




## Article

# What Drives Household Deforestation Decisions? Insights from the Ecuadorian Lowland Rainforests

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**Abstract:** Tropical forests, and more concretely, the Amazon Basin and the Chocó-Darién, are highly affected by deforestation activities. Households are the main land-use decision-makers and are key agents for forest conservation and deforestation. Understanding the determinants of deforestation at the household level is critical for conservation policies and sustainable development. We explore the drivers of household deforestation decisions, focusing on the quality of the forest resources (timber volume potential) and the institutional environment (conservation strategies, titling, and governmental grants). Both aspects are hypothesized to influence deforestation, but there is little empirical evidence. We address the following questions: (i) Does timber availability attract more deforestation? (ii) Do conservation strategies (incentive-based programs in the Central Amazon and protected areas in the Chocó-Darién) influence deforestation decisions in household located outside the areas under conservation? (iii) Does the absence of titling increase the odds of a household to deforest? (iv) Can governmental grants for poverty alleviation help in the fight against deforestation? We estimated a logit model, where the dependent variable reflects whether or not a household cleared forest within the farm. As predictors, we included the above variables and controlled by household-specific characteristics. This study was conducted in the Central Amazon and the Chocó-Darién of Ecuador, two major deforestation fronts in the country. We found that timber volume potential is associated with a higher odds of deforesting in the Central Amazon, but with a lower odds in the Chocó-Darién. Although conservation strategies can influence household decisions, the effects are context-dependent. Households near the incentive-based program (Central Amazon) have a lower odds of deforesting, whereas households near a protected area (Chocó-Darién) showed the opposite effect. Titling is also important for deforestation reduction; more attention is needed in the Chocó-Darién where numerous households are living in untitled lands. Finally, governmental grants for poverty alleviation showed the potential to generate positive environmental outcomes.

**Keywords:** tropical forest; Amazon; Chocó-Darién; Socio Bosque; protected areas; titling; timber; cash transfers

## 1. Introduction

The world's forest area declined from 4128 M ha in the 1990s to 3999 M ha in 2015 [1], with an annual net forest loss of 4.7 M ha between 2010 and 2020 [2]. South America accounts for 21% of the world's remaining forest [1]. Within South America, the Amazon Basin and the Chocó-Darién are two important ecoregions due to their role in sustaining biodiversity, supplying local and global ecosystem services, and supporting local livelihoods [3–6]. Both regions are, however, highly threatened by deforestation activities. In Ecuador, more than 50% of forests (6.3 M ha) are in the Central Amazon and on the Northern Coast, the latter comprising part of the Chocó-Darién [7,8]. Similar to other tropical areas, deforestation has reduced Ecuadorian forests from 14.6 M ha in 1990 to 12.5 M ha in 2018, with an annual net deforestation rate of  $-0.46\%$  (58,429 ha) between 2016 and 2018 [7]. Crop expansion, logging activities, cattle ranching, oil palm plantations, mining, and oil concessions are highlighted as the direct drivers of deforestation in the country [9–12]. In Ecuador, the major deforestation hotspots are in the Chocó-Darién and in the Amazon Basin [7,13]. The Chocó-Darién is highly deforested on the Ecuadorian side [13,14] and has the highest deforestation rate in both the entire ecoregion and within South America [7,15]. Compared with the Chocó-Darién, the Central Amazon demonstrates low deforestation rates [7], yet it is nonetheless experiencing a gradual forest decline.

The Ecuadorian government established two major conservation strategies to halt deforestation: protected areas (PAs) and the incentive-based conservation program called Socio Bosque (SBP). PAs dominate conservation strategies around the world [16]. They are a command and control policy based generally on rigorous mechanisms to keep forests and wildlife intact [17,18]. In Ecuador, PAs also stipulate the long-term strict protection of natural ecosystems [19]. They represent the largest conservation strategy in the country, covering around 19% (4.8 M ha) of the continental territory [7,20]. SBP, on the other hand, provides direct monetary transfers to individual and communal landowners who voluntarily agree to conserve their forests under a 20 year contract that is regularly monitored by the government [21,22]. SBP covers 6.3% of the territory (1.6 M ha) [7,23] and is among the ten largest incentive-based conservation programs in the world [24]. Although more than 25% of Ecuadorian forests are under some type of conservation program [7], there is still a significant proportion of forests without protection [25].

