coca Presence	0.1575***	0.1579***		
	(0.0608)	(0.0606)		
Coca Std. Density			0.0215***	0.0215**
			(0.0090)	(0.0090)
Coca presence x Road std density(km)		-0.0097***		
		(0.0140)		
Coca Std. Density x Road std density(km)				-0.0051***
				(0.0017)
Mean	2.829	2.829	2.829	2.829
	(1)	(2)	(3)	(4)
Panel (b): Deforestation Presence				
Coca Presence	0.1042***	0.1054***		
	(0.0076)	(0.0076)		
Coca Std. Density			0.0147***	0.0148***
			(0.0010)	(0.0010)
Coca presence x Road std		-0.0195***		

density(km)		(0.0036)		
Coca Std. Density x Road std density(km)				0.0031*** (0.0005)
Mean	0.302	0.302	0.302	0.302
N	7,620,270	7,620,270	7,620,270	7,620,270
Grid FE	✔	✔	✔	✔
Year FE	✔	✔	✔	✔
Mun X Year FE	✔	✔	✔	✔
***1% **5% *10%				

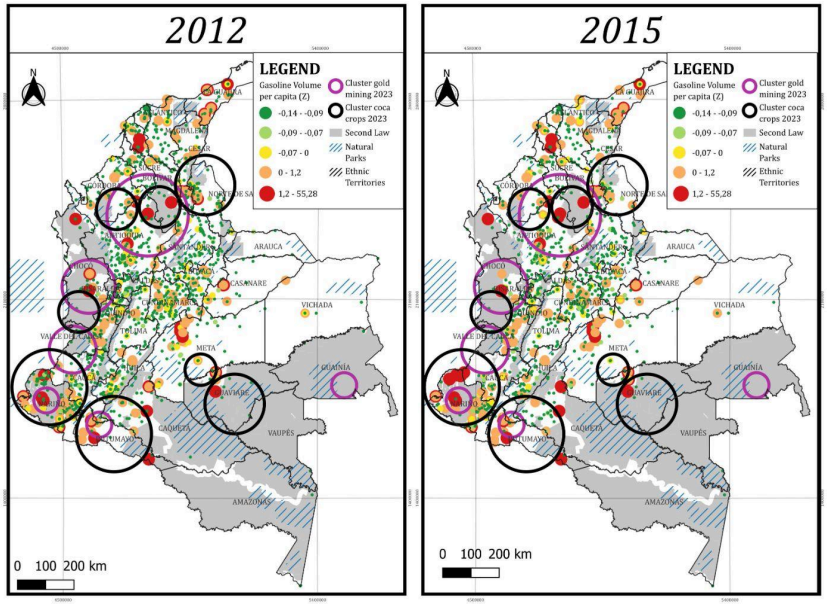
Notes: Standard errors are clustered at the vereda level. Models were estimated using Poisson pseudo-maximun likelihood regressions.The reported coefficients correspond to percentage changes obtained by transforming the estimates with $e^{\beta} - 1$

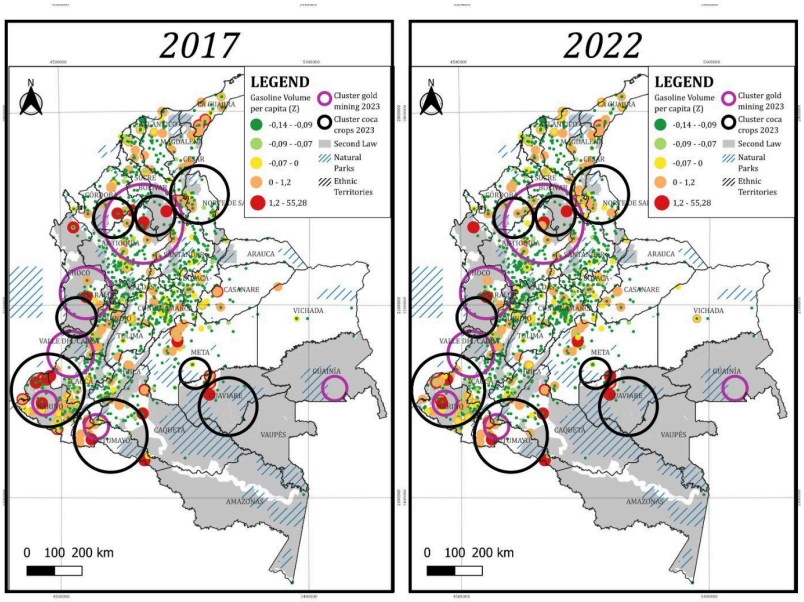
Source: Own elaboration.

8.2 Coca and Gasoline

Since gasoline is a key input for producing cocaine hydrochloride, we analyzed correlations between coca production hubs and abnormal gasoline sales using georeferenced transaction data. Anomalous sales—defined as 1.2 to 55.28 standard deviations above the mean—were concentrated near coca cultivation areas, suggesting their involvement in processing or transport (see Figure 17) this might suggests further environmental impacts regarding water and soil contamination that deserves further research.

Figure 17. *Spatial distribution of gasoline volume per capita.*





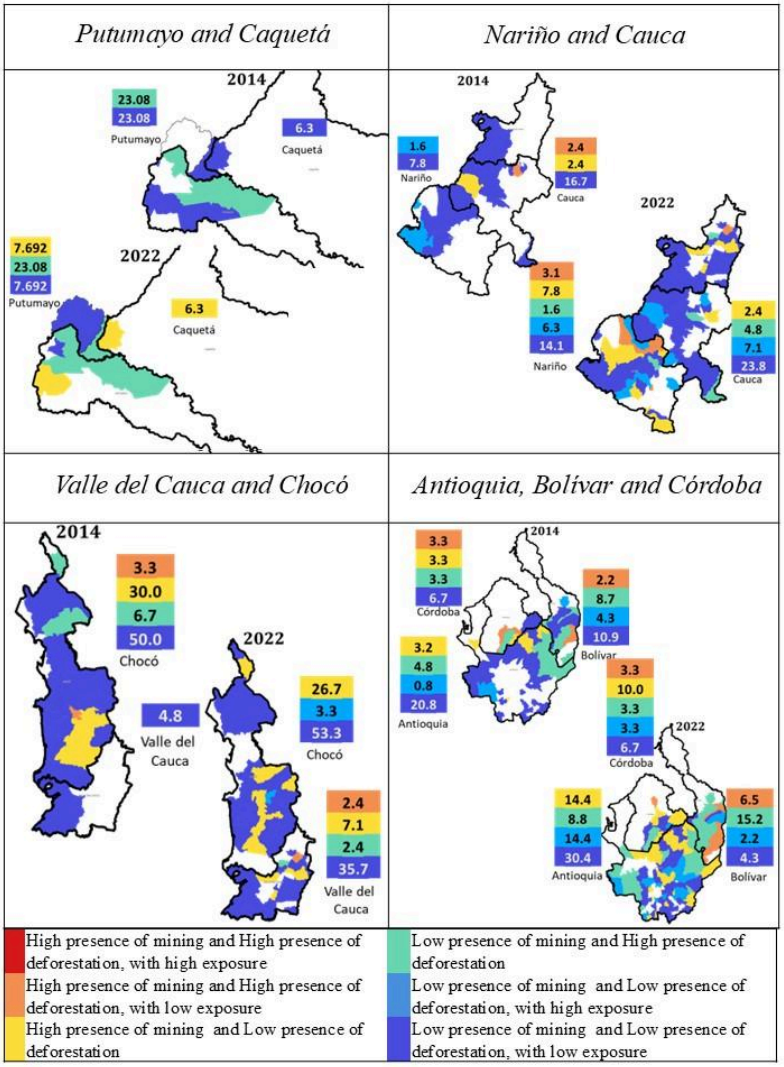
Source: Own elaboration based on data from the Ministry of Mines and Energy and NASA SEDAC (Gridded Population of the World dataset). The size of the circles represents the Z-scores of the normalized gasoline volume per capita, calculated using gasoline sales data. The normalization process considered the population within the area of influence of each gas station, excluding those located on primary roads.

8.3 Gold and Deforestation

To analyze the relationship between gold mining and deforestation, we first present the correlations between the presence of gold mining and deforestation, following the methodologies briefly outlined in section 2.

Table 7 shows the percentage of municipalities by department within the categories of the Index between gold mining and deforestation. Maps in Figure 18 illustrates these spatial patterns, showing the percentage of municipalities in each category. The three most frequent categories are: "Low presence of gold mining and Low presence of deforestation, with Low exposure ", "Low presence of gold mining and High presence of deforestation," and "High presence of gold mining and Low presence of deforestation." Two less frequent categories are "High presence of gold mining and High presence of deforestation, with low exposure" and "Low presence of mining and Low presence of deforestation, with high exposure," both of which appear only in a few municipalities and years.

Figure 18. *Moran's relationship between coca and deforestation (2002-2022).*



Source: Own elaboration.

The absence of a dominant "High presence of gold mining and High presence of deforestation" category can be explained by the nature of alluvial gold mining. Since this activity occurs primarily in riverbeds and surrounding areas, it does not require extensive tree clearing, resulting in a lower direct association with deforestation. This distinction is reflected in the classification of municipalities across the different categories.

The classification of municipalities highlights a dominant trend of "Low presence of gold mining and Low presence of deforestation, with Low exposure", particularly in Antioquia, Valle del Cauca, and Chocó, where this category increased significantly in 2021-2022. In Valle del Cauca, for example, it rose from 5% in 2014 to 36% in 2022, suggesting a decline in both mining activity and deforestation pressure.

Meanwhile, "Low presence of gold mining and High presence of deforestation" remains consistently high in Bolívar and Putumayo, peaking between 2018 and 2020. This suggests that deforestation in these regions is driven by factors other than gold mining. Putumayo, in particular, has fluctuated between 23% and 31%, showing persistent deforestation despite low mining presence.

Finally, "High presence of gold mining and Low presence of deforestation" is remarkably stable in Chocó, maintaining 30% of municipalities in this category from 2014 to 2021, with only a slight decline in 2022. Overall, the years 2020–2022 mark key shifts, with some areas stabilizing while others, like Putumayo and Bolívar, continue to experience high deforestation despite low mining activity. These trends emphasize the complex and evolving relationship between gold mining and deforestation over time.