In Ecuador, farm households are important agents for the conservation and the conversion of lowland rainforests [26–30]; they are the ones who make most land-use decisions, e.g., area for cultivation or area for conservation [31]. Due to the presence of imperfect markets that characterize developing countries such as Ecuador, land-use decisions adopted by agricultural societies are determined by factors that go beyond the notion of profit maximization, making deforestation not only a market-driven decision [32,33]. In these contexts, land-use decisions reflect the management of the production factors land, labor, and capital in connection with household demographics and exogenous elements that characterize the natural and institutional environment [34].

Generally, there is still a continuing debate on the influences on deforestation decisions at the farm level [33]. Due to the high costs associated with household data collection, few studies have focused on the agents of deforestation [26]. Existing research shows that considerable attention has been devoted to understanding the relationship between household-specific variables and deforestation [33,35–37]. However, the influence of the quality of natural resources and the conservation strategies remain largely understudied [38]. Likewise, little attention has been devoted to the potential relationship between governmental grants aimed at reducing poverty and deforestation [39].

In Ecuador, most deforestation studies have been conducted from the spatial perspective with aggregated information [7,9–15,29,40]. Despite the substantial contribution of such studies, accounting for factors influencing household deforestation decisions in spatial models is challenging [41]. Most of the few deforestation assessments at the household level in Ecuador are located in the Northern Amazon [34,42–45], evidencing the need to include other regions with different contexts. Moreover, these studies date from the 1990s, calling for new empirical evidence that re-evaluates the relationship between household behavior and deforestation [29,46].

In this study, we explore the determinants of household deforestation decisions in the lowland rainforest frontiers. We focus on exogenous elements that reflect the quality of the forest resources (timber volume potential) and the institutional environment (conservation strategies, titling, and governmental grants for poverty alleviation). These aspects have been hypothesized to influence land-use decisions in the forest frontiers [34,45], but with the exception of titling, results from empirical models are still missing [47,48]. We address the following questions: (i) Does timber availability attract more deforestation? (ii) Do conservation strategies (SBP and PAs) influence deforestation decisions in households located outside the areas under conservation? (iii) Does the absence of titling increase the odds of deforestation at the farm level? (iv) Can governmental grants for poverty alleviation help in the fight against deforestation? We estimated a logit model, where the dependent variable indicates whether or not forest was cleared by a household in the farm. As predictors, we considered the variables previously mentioned, and we controlled by household-specific characteristics. This research was conducted in the Central Amazon and the Chocó-Darién of Ecuador, two regions that host lowland rainforests with high biodiversity and a good capacity to supply multiple ecosystem services [3,4,49–51]. These regions undergo contrasting deforestation processes where rural households maximize their welfare in a context of imperfect markets.

By using in-situ information, we can represent the real conditions of households, local markets, and forest resources, capturing with more accuracy the socioeconomic and environmental contexts of our study regions [52]. Exploring the factors that influence household deforestation decisions is crucial for the design and implementation of effective conservation policies harmonized with the local and global development pathways [9,53].