Table 7. *Percentage of Municipalities by Department According to Moran's Representative Categories for Gold- Deforestation.*

Department	Index Category	2014	2016	2018	2020	2022
Antioquia	HPGM-LPD	3	6	6	7	14
	LPGM-HPD	5	6	6	6	9
	LPGM-LPD-LE	21	14	6	4	30
Bolívar	HPGM-LPD	0	2	2	2	0
	LPGM-HPD	9	17	17	22	15
	LPGM-LPD-LE	11	7	2	2	4
Caquetá	HPGM-LPD	0	0	0	0	6
	LPGM-HPD	0	6	0	6	0
	LPGM-LPD-LE	6	6	6	0	0
Cauca	HPGM-LPD	2	5	5	5	2
	LPGM-HPD	0	5	0	0	5
	LPGM-LPD-LE	17	19	14	12	24
Córdoba	HPGM-LPD	3	7	7	7	10
	LPGM-HPD	3	0	0	0	3
	LPGM-LPD-LE	7	3	3	3	7

Department	Index Category	2014	2016	2018	2020	2022
Chocó	HPGM-LPD	30	30	30	30	27
	LPGM-HPD	7	3	0	3	0
	LPGM-LPD-LE	50	37	30	30	53
Nariño	HPGM-LPD	0	0	2	2	8
	LPGM-HPD	0	0	0	0	2
	LPGM-LPD-LE	8	9	9	9	14
Valle del Cauca	HPGM-LPD	0	0	0	0	7
	LPGM-HPD	0	0	0	0	2
	LPGM-LPD-LE	5	10	5	5	36
Putumayo	HPGM-LPD	0	0	0	0	8
	LPGM-HPD	23	23	23	31	23
	LPGM-LPD-LE	23	15	23	0	8
Legend for Acronyms						
HPGM-LPD	High presence of mining and Low presence of deforestation					
LPGM-HPD	Low presence of mining and High presence of deforestation					
LPGM-LPD-LE	Low presence of gold mining and Low presence of deforestation, with Low exposure					

Source: Own elaboration.

As discussed above, raw spatial associations do not examine variation over time or adjust for other variables which can mask important results. For this reason, we once again take a closer look at these spatial patterns employing a fixed effects econometric specification. In our preferred models, which include a municipality-level linear trend (see columns 2 and 4, Table 8), **we find that the presence of gold mining in the previous year is associated with an 8.9% lower rate of deforestation, although this coefficient is only statistically significant at the 90% confidence level.** We further investigate regional differences and find that, in most Colombian departments, there are no statistically significant relationships between gold mining and deforestation. In Valle del Cauca, gold mining density is negatively associated with deforestation outcomes, while in Antioquia and Guainía, negative relationships are observed between gold mining density and the deforestation rate and probability, respectively.

Table 8. *Relationship between Gold Mining and Deforestation*

	Dep. Var. : Deforestation			
	(1)	(2)	(3)	(4)
Panel (a): Deforestation Rate				
Gold mining Presence	-0.0834	-0.0894		
	(0.0557)	(0.0542)		
Gold mining Std. Density			-0.0011	-0.0011
			(0.0059)	(0.0085)
Mean	1.915	1.915	1.915	1.915
Panel (b): Deforestation Presence				
Gold mining Presence	-0.0358***	0.0051		
	(0.0145)	(0.0148)		
Gold mining Std. Density			-0.0013	0.0002
			(0.0011)	(0.0011)
Mean	0.555	0.555	0.555	0.555
N	538,468	538,468	538,468	538,468
Grid FE	✔	✔	✔	✔
Year FE	✔	✔	✔	✔
Depto X Year FE	✔		✔	
Mun X Year FE		✔		✔

***1% **5% *10%

Notes: Standard errors are clustered at the vereda level. Models were estimated using Poisson pseudo maximun likelihood regressions.The reported coefficients correspond to percentage changes obtained by transforming the estimates with $e^{\beta} - 1$

Source: Own elaboration.

When considering the spatial dimension—measured by the number of neighboring grid cells with gold mining activity and the density in neighboring areas (defined by immediate neighbors and buffers of 5 and 10 kilometers)—we find that the direct relationship between gold mining and deforestation is statistically insignificant. Additionally, the coefficients for exposure to gold mining (number of neighbors with gold mining and density of gold mining in neighboring areas) are statistically insignificant in most cases. Only the coefficients for areas with 3 (between -11.9% and -13.3%) and 5 (between -17.4% and -19.6%) neighboring cells are negative and significant for deforestation rates. The estimates associated with gold mining density in neighboring grid cells are negative, ranging between -13.2% and -13.9% when predicting deforestation rates. Therefore, we do not find evidence

of positive, direct associations between gold mining and deforestation patterns, nor between exposure to gold mining and deforestation.

For the models estimating the associations between gold mining and deforestation, we also include road density and cattle ranching as control variables. Once again, the previously identified null correlations between gold mining and deforestation remain consistent even with the inclusion of these variables. The same results were found when including gasoline hotspots.

The low relationship between alluvial gold mining and deforestation could be explained by the location of mining activities. In our spatial analysis, we crossed UNODC's EVOA alluvial gold mining areas with rivers and found that, on average, 94% of these areas are located within riparian zones. This suggests that alluvial gold mining primarily depends on aquatic ecosystems, reducing its direct impact on areas with dense forest cover.

Table 9. *Alluvial Gold Mining Overlap with Rivers: Hectares and Percentage by Year (2014–2022)*

Year	2014	2016	2018	2019	2020	2021	2022
Hectares of alluvial gold mining overlapping with rivers	75,090	78,866	86,668	91,698	94,426	92,568	88,774
Percentage of alluvial gold mining area overlapping with rivers	95%	94%	94%	94%	94%	94%	94%
Total hectares of alluvial gold mining	78,939	83,620	92,046	98,028	100,752	98,567	94,733

Source: Own elaboration

These results contrast with those observed by Hänggli et al. (2023) in Madre de Dios (Peru) and Guyana, where evidence shows a significant correlation between gold mining and deforestation. This correlation is largely driven by the high dependence of local communities on gold mining, the large-scale of mining, and by the increased international demand for gold, which has raised its price and stimulated the activity (Alarcón Aguirre et al. 2021; Hänggli et al. 2023; Luque, 2022; Sacha, 2022). In fact, Hänggli et al. (2023) highlight that the expansion of agricultural frontiers for cattle ranching and commodity crops is the primary driver of deforestation across the Amazon basin, except in Guyana where gold is the most important driver.

In Peru, particularly in Madre de Dios region, gold mining is characterized by medium- to large-scale operations, many of them illegal, utilizing heavy machinery such as excavators and large dredges, resulting in significant deforestation (Ministerio del Ambiente del Perú, 2015). Similarly, in Guyana, gold mining is one of the leading causes of deforestation, not only due to the presence of large-scale mining concessions but also because of the high concentration of artisanal miners, whose combined activity generates a significant forest impact. As the sector continues to grow, many of these miners seek financing to acquire heavy machinery, further accelerating the expansion of mining and its effects on natural ecosystems (Arias, C., & Gómez, 2024).

In contrast, in Colombia, although similar mechanized operations exist, alluvial gold mining is more diverse, with an emphasis on small-scale mining. Additionally, the deforestation area in dredging operations ranges between 0.1 and 1 hectare per operation front (typically involving one to three dredges), as these operate in rivers and do not require large, cleared areas except for camp facilities (SPDA, 2024). Therefore, as suggested by the case study results discussed in the next section, illegal gold mining in Colombia has a more significant impact on water contamination and the erosion of watersheds than on deforestation.

8.4 Gold Mining and Gasoline

Since gasoline is an essential input for the operation of mining machinery, we explored correlations between anomalous sales and alluvial gold mining zones. The results are not as conclusive as in the case of coca. Although enclaves in the Antioquia, Chocó, Nariño, and Putumayo regions show areas with disproportionate gasoline sales, these same enclaves spatially overlap with coca productive enclaves. Conversely, in mining enclaves in Cauca and Guainía where there is only gold mining, we did not identify the presence of disproportionate gasoline sales (See maps in Figure 17).

9. Case Studies: Interactions Between Illicit Economies and Environmental Damage

The national statistical analysis in the previous sections establishes general relationships between the variables of interest and highlights regional heterogeneities. This section shifts focus to three case studies, not as direct illustrations of the broader statistical patterns, but as explorations of the specific mechanisms and local dynamics through which illicit economies and environmental damage interact. In particular, the next sections explore how the coca-cocaine economy catalyzes deforestation, transitions to cattle ranching, and environmental degradation tied to gold mining.

9.1 Description of Case Studies

The municipality of Vistahermosa, in the department of Meta, was selected not only because it has been a traditional coca-producing territory since the 1990s, but also because it includes areas that have undergone an economic transition from coca cultivation to cattle ranching. According to the most recent UNODC report (2024), Vistahermosa is among the territories where coca crops are systematically deconcentrating. Although the municipality is neither part of nor adjacent to any of Colombia's fifteen coca-producing enclaves (UNODC, 2023a; UNODC, 2024), some neighboring areas—particularly along the borders with San José del Guaviare (Guaviare) and Puerto Rico (Meta)—have experienced an intensification of coca cultivation in recent years.

Covering an area of 4,811 km² and with a population of 19,392 (TerriData, 2024a), 48.5% of Vistahermosa's residents live in multidimensional poverty (DANE, 2023). The presence of ethnic minority populations is relatively low, with only 1.54% identifying as Indigenous, Black, Mulatto, Afro-Colombian, or Romani (Gypsy). Unlike other regions, Vistahermosa does not have Indigenous Reserves or Community Councils of Black Communities, but it does have 84 Community Action Boards the local peasants' organizations (Alcaldía Municipal de Vistahermosa, 2020).

Puerto Guzmán, in the department of Putumayo, is also a traditional coca-producing municipality with areas that have transitioned from coca cultivation to cattle ranching. It is likewise a territory where coca crops are deconcentrating, according to UNODC (2024). In addition to coca, Puerto Guzmán is home to communities with a history of small- and medium-scale gold mining. In recent years, the municipality has witnessed increased mining activity along the Caquetá River. Located 200 km by road from San Miguel (one of the municipalities within the Frontera Putumayo coca enclave) and 140 km from Orito (home to the Orito-Vides enclave), Puerto Guzmán offers a valuable case for exploring the interactions between coca cultivation, gold mining, and cattle ranching.

Spanning 4,565 km² with a population of 38,586 (TerriData, 2024a)—roughly twice that of Vistahermosa—Puerto Guzmán reports higher multidimensional poverty (62.2% vs. 48.5%, DANE 2023) and a greater ethnic minority presence: 10.46% Indigenous and 5.84% Black, Mulatto, or Afro-Colombian. This diversity is reflected in its local organizational structure, which includes six Indigenous Reserves, seven Community Councils of Black Communities, and 206 Community Action Boards (Alcaldía Municipal de Puerto Guzmán, 2020).

Tumaco, in the department of Nariño, is smaller in area (3,778 km²) but has a significantly higher proportion of Afro-Colombian (80.22%) and Indigenous (13.41%) populations. It hosts a wide range of ethnic organizations: 18 Indigenous Reserves, 15 Community Councils, and 130 Community Action Boards. More than half of the population lives in multidimensional poverty (53.7%).

As a Pacific coastal municipality bordering Ecuador, Tumaco is strategically located for the transit and export of goods, including illicit ones such as cocaine. It is one of Colombia's principal coca-producing enclaves. Additionally, in the northeast of Tumaco lies the Telembí Triangle (Nariño), which includes the municipalities of Magüí, Roberto Payán, and Barbacoas, a region where coca cultivation and gold mining coexist. Coca crops are mainly concentrated in the district of Llorente and within the Community Council of Alto Mira and Frontera. These features make Tumaco and Telembí Triangle a key case for analyzing the overlap between coca and gold economies and for examining the dynamics of region with intensive coca and cocaine production.

9.2 Local Functioning of Illicit Economies

Coca and Cocaine Economy

The local functioning of the coca and cocaine economy varies across the three municipalities. Two of them—Vistahermosa and Puerto Guzmán—are located in deconcentrating areas (UNODC, 2024), while Tumaco is a productive enclave (a zone of higher productivity and linkages). As previously mentioned, coca cultivation in Vistahermosa and Puerto Guzmán has declined compared to peak periods when both municipalities reached thousands of hectares.

In Vistahermosa, cultivation decreased systematically between 2017 and 2020, followed by a slight increase from 506 hectares in 2021 to 566 hectares in 2023. Similarly, Puerto Guzmán experienced a steady decline from 2017 to 2020 but saw an uptick in 2021–2023, reaching 2,765 hectares. Coca crops in these municipalities are concentrated in specific areas: the northwestern zone of Puerto Guzmán (near the border with Puerto Asís) and the southeastern part of Vistahermosa (adjacent to Puerto Rico, Meta, and San José del Guaviare, Guaviare).

At the departmental level, Meta (where Vistahermosa is located) remained stable in 2023, with 2,194 hectares of coca crops. No municipality in Meta ranks among the top 10 nationally, and the department is a deconcentrating zone, accounting for just 0.87% of Colombia's total coca cultivation in 2023. In contrast, Putumayo (where Puerto Guzmán is located) is a concentration zone, representing 20% of the national total. It hosts two productive enclaves: the Putumayo-Ecuador border

(12,112 hectares in 2022; 2023 data unavailable) and Orito-Vides (2,113 hectares in 2022; 2023 data unavailable) (UNODC, 2024). Putumayo's coca cultivation surged from 28,205 hectares in 2021 to 50,343 hectares in 2023, with four of its municipalities (Puerto Asís, Orito, Valle de Guamuez, and San Miguel) ranking among the top 10 nationally.

Tumaco differs significantly from Vistahermosa and Puerto Guzmán, as it remains a coca and cocaine production enclave. After a sharp decline from 2016 to 2020, cultivation has risen steadily since 2021. Tumaco currently has 22,396 hectares of coca, and its department, Nariño, accounts for 25.7% of the national total. Nariño's cultivation increased from 59,534 to 64,750 in 2023, with three municipalities (Tumaco, Olaya Herrera, and El Charco) among the top 10 nationally. Additionally, 44,7% of Tumaco's coca crops are located in Black Community Councils (*Consejos Comunitarios*), and 53% are in Indigenous Reserves.

In Vistahermosa and Puerto Guzmán, coca was once the primary peasant economy but now plays a secondary role as many farmers have shifted to activities like cattle ranching. In Vistahermosa's southern border zone (near San José del Guaviare), the mechanisms regulating coca production remain unclear. In Putumayo, coca paste is purchased primarily by Comandos de la Frontera – which forbids peasants to sell the product to other buyers, whether civilians or other groups – and, to a lesser extent, the Frente Carolina Ramírez. Since late 2022, low purchase prices have eliminated profitability for peasants but since mid 2024 there are signs of recovery.

In Tumaco, coca paste is bought by Organized Armed Groups (OAGs) under the Guerrilla Coordinator of the Pacific. Field sources report that these OAGs also purchase future crops from peasants, enforcing exclusive buying rights in their territories. According to reports from July 2024, growers do not receive immediate payment, but deliver the coca paste with the promise of receiving payment within 15 to 20 days.

Both Tumaco and Putumayo (near Puerto Guzmán) show signs of large-scale coca cultivation managed or owned by OAGs according to field interviews. In these enclaves, an agro-industrial model integrates production, processing, and cocaine trafficking (UNODC, 2024).

Gold mining

Only two of the case studies presented gold mining activity: Puerto Guzmán and Tumaco (including the nearby Telembí Triangle, located 162.1 km away by car). In Puerto Guzmán, gold mining has not been a major economic activity since colonial times, unlike in the Pacific Coast (Tumaco and the Telembí Triangle). However, the sector has expanded significantly in recent decades, with mining hectares increasing by 191% between 2014 and 2022. According to EVOA data, Puerto Guzmán currently has 393 hectares dedicated to gold mining, though this is likely an underestimate, as fieldwork observations along the Caquetá River revealed broader activity than officially recorded.

In Tumaco, gold mining has remained stable, with 70–96 hectares under exploitation. By contrast, the Telembí Triangle—where mining has been a dominant economic activity since the colonial era—saw a 155% increase in extraction areas from 2014 to 2022. As of the latest data, Barbacoas has 1,677 hectares dedicated to mining, Magüí has 1,588, and Roberto Payán has 195.

At the departmental level, Putumayo (where Puerto Guzmán is located) has 585 hectares dedicated to gold mining, 67% of which are concentrated in Puerto Guzmán. However, EVOA data does not distinguish between illicit and lawful exploitation. In Nariño (home to Tumaco and the Telembí Triangle), 4,236 hectares are dedicated to mining, 82% of which lie within the Telembí Triangle. Here, 90% of EVOA-detected mining is illicit, while 10% is in transition to legality (UNODC, 2023b).

In Puerto Guzmán, mining operations are geographically divided: soil mining occurs in the northwest, while river mining takes place along the Caquetá River. In soil mining, land is either privately owned by miners or held communally by villages. Backhoes are leased from local or external operators for earthmoving, and operations are small to medium in scale, covering one or a few hectares with limited machinery. For river mining, precise operational details are scarce, though there are indications that the Comandos de la Frontera control some mining machinery along the Caquetá.

In Tumaco, mining occurs along the Mejicano and Rosario rivers and within the Alto Mira y Frontera Community Council. The Telembí Triangle primarily practices

soil mining under a lease-based model: farm owners rent land to miners in exchange for a percentage of the extracted gold (terms vary by agreement). The scale of operations depends on the mine's size, with fluctuating numbers of workers and machinery. Despite efforts by Community Councils to regulate mining, they have been unable to restrict outsiders. Between 2007 and 2008, foreign miners from Ecuador and Brazil entered the region with backhoes, accelerating the mechanization of mining activities.

Cattle ranching

Cattle ranching is economically significant only in Vistahermosa and Puerto Guzmán, both of which have long-standing traditions of small- to medium-scale livestock farming. In 2024, 52.6% of Vistahermosa's livestock farms had 1–50 head of cattle, while 22.3% had 51–100. Similarly, in Puerto Guzmán, 53.4% of farms fell into the 1–50 category, and 26.7% had 51–100 head. Since 2009, small- to medium-scale farms (1–50 cattle) have grown dramatically in both municipalities: by 1,188% in Vistahermosa (from 67 farms in 2009 to 863 in 2024) and by 429% in Puerto Guzmán (from 191 to 1,011 farms over the same period).

Large-scale ranching also exists. In Vistahermosa, 22.47% of farms had 101–500 head of cattle in 2024, and 45 farms had over 500 (up from just 12 in 2014). Puerto Guzmán had 18% of farms in the 101–500 range and 6 farms exceeding 500 head. Overall, large-scale operations (farms with 100+ cattle) increased by 96% in Vistahermosa and 65.7% in Puerto Guzmán since 2009.

9.3 Conflict, Governance, and the Changing Landscape of Environmental Harm

The governance structures imposed by OAG after the peace process with FARC- EP implies several changes in the local dynamics and territorial control. First, economic and territorial regulation takes precedence over broader aspects of social and family life. Unlike the former FARC-EP, whose territorial control was mediated through strict coexistence manuals, the current OAGs prioritize economic norms, particularly those governing economic activities, both illicit and licit (Trejos, 2025). Trejos (2025) explains this change as a shift from a revolutionary project of taking over central state power (FARC-EP) to a dispute over economic and human resources among different armed actors.

The new economic rules have direct environmental consequences. During the FARC-EP era, strict tree cutting restrictions were enforced, as the group relied on the forest to conceal troop movements. However, post-FPA groups regulate activities such as tree cutting and land use by imposing fines and penalties (Crisis Group, 2024). Deforestation has become a major source of income, as OAG issue permits for logging in exchange for payment and this control has been leveraged for political purposes, as the groups adjust their stance on deforestation in response to the political situation, signaling their position in the *Paz Total*[6] negotiations with the Petro government and its environmental agenda (Crisis Group, 2024).

A clear example of this strategy was the announcement on May 2022 in Meta and Guaviare by a faction of the Estado Mayor Central (EMC) a FARC-EP dissent group: *"This year, no one is to cut down trees; everyone must clear the pastures with brush, and once their land is organized, they will be allowed to cut again with the authorization of the FARC-EP. Those who do not comply will be fined COP 1,000,000 [USD 230] per hectare cut."*

Despite these restrictions, interviews with local farmers during fieldwork revealed that environmental decisions remain heavily influenced by economic incentives. Deforestation bans can be bypassed through fines or direct negotiations with OAG, effectively creating a system where those with greater economic resources—such as large landowners and land grabbers—continue to engage in deforestation despite formal prohibitions.

A second key aspect of OAG control includes the significant participation from former FARC-EP dissidents, many of whom possess expertise in the coca-cocaine economy in the reconfiguration of new groups. This know-how enables the expansion of illicit activities, reinforcing economic structures that drive environmental degradation. According to InSight Crime (2019c), the key commanders of dissident factions operating in these areas were previously prominent figures in the coca economy under the FARC-EP.

[6] Peace policy of Gustavo Petro's government in Colombia, aims to simultaneously negotiate with all armed groups (guerrillas, paramilitaries, and criminal organizations) to end the armed conflict and violence in the country, as regulated by Law 2272 of 2022.