## 2. Materials and Methods

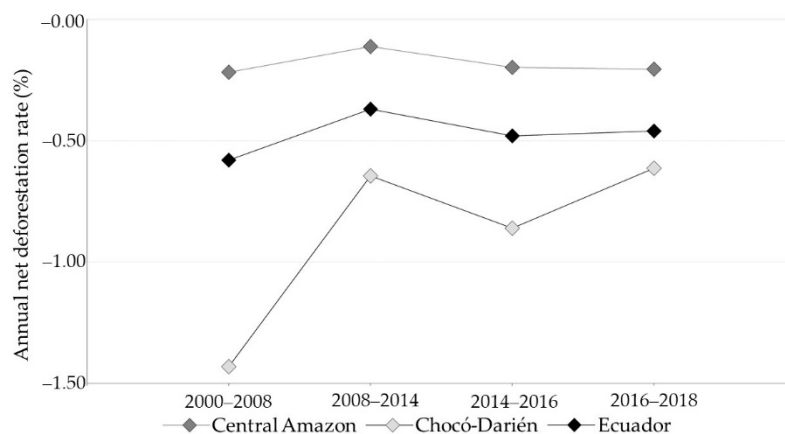
### 2.1. Study Region

Our study was conducted in the lowland rainforest frontiers of the Central Amazon (Napo, Pastaza, and Orellana provinces) and the Chocó-Darién (Esmeraldas province) of Ecuador. These two areas are considered biodiversity hotspots [4,5], hold approximately 6.3 M ha of forests, and account for 68% of the legally harvestable timber volume of suitable quality in Ecuador [8]. Despite the biological importance of the Central Amazon and the Chocó-Darién, these regions are highly susceptible to deforestation.

Based on Angelsen and Rudel [54], the selected study areas illustrate two stages of the forest transition. On the one hand, the Chocó-Darién depicts a stage characterized by high deforestation and low forest cover; it is estimated that in 1970 more than 80% of this region was covered by lowland forests, but now, more than 85% of the original forest cover has been lost [40]. Between 2000 and 2008, the Chocó-Darién of Ecuador had an annual net deforestation rate of  $-1.43\%$ , and it decreased to  $-0.61\%$  between 2016 and 2018 (Figure 1), yet this region has 2.5 times the level of deforestation as compared to both the Ecuadorian and South American rates [7,55]. In the Chocó-Darién, the proximate drivers of deforestation are commercial logging followed by agricultural expansion and infrastructure extension [27,40]. The Central Amazon, on the other hand, is in the initial stage of the forest transition, with 82% of forest cover [56] and an annual net deforestation rate of  $-0.21\%$  between 2016 and 2018 (Figure 1). Despite having low deforestation levels when compared to the Chocó-Darién, deforestation in the Central Amazon is slowly increasing. Small-scale agricultural expansion is the most predominant proximate cause of forest loss in this area [10,11].

The study sites were originally inhabited by indigenous people; now, however, settlers also occupy part of the territory. Together indigenous and non-indigenous groups own and manage the land, with indigenous people occupying the largest share of the territory. In the Central Amazon, more than two thirds of interviewed households belong to the Amazonian Kichwas, the largest indigenous population in the Ecuadorian Amazon [57]. In the Chocó-Darién, around 20% of households belong to the indigenous Chachis. The remaining percentages are comprised of settlers or locally called mestizos (mix of Spaniards and Indigenous descendants) and afro-Ecuadorians (descendants of African slaves),

who, partly motivated by the land reforms of 1964 and 1973, migrated from the different parts of the country in search of land. Our study regions are characterized by old and stable settlements, with the presence of elementary schools and, in some cases, with basic primary care facilities. On average, in the Central Amazon, interviewed households were established 23 years ago and, in the Chocó-Darién, 17 years ago.



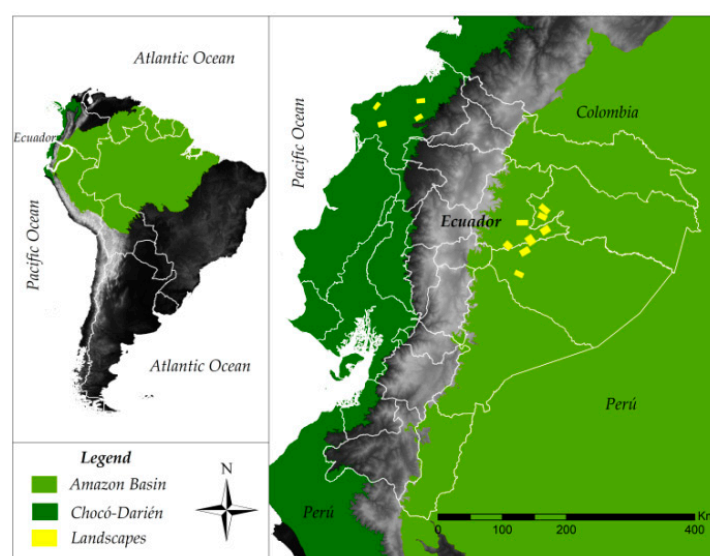
**Figure 1.** Annual net deforestation rate in the study areas selected. The periods 2000–2008, 2008–2014, 2014–2016, and 2016–2018 correspond to the national deforestation assessments carried out by the Ministry of Environment of Ecuador. Source: authors' own elaboration based on the information available in the Ecuadorian system for environmental information (SUIA by its Spanish acronym) [7].