A third feature is their regulation of mobility and transit, which has significant environmental consequences. Farmers, particularly those affiliated with the JAC, face strict mobility controls, mandatory identification cards, forced participation in land and livestock censuses, and the imposition of "taxes" to finance OAG operations. These restrictions prevent communities from making independent decisions about sustainable land use, reinforcing unsustainable practices. For instance, JAC members are often unable to intervene in cases where deforestation, illegal mining, or other environmentally harmful activities occur, even though they hold significant legitimacy within local governance structures. By suppressing local environmental oversight, OAG indirectly facilitates ongoing deforestation and ecosystem degradation.

Additionally, OAG-imposed mobility restrictions discourage the presence of environmental protection officials, leading to an absence of institutional oversight in key ecological zones. This vacuum hinders enforcement of environmental laws and prevents the promotion of economic alternatives, such as tourism, which could otherwise provide economic opportunities with less environmental harm. The lack of official presence further strengthens illicit economies, such as coca cultivation and illegal mining, which accelerate forest loss, soil degradation, and water pollution. Thus, while OAG territorial control is primarily aimed at maintaining economic and military dominance, their regulatory mechanisms over land and mobility contribute to a broader pattern of environmental degradation, reinforcing extractive and illicit economies at the expense of sustainable development.

A fourth aspect affecting the environment is the climate of uncertainty resulting from the evolving dynamics of the conflict, particularly the disputes within the EMC over the Paz Total negotiation process. The ongoing conflict between the Jorge Briceño Suárez Block (led by alias Calarcá) and the Amazonas Manuel Marulanda Vélez Block (led by alias Mordisco), both formerly coordinated under the EMC, has created an atmosphere of fear, instability, and threats in municipalities such as Vistahermosa and Puerto Guzmán. This fragmentation is further exacerbated by the presence of other OAG, intensifying territorial disputes and their environmental consequences.

As observed during fieldwork, factional warfare has made environmental governance increasingly erratic. Contradictory environmental policies are being imposed by different armed actors vying for control. For example, some groups have imposed restrictions on deforestation as a strategic measure, but these are often disregarded or overturned when rival factions take over a given area. Rather than reflecting a genuine commitment to environmental protection, these shifting rules are instrumental in asserting territorial control, further destabilizing governance in these regions.

The intensification of conflict has also deepened state abandonment, leaving many of these territories without effective environmental oversight. Communities report that environmental protection officials are either absent or unable to enforce regulations due to security concerns. This institutional vacuum, already weakened by OAG-imposed restrictions on mobility and local governance, is further exacerbated by the instability of the conflict. In this context, the absence of enforcement mechanisms enables deforestation, illegal mining, and other environmentally harming activities, reinforcing a cycle of degradation in areas already vulnerable to conflict-related ecological damage.

9.4. “Taxes” on Coca, Gold Mining and Cattle Farming

In the case of coca cultivation, OAG play a direct role in the economy by purchasing coca directly from farmers who cultivate and process it. Additionally, a taxation system exists for coca cultivation, processing, and transportation. Although these payments constitute a form of extortion, local communities commonly refer to them as "taxes," a term we retain in this report to reflect their perception that implies that OAG are regulating this economy. Further, some interviewed experts suggest that in certain parts of the country, the coca economy is shifting toward an agro-industrial model, where land-intensive cultivation has a greater impact on deforestation, and small farmers increasingly play a marginal role, often working as laborers rather than independent producers. Thus, beyond taxation, OAG appear to have coca crops, cattle and gold mining machinery under their property.

UNODC (2023a; 2025) supports this observation, describing how OAG promote agro-industrial models that integrate production, processing, and trafficking of cocaine. UNODC (2023b) highlights that OAG involved in the trafficking of coca,

cocaine, and marijuana are diversifying into other illicit activities, including illegal land appropriation, illegal logging, trafficking of metals and precious minerals, illegal mining, and wildlife trafficking. This diversification further exacerbates environmental degradation, particularly in regions lacking effective governance or environmental oversight.

In any case, while some areas are experiencing a shift toward an agro-industrial coca economy, this trend is not uniform across the country. In many territories, including the cases studied in this report, traditional taxation systems on coca cultivation remain in place. This coexistence of models suggests that OAG are adapting their economic strategies based on regional dynamics, maintaining direct taxation where coca cultivation remains fragmented while promoting more integrated, large-scale operations elsewhere.

OAG also impose taxes on gold mining operations and, in some cases, directly purchase gold from miners. In Puerto Guzmán, for instance, farmers report that OAG collect a monthly tax of two grams of gold per motor used in mining operations, in addition to a monthly cash payment of 25,000 COP (approximately USD 46) for the *Comandos Bolivarianos de la Frontera's* mining committee. This information has been also reported by journalists (Macías, 2024). Other sources indicate that miners are required to deliver one to two grams of gold per month to OAG. Given that the Colombian Central Bank listed the price of one gram of gold at approximately USD 71 in August 2024 (Banco de la República de Colombia, 2024a; 2024b), these payments represent a substantial financial burden on miners while reinforcing OAG control over the sector.

Beyond taxation, fieldwork findings suggest that in municipalities near Puerto Guzmán (such as Valle del Guamuez, Orito, and San Miguel), OAG actively promote or impose gold mining through loan directives or operational restrictions (individual interview with an expert, August 6, 2024). According to the same expert, OAG frequently act as primary buyers of gold, replicating their previous role in the coca economy under the FARC-EP, where they controlled the purchase and regulation of coca paste production.

In the Telembí Triangle in Nariño, where gold mining is conducted on a larger scale, OAG-imposed taxes are significantly higher. Fieldwork interviews revealed that these groups charge between 4 and 5 million COP per month (USD 997 to USD 1,247) per excavator. The environmental consequences in this region are severe, including river pollution, soil infertility, and land degradation. Once land has been mined, it often becomes unfit for agricultural use, further compounding the environmental damage. Although these territories are controlled by a different OAG than Puerto Guzmán, the primary regulatory mechanism in both areas appears to be taxation, which facilitates continued exploitation of natural resources.

Cattle ranching and land ownership are also subject to OAG taxation. This practice is not new—historically, the FARC-EP imposed taxes per head of cattle in many of its controlled territories, and OAG have continued this system. Currently, in Vistahermosa and Puerto Guzmán, taxes on cattle and land remain in place. In Vistahermosa, the annual tax is 10,000 COP (USD 2.48) per hectare of land and per head of cattle, while in Puerto Guzmán, a tax of 7,000 COP (USD 1.74) per head of cattle is reported, though the frequency of collection is unclear.

OAG taxation not only reinforces the economic structures of illicit economies but also intensifies the environmental destruction associated with them. Indeed, the taxation system imposed by OAG is more than a revenue stream—it serves as an economic framework that protects and expands environmentally harmful activities. By legitimizing coca cultivation, gold mining, and cattle ranching through taxation, OAG reinforce these industries as dominant economic activities in conflict-affected territories, making them harder to regulate and exacerbating their environmental consequences. In the absence of effective state governance and environmental oversight, these taxation systems further entrench deforestation, land degradation, and ecosystem destruction across these regions.

9.5 Interaction Between Coca, Cocaine and Cattle Ranching Economies

9.5.1 Pathways leading from Coca to Cattle

As observed at the national level, our fieldwork indicates that the relationship between coca cultivation and deforestation is not always direct but is often mediated by other economic activities catalyzed by the coca economy, such as cattle ranching. Given this dynamic, this section examines the transition from coca cultivation to cattle ranching and the multiple factors that have facilitated this shift. The pathways leading from coca to cattle farming vary, and our fieldwork identified several key drivers of this transition: (i) soil degradation caused by chemicals and toxins, which altered land value and use; (ii) state-led substitution programs and the promotion of cattle farming as an alternative; (iii) the absence of restrictions on forest clearing by the FARC-EP; (iv) regional conditions that made cattle ranching a competitive alternative to coca cultivation; and (v) large-scale land acquisitions.

The following sections will analyze each of these elements in detail, shedding light on the environmental and economic transformations occurring in these regions.

Soil degradation

State-led eradication efforts, such as the Program for the Eradication of Illicit Crops by Aerial Spraying with Glyphosate (PECIG), accelerated the shift toward cattle farming by altering soil fertility and limiting agricultural alternatives. In Vistahermosa, PECIG's interventions occurred between 1994 and 2015 (Observatorio de Drogas de Colombia, 2024), and in Puerto Guzmán between 1997 and 2015 (Observatorio de Drogas de Colombia, 2024). In both municipalities forced eradication by aerial spraying, according to locals, damaged the soil, allowing only for the cultivation of pastures which was the only crop that could survive in these gravely damaged soils. Indeed, besides the known socio-environmental impacts of glyphosate (Rubiano et al., 2020), farmers and other authors (Lyons, 2021) reported that after spraying, soils were severely affected and could not be used for agriculture or forestry for six to eight years. The only viable use of the land was for pasture. After aerial spraying, several farmers converted these infertile, "intoxicated" soils into pastures.

Additionally, the chemicals used in coca cultivation also degraded the soil and limited its future use to growing pastures. As Velásquez (2025) points put, "the chemical residue left by coca cultivation makes the land conducive to sustaining only pastures for cattle or may even result in areas being left fallow, leading to deforestation or the seeding of pastures adjacent to them" (p. 23). Thus, the chemical framework that supported the coca economy during its peak contributed to the economic transition to cattle farming, as it became one of the few viable options after eradication policies.

Soil degradation not only influenced the transformation of coca cultivation areas into pastures, but also coincided with the displacement of farming families, especially in Vistahermosa, that further fueling this shift. During periods of eradication and clashes between guerrillas, public forces, and paramilitaries (2002-2007), many families stopped growing coca and abandoned the land. According to some locals, this abandonment led to a depreciation of land values. As a result, some people took advantage of the situation to acquire land at very low prices, allowing certain families to expand their farms, particularly for cattle farming which led to deforestation. This phenomenon reshaped the region's agrarian and environmental structure, with a notable increase in land concentration for cattle.

State substitution programs

The transition from coca cultivation to cattle ranching in municipalities like Puerto Guzmán and Vistahermosa has been shaped by alternative development programs such as the *Comprehensive Consolidation Plan of La Macarena* (PCIM, 2007–2010) and the *National Comprehensive Program for the Substitution of Illicit Crops* (PNIS, 2017–present). These initiatives allocated resources to help farmers shift their economic activities, with some beneficiaries using the funds to strengthen livestock farming. However, according to interviewees, PNIS failed to facilitate sustainable economic substitution for most participants due to delays in payments, inadequate supplies, and unfulfilled promises of technical support. In contrast, farmers who had already invested in cattle ranching—either by diversifying their income sources or reinvesting savings from coca cultivation—were able to leverage program resources to expand their livestock activities.

The experiences of Puerto Guzmán and Vistahermosa reflect a broader national trend. A recent nationwide evaluation of PNIS, implemented as part of the peace agreement with the FARC, found that many projects overlooked critical environmental factors, leading to unintended consequences. In several regions, program incentives encouraged cattle ranching in ecologically unsuitable areas, exacerbating environmental degradation (DNP, 2023, p. 57). The evaluation also highlights a significant increase in cattle ranching in areas previously associated with coca cultivation (DNP, 2023, p. 119). Moreover, deforestation surged in PNIS beneficiary zones, rising by up to 15.4%, while neighboring regions experienced increases between 13.4% and 19.3% (DNP, 2023, p. 118).

Absence of restrictions on forest clearing

Another key factor in this transition was the absence of forest use restrictions after the FARC-EP disbanded. Previously, alongside its regime on coca cultivation, the group had enforced strict rules on deforestation and land use; according to farmers in several villages of Puerto Guzmán and Vistahermosa, at least 30% of each farm had to be preserved as forest. However, following the 2016 peace agreement, a regulatory vacuum emerged, as no armed group enforced conservation rules. In this context, many farmers expanded their lands for livestock farming, while others converted former coca fields into pastures as an alternative source of income.

In the years after the peace agreement, this shift had a dual effect on informal land markets. Previously colonized lands increased in value, driven by improved security conditions and expanded access to public credit, particularly for cattle ranching and other agricultural activities. Rising land prices in more central areas made lands just beyond the agricultural frontier increasingly attractive, as their potential profitability outweighed the costs of deforestation and settlement. As a result, deforestation surged alongside rising land prices, transforming the local economic landscape.

Regional characteristics of cattle farming

At the local level, specific characteristics of livestock farming made it the most viable alternative to offset some of the opportunity costs of replacing coca. In Puerto Guzmán, cattle farming has expanded in recent years, largely through the

avaluo system—a financing arrangement in which large ranchers lend a small number of heifers (typically ten) to local farmers, who are responsible for their care and feeding over several years. These agreements specify whether the farmer assumes all costs or shares them with the rancher. At the end of the agreed period, the farmer returns the cows along with a set payment per head, usually around one million pesos, while profits from milk production and calves are divided equally.

Widely used by local farmers and ranchers—mostly from Caquetá—the *avaluo* system has facilitated cattle farming among those with limited personal capital. As an informal arrangement, it exemplifies a functioning grey market that may be enabling in some instances an economic transition between legal and illegal activities. Indeed, concerns persist regarding its potential use for money laundering. The property valuation (*avaluo*) mechanisms involved can be exploited to obscure illicit financial flows, raising red flags about its role in integrating drug trafficking proceeds into the local economy.

Some residents of Puerto Guzmán think that cattle farming may be linked in some instances to the *avaluo* system may serve as a conduit for laundering drug money. While this practice has long been a traditional financing method in the region, its structure allows for hidden ownership, making it an attractive vehicle for illicit capital. Since the true owners of the cattle are not always formally registered, the system may facilitate figurehead ownership, further complicating efforts to trace illicit financial activity.

Although money laundering is inherently difficult to detect, expert interviews suggest that some actors involved in cocaine trafficking actively promote cattle ranching as a means of consolidating landholdings and legitimizing illicit capital. One interviewee noted cases in which traffickers facilitated forest colonization by providing land and capital for peasants to establish farms (Individual interview with an expert, May 17, 2024). This dynamic suggests that cattle ranching in the region is fueled not only by official credit but also by informal financial flows, potentially including laundered drug money. This underscores the urgent need to strengthen state capacity and enhance data transparency to improve oversight and enable a more comprehensive analysis of the entire cattle supply chain.

Other dynamics include community associations that have formed commercial agreements with large dairy companies, allowing for extensive dual-purpose livestock farming, particularly in villages near the Serranía de la Macarena in Vistahermosa. These partnerships have also facilitated access to affordable credit, enabling members to invest in land or cattle. Compared to other productive alternatives, such as cacao, livestock farming is perceived as a more viable path for economic transition. While cacao—a long-cycle crop—can take up to three years to generate significant income and requires higher investment and risk, livestock farming provides faster economic returns, making it a more attractive option for families seeking immediate financial stability. This disparity in return on investment time explains why many farmers in Puerto Guzmán and Vistahermosa have opted for cattle ranching over other alternatives, making it a key mechanism in the shift from coca cultivation to legal economic activities.

Mass land purchases

Land grabbing appears to be taking place in Vistahermosa, where large-scale land purchases and subsequent cattle grazing raise concerns about deforestation and land concentration. Examining this phenomenon provides further context for understanding how land dynamics evolve alongside economic and armed actors.

According to some residents of the municipality, since 2016 large-scale land purchases have taken place in the central part of the municipality, on the right bank of the Güejar River, forming a strip from the Serranía de La Macarena to the border with Puerto Gaitán (Meta), near the area where coca cultivation has concentrated in recent years (UNODC, 2023a). Land is being bought at prices ranging from 350,000 to 500,000 COP per hectare (around US$84.5 to US$120 per hectare). This land-grabbing pattern has led to the disappearance of at least six villages as legal entities due to population decline. While the involvement of armed actors in this process is unclear, it is known that acquiring such land requires permits and “tax” payments to armed groups, suggesting some level of agreement.

Using satellite images and cross-referenced with deforestation patch data from IDEAM, we confirmed that the area mentioned in interviews accounts for 78% to 86% of the increase in deforestation in the municipality of Vistahermosa between 2016 and 2024.

In the area where this large-scale land acquisition is occurring, pastures for livestock are being established. The exact scale of these livestock projects remains uncertain, but some farmers have expressed concerns over deforestation linked to land preparation. It is also unclear whether cattle herds are expanding in these areas.

9.5.2 Environmental impacts of Coca, Cocaine and Cattle Ranching

The interaction between coca, cocaine, and cattle ranching economies has significant environmental impacts, especially due to economic transitions from coca cultivation to cattle ranching, which are drastically changing the Amazonian landscape in Puerto Guzmán and Vistahermosa. Previously, as some farmers explained, a few hectares of land were cleared for coca cultivation and other agricultural products. This land use was further restricted by the former FARC-EP rules to conserve forests. Currently, the land-intensive cattle ranching activity requires larger areas of pasture and, consequently, more forest clearing. Thus, deforestation is the most visible environmental impact, a result of the coca economy and its transition to cattle ranching, which we observed during fieldwork. The deforestation caused by the expansion of cattle ranching has also contributed to soil erosion along the banks of the Caquetá River and, according to some residents, to extreme drought and rainfall conditions in recent years.

In the past, the coca economy impacted forests not only through forest clearing for cultivation but also through cattle ranching activities. Through the capital generated by the coca economy, some farmers cleared land for pastures and saved their earnings by accumulating cattle. The goal was not necessarily to transition from one activity to another; rather, coca sometimes enabled savings, which were mainly used to start or strengthen cattle ranching projects. Additionally, forests were also cleared to build roads and paths using resources obtained from coca.

Although deforestation related to drug money laundering was not documented in detail in the case studies in Colombia, evidence of its existence could suggest similarities to the phenomenon observed in Central America. Actors involved in cocaine trafficking use deforestation for activities such as money laundering, territorial control, and the construction of clandestine airstrips (Devine et al., 2020).

This type of deforestation could thus be one of the main drivers of deforestation, as seen in the Maya Biosphere Reserve in Guatemala (Tellman et al., 2020).

Thus, the coca and cocaine economy have not only caused environmental impacts through its ties to cattle ranching but also through the continuous use of agrochemicals in coca cultivation and chemicals in the coca base paste processing, as fieldwork and literature suggests. This affects soil fertility and generates solid waste pollution from chemical containers. As proposed by Tellman et al. (2020), these multiple impacts suggest that the environmental effects of the coca and cocaine economy are more varied and complex than previously documented and extend beyond deforestation.

9.6 Interaction Between Coca, Cocaine and Gold Mining Economies

The coca, cocaine, and gold economies have been deeply interconnected for decades in regions like the Colombian Pacific and Putumayo (Molano, 2017; CNMH, 2015). This relationship manifests in various ways: in some villages, the same local workforce engages in both mining and coca harvesting, as documented by Ortiz-Riomalo and Rettberg (2018). Rural workers often migrate between these activities based on demand; on the same property, both coca crops and mining can coexist, and even the same person may cultivate or harvest coca while also working in a mine. However, recent changes in coca and cocaine production, such as falling base paste prices and reduced hiring of harvesters, have made mining more relevant, especially in areas like Puerto Guzmán and the Telembí Triangle.

In Puerto Guzmán, a traditional mining area, coca crops and base paste processing have also existed at different times. Farmers used to have both gold extraction sites and two or three hectares of coca on their land. Additionally, communal areas were used for gold extraction. Some miners explained that they organized their time between mining and coca cultivation throughout the week, prioritizing mining due to the greater effort it requires. Similarly, in the Telembí Triangle, coca became one of the most important economic activities in the 1990s, alongside gold mining, which has been a primary source of livelihood since colonial times. Afro-descendant farmers in the region divided their time between artisanal, low-mechanization mining and coca cultivation, sustaining their families for years. In many cases, gold extraction and coca crops coexisted on the same property.

However, according to the fieldwork findings, farmers in the mining areas of Puerto Guzmán are focusing on gold mining due to low coca prices during 2021 and 2023. In some cases, they supplement their income by working as laborers on other farms. A similar situation exists in the Telembí Triangle, though with a key difference: mining has dominated since 2008, when large-scale mechanization began. The mechanization of mining, with the arrival of excavators and miners from Ecuador, Brazil, and other parts of Colombia, has employed more people and made mining more profitable than coca cultivation for many inhabitants. This particularly benefits those employed by "entable" owners (machinery owners) or those who own the land where extraction occurs, as they receive income from land use, though they are not considered the mine owners. In both Puerto Guzmán and the Telembí Triangle, these mining operations are conducted without exploitation or exploration permits, classifying them as informal or illegal mining activities.

In Puerto Guzmán, some of those who previously harvested coca leaves are now working in gold extraction along the Caquetá River. Since the coca economy is labor-intensive and has provided jobs for rural populations, especially young people, the base paste price crisis in 2022 has forced many to migrate to mining. In other cases, former harvesters have migrated to work in other municipalities or departments. However, field observations suggest that mining does not fully replace coca farming, as commerce and other economic activities in the town have been affected. A clear example is the reduced number of people in commercial establishments and the significant number of closed businesses.

This economic transition primarily involves small-scale, informal mining. However, there are other connections between the coca, cocaine, and gold economies. According to Ortiz- Riomalo and Rettberg (2018), coca and gold revenues are contested by OAG, linking these economies to the armed conflict and criminality in Colombia, with regional variations. Furthermore, these authors argue that gold mining and the coca economy are part of a "resource portfolio" used by OAG to diversify risk through multiple income sources. In other words, involvement in both economies helps OAG mitigate risk and diversify their revenue streams (Ortiz-Riomalo & Rettberg, 2018). These OAG can capture gold revenues either directly (through operations they or their partners conduct) or indirectly, through taxes, which was the method observed during fieldwork.

9.6.1 Environmental impacts of the interaction between coca, cocaine, and gold economies

The economic transition from coca to mining activities has significant environmental impacts. In both cases studied, interviewees reported soil erosion along the riverbanks of the Caquetá, Patía, Telembí, Magüí, and Mira rivers, as well as damage to their watercourses and floodplains. Additionally, the population reports harm from water pollution due to the use of mercury in mining, the proliferation of dengue and leishmaniasis from uncovered pits, and various effects caused by the loss of forest cover resulting from the opening of mining operations.

The environmental effects of the transition depend on the scale and type of mining operation. In the case of Puerto Guzmán, the main impacts are from mining expansion along the Caquetá River, which does not necessarily lead to significant deforestation but does cause water pollution in several rural communities and soil erosion on segments of their farms. In the Triángulo de Telembí area, since mining is largely soil-based, forest degradation is one of the most evident environmental impacts, but water pollution is also a major concern for the communities living in the area. According to the research team's observations, the scale of soil-based mining operations in these Pacific territories of Nariño is larger than in northwestern Puerto Guzmán, which suggests that the environmental impacts are more severe.

10. State Responses to Illicit Economies and their Environmental Impacts

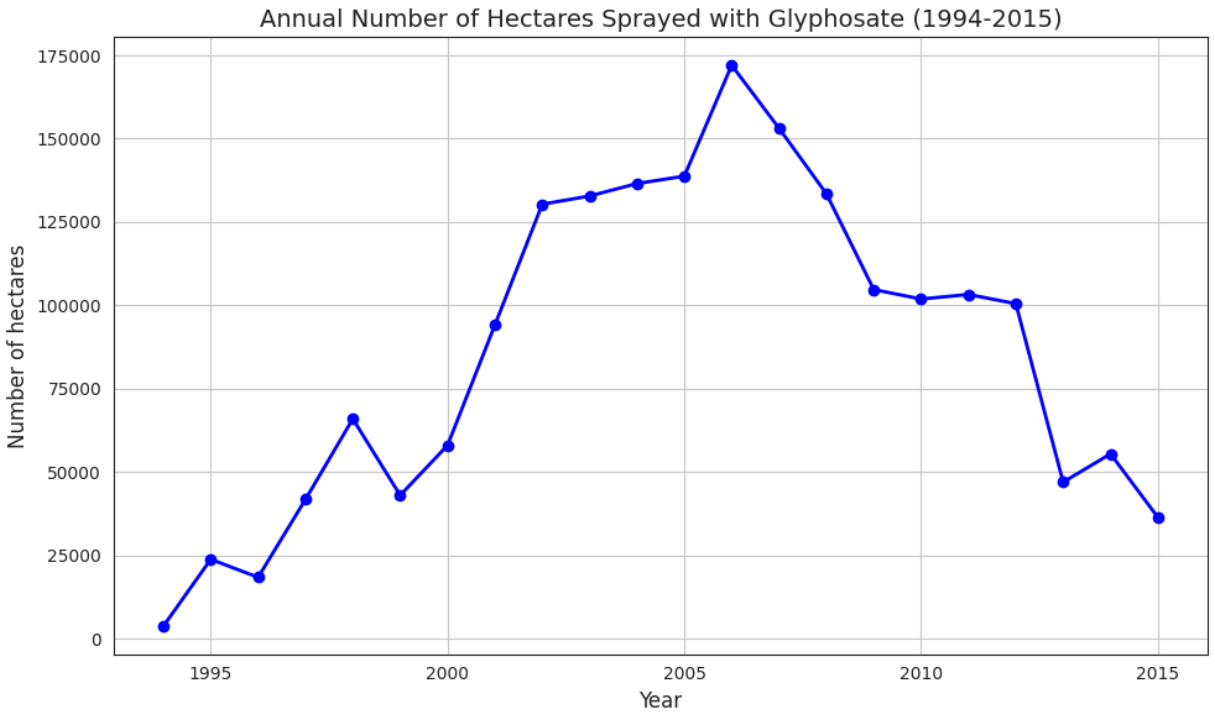
This section analyzes the responses of the Colombian state to the coca/cocaine economies, gold mining, and cattle ranching, with a focus on their environmental impacts.

10.1 Intervention Aiming at Controlling Supply (Coca and Cocaine)

Colombia has historically prioritized repressive measures to control coca leaf and cocaine production. The most widespread and intense strategy in the country has been aerial spraying of illicit crops with glyphosate, a technique that uses aircraft to apply herbicides like glyphosate over illicit crops to inhibit plant growth and cause their death (WOLA, 2008; WWF, 2021). Figure 19 shows the number of hectares sprayed with glyphosate annually until 2015, the year when the National Narcotics

Council suspended this strategy.*Influence on Neighboring Areas within 5 km and 10 km Buffers.*

Figure 19. *Annual number of hectares sprayed with glyphosate.*



Source: Own elaboration with data from the Ministry of Justice and Law.

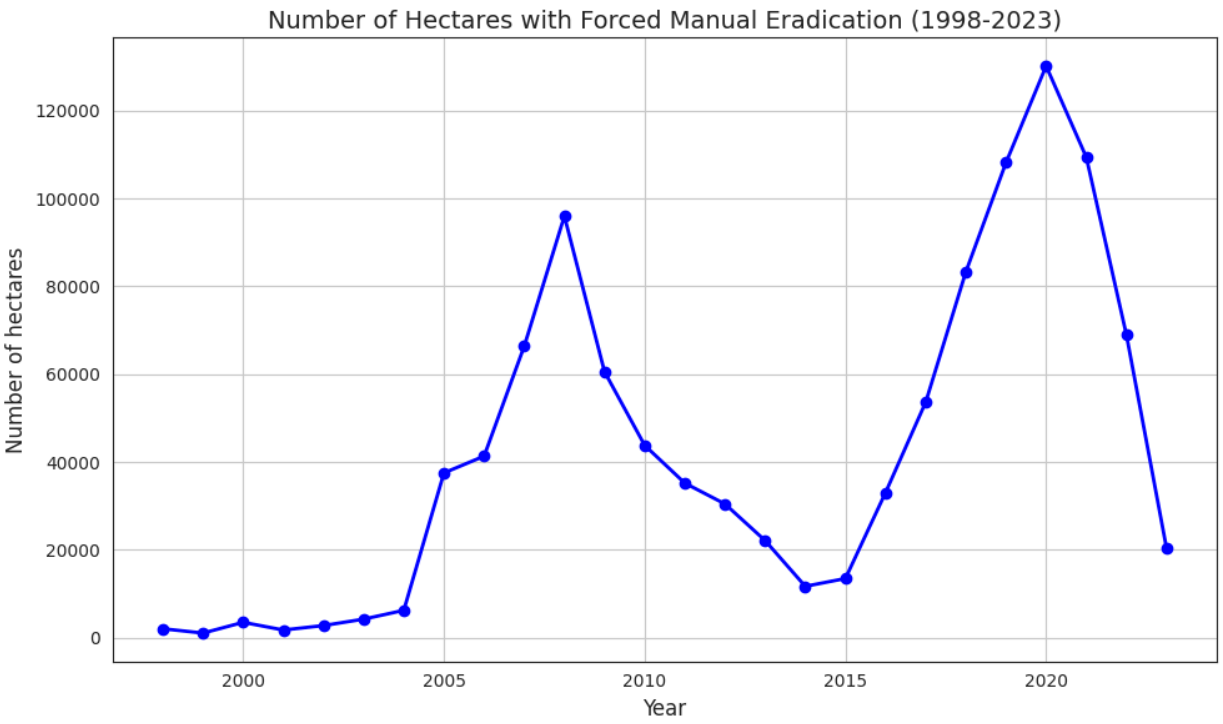
In addition to the inefficiency of this strategy in reducing drug trafficking (Mejía et al., 2017) and its social costs, which fail to address the root causes of households' involvement in these activities, significant environmental costs of this policy have also been documented (Rubiano et al., 2020). Environmentally, aerial spraying with glyphosate has led to deforestation due to the displacement of coca crops (Rincón-Ruíz & Kallis, 2013), particularly into environmentally strategic areas. Other environmental consequences include contamination of water sources and harmful effects on biodiversity. In terms of pollution, glyphosate has been found to be highly mobile, with significant occurrences detected in soils, sediments, precipitation, and rivers (Battaglin et al., 2014). Additionally, glyphosate has been shown to cause deformities and organ disruptions in frogs, affecting their mortality rates as well as those of their predators (Bernal et al., 2009; Brodeur et al., 2014; Howe et al., 2004; Lajmanovich et al., 2015; Lenkowski et al., 2015; Lynch & Arroyo, 2009; Rissoli et al., 2016; Van Bruggen et al., 2018). However, frogs are not the only species impacted by

exposure to this herbicide. Fish and pollinators have also shown altered locomotor and behavioral activity and disrupted migratory cycles due to exposure (Brower et al., 2012; De Brito Rodrigues et al., 2019; Pleasant & Oberhauser, 2012).

Although glyphosate is widely used in commercial agriculture, it has been classified by the World Health Organization (WHO) as "probably carcinogenic to humans", and its commercial mixtures pose even greater risks (Tarazona et al., 2017). In Colombia, the aerial spraying program for coca eradication (PECIG, for its Spanish acronym) requires glyphosate mixtures with adjuvants for aerial application modes (National Police – Anti-Narcotics Office, 2020). For example, the herbicide Roundup—one commercial glyphosate formulation—contains adjuvants such as POEA (a toxic substance linked to central nervous system disorders, respiratory/gastrointestinal issues, and animal cancers), Cosmo-Flux 411F (moderately toxic), and N-Nitroso Glyphosate (NNG, a carcinogenic compound) (Sánchez, 2020; Rubiano et al., 2020). Historically, PECIG employed a local glyphosate formulation tank-mixed with Cosmo-Flux (Marshall et al., 2009), a practice that studies associate with high risks to both environmental and human health (Sánchez, 2020).

Secondly, forced manual eradication—manual uprooting of plants or terrestrial glyphosate spraying— carried out by the military, is presented in Figure 20 with its evolution over time. Although the environmental damage of this strategy has not been documented, it has been shown to be ineffective in reducing the number of coca hectares, generating socioeconomic costs and increasing conflict between the public forces and local communities (Ciro, 2020; Gutiérrez et al., 2021; Marín-Llanes & Vélez, 2022; Observatorio de Tierras, 2020).

Figure 20. *Number of hectares eradication.*



Source: Own elaboration with data from the Ministry of Justice and Law.

A third type of intervention aiming at reducing supply on in Colombia has been the strategies implemented under the alternative development framework, which focuses on crop substitution programs for illicit crops. As Rubiano et al. (2022) suggest, these programs have been implemented in the country since 1996. While these interventions aim to create legal opportunities in marginalized areas affected by illicit crop cultivation, their effectiveness in reducing coca cultivation and protecting the environment has been disappointing (DNP, 2023).

The recent evaluation of the PNIS conducted by CESED and IPSOS for DNP (DNP, 2023), which has enrolled the largest number of beneficiary households worldwide, found that coca cultivation increased in areas neighboring those where beneficiaries were located (Marín-Llanes et al., 2024; Prem et al., 2023). Additionally, deforestation rose between 20.3% and 31.3%. The delivery of in-kind benefits from the program further increased coca cultivation by 53.4% to 55.6% in neighboring areas, along with a rise in deforestation. Deforestation impacts were found in areas with program beneficiaries (15.4%) and in neighboring zones (13.4% to 19.3%) (DNP, 2023). These outcomes can be explained by the "balloon effect" in coca cultivation,

the agricultural focus of the intervention without considering environmental criteria in important environmental areas together with beneficiaries' preferences that demanded cattle as part of their productive projects.

10.2 Interventions to Reduce Deforestation

The *Artemisa Operation* was a military strategy implemented by former President Iván Duque's government (2018-2022) to contain and reduce deforestation, especially in the Amazon's National Natural Parks of Colombia (PNN for its Spanish acronym) (Ganzenmüller, Sylvester, and Castro-Nuñez, 2022; Murillo-Sandoval et al., 2020; Paz- Cardona, 2022). The military approach was based on the idea that deforestation was driven by the presence of OAG, which profited from environmental destruction through coca crops, illegal mining and logging, extensive cattle ranching, and land grabbing. This justified targeting and prosecuting these structures (Alfonso-Sandoval, 2022; El Tiempo, 2021; Paz-Cardona, 2019; Tarazona and Parra, 2022).

In 2022, the National Government reported the recovery of 27,046 hectares of forest (Tarazona and Parra, 2022), the arrest of 96 individuals, and the seizure and destruction of houses, bridges, chainsaws, weed cutters, vehicles, heavy machinery, and cattle (Ejército Nacional, 2021a, 2021b; Minambiente, 2021). However, experts criticized the strategy, noting that it failed to meet its main goal. The number of recovered hectares was minimal compared to the 504,682 hectares deforested between 2019 and 2021 (IDEAM, cited by Tarazona and Parra, 2022). Moreover, the operation covered less than 20% of the critical areas identified (FCDS, cited by Tarazona and Parra, 2022).

Another criticism is that *Artemisa Operation* failed to balance environmental conservation with the rights of rural communities living in protected areas, many of them victims of the armed conflict. The operation primarily targeted small farmers instead of the main actors responsible for large-scale deforestation (Botero, cited by Tarazona and Parra, 2022; Clerici, cited by Tarazona and Parra, 2022; Dávalos, cited by Tarazona and Parra, 2022). Human rights violations were also reported, including arbitrary arrests of community leaders, disappearances, killings, firearm attacks, and the destruction of houses using explosives (Artehortúa-Gutiérrez, 2022; Bautista and Sierra, 2022; Tarazona and Parra, 2022). The military focus increased distrust

towards the state and limited opportunities for cooperation in environmental protection.

10.3 Interventions for Cattle Ranching and Land Issues

Regarding cattle ranching, the Colombian state has promoted strategies related to access to credit to foster and strengthen this economic activity. Loans are being granted to local farmers or small-scale ranchers through FINAGRO, an entity of the Ministry of Agriculture and Rural Development without enforcing environmental requirements.

This entity plays a crucial role in financing livestock in Colombia through its two financial instruments: subsidized loans and incentives for rural capitalization (FCDS, 2024; Garay, Cendales, and Movius, 2021). However, FINAGRO does not have the capacity to grant loans directly to users; it operates under the modality of *rediscounting*, which means that "commercial banks offer credit lines to livestock farmers with resources partially coming from promotion, rediscounting part of the loan value with FINAGRO at preferential rates, and the rest of the loan with their own resources" (Garay, Cendales, and Movius, 2021, p. 2). Banco Agrario is one of the banking entities that prioritizes credit lines for livestock through rediscounting with FINAGRO.

In 2019, COP 3.7 trillion were allocated in FINAGRO credits to livestock, of which 69.1% was directed to beef cattle and the remainder to dairy cattle (Henry Garay, Cendales, and Movius, 2021, p. 2). In the department of Guaviare alone, 78.6% of the credits granted to livestock farmers through Banco Agrario – FINAGRO amounted to COP 100,000,000,000 (USD 23,846,640) between 2015 and 2023 (FCDS, 2024).

These loans, largely aimed at beef cattle, have promoted and strengthened extensive cattle ranching, which involves transforming more forested areas into pastures for cattle, contributing to increased deforestation. Furthermore, the allocation of these credits toward the purchase of animals and land improvement, rather than the acquisition of new lands, suggests that extensive cattle ranching is being prioritized instead of improving practices in livestock to increase productivity (FCDS, 2024; Garay, Cendales, and Movius, 2021). Although the loans are not explicitly designed to promote deforestation, their emphasis on financing the

purchase of cattle and improvements to existing land inadvertently encourages cattle ranching practices that have environmental consequences.

The state has intervened in livestock activities concerning land grabbing, a phenomenon often realized through large-scale cattle ranching. The Constitutional Court, in its ruling SU-288 of 2022, declared that vacant lands cannot be appropriated through the mechanism of acquisitive prescription, as they are considered national goods intended to promote agrarian reform and facilitate land access for impoverished individuals (Corte Constitucional, Sentencia SU-288, 2022; Lamus Arango, 2024). The Constitutional Court found that individuals have been allowed to acquire these lands through acquisitive prescription authorized by civil judges, leading to an undue concentration and accumulation of land in the hands of a few, based on a misinterpretation of Law 200 of 1936 and despite what is established in Law 60 of 1994 (Corte Constitucional, Sentencia SU-288, 2022; Dejusticia, 2022; Burbano Villamarín, 2022; Lamus Arango, 2024).

Therefore, the Constitutional Court ordered the ANT to create a database of lands that have been improperly appropriated throughout the country (Corte Constitucional, Sentencia SU- 288, 2022; Dejusticia, 2022; Burbano Villamarín, 2022). It also ordered the creation of a recovery plan for vacant lands and prioritized areas with the highest concentration of lands. Additionally, it reiterated that the state must comply with the 2016 FPA, including the establishment of an agrarian jurisdiction and a multipurpose cadastre to properly register land ownership (Corte Constitucional, Sentencia SU-288, 2022; Dejusticia, 2022; Burbano Villamarín, 2022; Lamus Arango, 2024).

Following the Constitutional Court's ruling, the national government established the Monitoring Committee for Ruling SU-288 of 2022 as part of the High Council for the Administration of Rural Land Use Planning. This committee aims to oversee the implementation of public policies required by the Constitutional Court. By December 2024, the National Planning Department reported that the Implementation Framework Plan for the Integrated Post-Conflict Information System incorporates 47 indicators aligned with the compliance of Ruling SU-288 of 2022, and seven dissemination sessions regarding the ruling have been conducted. Furthermore, the Ministry of Agriculture reported the recovery of more than

140,000 hectares of unlawfully occupied public land as part of these efforts (DNP, 2024).

10.4 Interventions for Gold Mining

The Colombian state has intervened in the activity through regulatory measures based on the Mining Code of 2001. This regulatory framework is restrictive in its definitions, despite including some mechanisms to prioritize traditional mining communities, particularly ethnic communities. Efforts to formalize mining activities in the country have not significantly involved the population dependent on this activity, nor have they established environmental, labor, health, and safety standards for its execution. Thus, of the total area found in 2022 for alluvial gold exploitation (98,567 ha), 73% is classified as illegal exploitation (69,123 ha).

As documented by Vélez et al. (2024), formalization processes can be expensive and cumbersome for mining communities. According to the authors' calculations, the costs of formalizing mining activities in a Pacific community can reach up to US$ 290,900, a very high amount that is difficult to cover without external assistance (Vélez et al., 2024). For artisanal miners, the barriers to formalization are also significant. Subsistence mining, recently defined by Decree 1666 of 2016 as alluvial mining carried out without machinery, requires procedures that are difficult for miners with limited internet access (Vélez et al., 2024).

For Afro-descendant communities, the Mining Code of 2001 included *Special Mining Zones for Black Communities* (ZME-CN for its Spanish acronym) as a special exploitation category. However, this figure does not directly grant the right for Afro-descendant communities to explore and exploit mineral resources on their territory; instead, it gives them preference over third parties for the authority to assign them a mining concession (Rodríguez and Vélez, 2020). This provision has not been sufficient to guarantee autonomy and restricted community use for Black communities in the Pacific, nor has the recent regulation of Chapter Five of Law 70 of 1993, which addresses mining in the region (Decree 1384 of 2023). This regulation sought to define differential processes for formalization and access to mining titles for Afro-descendant communities.

In Putumayo, efforts to formalize mining activities have been limited, as this area is not considered traditional mining, and the activity has only recently gained prominence. However, since the early 20th century, interviewed miners report that mineral extraction has taken place in the area and have demanded state actions beyond the confiscation of machinery and the detention and/or imprisonment of farmers. According to the interviews conducted, the formalization of mining activities in the area has been stalled due to an existing mining title for the underground granted to an oil company (social cartography, Puerto Guzmán, June 2024).

Finally, the *Environmental Bubble* strategy, applied in the departments of Caquetá, Putumayo, and Amazonas since 2017, aims to locate and prosecute individuals involved in illegal logging of public and private forests and those engaged in illegal mining (SINCHI, 2023). Corpoamazonía, the National Army of Colombia, the National Police, the Ministry of Environment and Sustainable Development, and the Government of Putumayo have used this strategy to destroy machinery and arrest individuals linked to illegal mining, followed by their prosecution (SINCHI, 2023; Corpoamazonía, n.d.). In the rural areas of Santa Lucía and El Jauno in Puerto Guzmán, these interventions have caused conflicts among communities and harmed the socioeconomic conditions of families reliant on these activities, without offering any alternatives (SINCHI, 2023; Corpoamazonía, n.d.). Throughout 2023, operations continued to destroy dredges on the Caquetá River, confiscate machinery and artisanal equipment, as well as supplies in the municipality of Puerto Guzmán (SINCHI, 2023).

The interventions that destroy machinery and the limited efforts to formalize mining intensify socio-environmental conflicts between rural communities and the state, without truly establishing regulations with labor and environmental standards. There are several challenges to achieving formalization of mining in Colombia. However, so far, strategies to recognize the varying conditions of populations involved in these activities and adjustments to regulations, bureaucracies, and fees based on those characteristics have not been sufficient. Ultimately, in practice, it has not been possible to distinguish informal or artisanal small- scale mining from criminal mining.

11. Conclusions

Based on the research findings, the main discussion points and conclusions are presented below.

First, the research identified that illicit economies vary in scale and involvement from armed actors or criminal organizations. However, several segments operate under peasant-driven dynamics. For example, the early stages of value chains in gold, coca/cocaine, and cattle ranching are often governed by norms established by armed structures. Yet, peasants working within these segments are not affiliated with criminal organizations.

Second, a positive correlation was found between coca cultivation and deforestation, although the overall national impact is limited. The significance lies not in coca cultivation alone but in the broader social and economic shifts it generates. In regions with coca, there is often an expansion of cattle ranching or shifts from forested areas to pastureland. Coca booms stimulate local economies, increasing municipal-level trade, productive projects, and labor demand across sectors. This relationship between coca and deforestation varies by region, shaped by local regulations, the interplay between cattle ranching and coca, and legacies from the FARC-EP's prior governance.

Third, no direct national-level correlation between mining and deforestation was identified. While gold mining may involve forest clearing, its primary environmental impacts are more localized, including water contamination from mercury and cyanide, erosion of riverbanks, and the alteration of watercourses. In particular, alluvial mining does not primarily cause deforestation but contributes to significant environmental degradation through pollution and hydrological disruption. Contamination of local water sources affects not only water quality and aquatic life but also threatens the health and livelihoods of nearby communities. Moreover, the long-term ecological consequences of mining are most evident in landscape alteration and the disruption of water systems, which, although not always immediately apparent in terms of forest loss, still result in widespread environmental damage. These impacts often exacerbate the broader environmental crisis in regions already affected by illegal mining activities.

The research also underscores the unintended environmental damage caused by state interventions targeting illicit economies. Regulations and enforcement measures against coca, cocaine, mining, and cattle ranching have environmental costs. Eradication strategies often left the land degraded, making its transformation into pastures the only viable option, which further exacerbated environmental harm, as mentioned throughout this report. However, these interventions have failed to address the structural causes driving household participation in illicit activities. This underscores how state efforts to combat these markets have consistently resulted in environmental harm.

Lastly, the evolving socio-political dynamics in Colombia contribute to instability, as evidenced by fieldwork in three municipalities. The ongoing fragmentation and competition among OAG create volatility, disrupting rural communities and the value chains of illicit economies. The lack of a dominant armed group, contrasting with the FARC-EP's past control, exacerbates conflict unpredictability and economic hardships for peasant communities. Furthermore, OAG maintain their presence, control and socioeconomic regulations even in areas where coca economy is being replaced by cattle ranching and gold mining. These interactions between illicit and licit economies in armed-conflict contexts are leading to multiple environmental impacts: deforestation caused by the expansion of cattle ranching; soil erosion along riverbanks, damage of watercourses and floodplains, and mercury water pollution from gold mining.

Despite the National Government's *Paz Total* policy, structural transformations essential for sustainable economic transitions have not materialized. This is especially critical given last coca price crisis, which placed additional pressure on rural livelihoods and highlights the urgency for viable economic alternatives. In this context, deforestation has become both a political tool and a significant source of income for post-FPA armed groups like the EMC. These groups issue logging permits in exchange for payment and adjust their deforestation stance based on political shifts, using this leverage in negotiations with the Petro government, which prioritizes environmental issues.

12. Policy Recommendations

The following recommendations assume a model in which the connections between criminal, informal and grey markets emerge from the convergence of local livelihood needs, resources from illegal activities such as cocaine, and legal but mainly informal activities like gold mining and cattle ranching. Financial resources—both legal and illegal—converge in these economies, with armed groups in some cases controlling or regulating these economies. We believe that a smarter regulatory approach is necessary—one that balances effective oversight with active community participation and priorities. However, this must be accompanied by carefully planned, integrated state interventions. Direct interdiction strategies must align with economic development, environmental sustainability, and justice to avoid reinforcing conflict dynamics and promote stability in these regions.

12.1 General Recommendations

Adopt a comprehensive approach to illicit economies. Licit and illicit economies are deeply interconnected—not only through the armed actors that regulate them but also through shared resource flows. Therefore, state interventions must address them holistically rather than in isolation, given that phenomena like money laundering and land grabbing emerge from the interactions between these economies.

Clarify distinctions in economic activities. Develop nuanced criteria that differentiate peasant or informal economies from those controlled by criminal organizations. Policies must reflect these distinctions to ensure that interventions are tailored appropriately and reduce unintended consequences for communities.

For peasant or informal economies shift from punitive interventions toward community-focused strategies. State efforts should prioritize improving household livelihoods and strengthening community organizations (Lobo and Vélez, 2022). Mitigating environmental impacts and including local participation in decision- making processes are essential components.

Strengthen local justice mechanisms over military actions. Rather than focusing on military operations, such as Operación Artemisa, the state should enhance the capacity of the Fiscalía General de la Nación to address environmental crimes and illicit economies, especially at the municipal level.

Strengthening Marine Corps Engagement in Riverine Security. Enhancing the resources and capabilities of the Marine Corps to strengthen river control will serve as a complementary measure to justice and criminal investigation mechanisms. This will bolster security and mitigate authority gaps in riverine areas used by armed groups for illegal activities (Toro Carvajal, 2023).

Protect social and environmental leaders. Reducing impunity for attacks on leaders and simplifying the processes for requesting protection are essential (Marín-Llanes and Vélez, 2020). Ethnic communities must receive support for self-protection mechanisms, such as Indigenous and Cimarrona Guards, while the early warning system of the Defensoría del Pueblo should be reinforced (Caicedo, Rubiano, and Vélez, 2022).

Address the governance roles of OAG. Public policy must acknowledge the de facto regulations established by non-state armed groups and work to replace them with effective state institutions. The goal is to reassert state authority and recover state's legitimacy while responding to local social and economic needs.

Integrate environmental components into conflict resolution processes. Negotiations with armed actors should include commitments to halt violence against civilians. Additionally, there should be an environmental component for achieving measurable conservation outcomes in the short to medium term.

Expand Payments for Environmental Services (PES). PES programs should prioritize households in vulnerable areas and provide funding for community life plans, ethno-territorial strategies, and transitions to legal agricultural activities (DNP, 2023; Londoño, Marín, and Vélez, 2024). For collective territories, an ethnic PES route must ensure equitable access to these resources (DNP, 2023).

Coordinate efforts across state agencies. An integrated approach across government institutions is necessary to combat environmental crimes and illicit economies effectively. Recognizing the transnational nature of these challenges is key to developing sustainable solutions.

Foster academic partnerships for policy support. Academia can contribute to the formalization of mining, livestock traceability, and transitions from coca to legal economies. Research should provide evidence-based insights to refine policies at the municipal, departmental, and national levels.

12.2 Coca and Cocaine Economy

Adopt a socio-environmental approach for alternative development. Transition programs must align with the environmental vocation of each territory to prevent unintended deforestation or other environmental damage. Initiatives such as conservation projects, ecotourism, and sustainable agriculture should be prioritized to provide communities with viable alternatives (DNP, 2023; Londoño, Marín & Vélez, 2024).

Renegotiate PNIS agreements with environmental alignment. In protected areas, PNIS agreements must reflect local environmental priorities (DNP, 2023; Londoño, Marín & Vélez, 2024). Providing effective technical assistance will be key in guiding communities toward sustainable economic activities (Rubiano, Vélez & Arenas, 2022).

Implement community-based monitoring systems. Agreements with peasant communities to oversee coca cultivation can facilitate the decriminalization of growers and contribute to peacebuilding (DNP, 2023; Londoño, Marín & Vélez, 2024), as seen in Bolivia's Cochabamba Tropic (Ramos et al., 2023).

Regulate the cocaine economy strategically. Shifting from prohibition to regulated production could reduce the socio-environmental harm caused by illicit economies. However, this must be part of a broader state presence that meets the region's social and economic needs while addressing the influence of armed actors.

Enhance the Ministry of Environment's capacity for transition programs. The Ministry must lead efforts to identify and promote sustainable alternatives to coca cultivation, particularly in the Amazon, providing communities with viable legal income sources.

12.3 Cattle Ranching

Implement a robust livestock traceability system. Tracking the origin of cattle will help control its environmental impact and restrict ranching activities in protected areas.

Develop productive zoning for cattle ranching. Zoning plans should guide ranching activities toward areas best suited for sustainable livestock practices, based on agro- ecosystem potential (Botero, 2024).

Promote sustainable ranching models. The state should encourage agroforestry and silvopastoral systems to improve environmental outcomes and mitigate deforestation (Botero, 2024).

12.4 Gold Mining

Formalize mining with an environmental focus. Regulatory frameworks must address the unique environmental and ethnic conditions of mining areas, ensuring formalized operations are distinguished from criminal activities.

Encourage responsible practices through certification programs. Certifications that reward socially and environmentally responsible practices can open new market opportunities for rural miners (Rubiano, Rueda & Vélez, 2020).

Facilitate technical support from large-scale mining companies. Medium- and large-scale mining firms should share knowledge and technology to improve the production practices of local mining communities, minimizing environmental damage (Rubiano, Rueda & Vélez, 2020; Veiga, Restrepo-Baena and Tomi, 2022).

Research on water pollution solutions for gold mining-affected areas. Mercury and cyanide from gold mining operations are contaminating water sources in rural communities. However, there is limited research on how to restore or treat affected rivers.

Consider the relationship between gold mining and cattle ranching in future research: The links between gold mining and cattle ranching, have not been sufficiently explored in Colombia. Future research should address these relationships to better understand their environmental and socio-economic impacts, providing a stronger basis for policy development and land-use planning.

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