Most farmers in our study areas are poor or extremely poor. The average annual household income is estimated in USD 4360 in the Central Amazon and USD 6560 in the Chocó-Darién; farm-related activities (mainly crop production) contribute more than 56 and 69% to the household income, off-farm income is between 32 and 25%, and governmental grants among 11 and 6% [58]. Off-farm jobs are often sporadic and many of households from our sample have no off-farm employment opportunities. Governmental grants are probably the only secure cash income a household receives in the course of the year. These grants are monthly cash transfers given by the Ecuadorian government to households under extreme poverty. Households benefiting from this policy are expected to invest the money in health and education in order to reduce chronic malnutrition and preventable diseases in children, and to increase the return-to-school rate and continue education to children and teenagers [59]. Around 68% of interviewed households in the Central Amazon and 56% in the Chocó-Darién benefit from these transfers, which also reflect the high levels of poverty that characterize these areas.

The co-existence of diverse cultures creates a mix between traditional and non-traditional lifestyles. In the past, indigenous people combined crop cultivation, such as cassava and plantain, with fishing, hunting, and gathering wild resources exclusively for domestic consumption. Due to their contact with other groups and their socioeconomic systems, today indigenous' farms also include some cash crops such as cacao [60], while the consumption of wild resources is declining [61]. Settlers also maintain a mix between cash and food crops and some of them own cows [62]. Given the climatic conditions, cultivation in both regions is possible year-round, with family labor as the main input for production [58]. Slash and mulch is a common clearing technique (the felled vegetation is not burned but is left on the ground to decompose); burning is less feasible due to the presence of constant precipitation and humidity [34,63,64]. When clearing the forest, farmers extract trees and sell them to the intermediaries or directly in the local markets [65]. Farm households face several problems with regard to their production and consumption decisions. These include a lack of credit (households that received a credit account for 34% in the Central Amazon and 18% in the Chocó); price and yield fluctuations; inadequate soil management; lack of knowledge; rudimentary technology, and insufficient technical assistance [66,67].

## 2.2. Sample Selection and Data Collection

We randomly selected 12 sites of approximately  $10 \times 10$  km representing the most characteristic production activities within the regions (Figure 2). In the Central Amazon, we selected eight sites, four of them containing areas under SBP. In the Chocó-Darién, we chose four sites, two of them influenced by a PA. In each site, we conducted face-to-face household surveys to collect socioeconomic data including household socio-demographics, land-use and forest cover change, and the institutional environment. In the 12 sites, we also installed a total of 69 plots of  $40 \times 40$  m in old-growth forests (36 plots) and logged forests (33 plots) to collect data to estimate the timber volume potential used in the regression analysis. Old-growth forests are areas with unknown human disturbance. Logged forests correspond to areas where timber extraction was conducted in the last two to five years; in the Central Amazon, this extraction was under simplified harvesting programs (Programa de Aprovechamiento Forestal Simplificado–PAFSI in Spanish), whereas in the Chocó-Darién was under the so-called sustainable harvesting program (Programa de Aprovechamiento Forestal Sustentable–PAFSU in Spanish).



**Figure 2.** Location of sites selected for our study in the Central Amazon and the Chocó-Darién of Ecuador.

## 2.3. Econometric Model

Our empirical model departs from the agricultural household theory [68], which has been adapted in several studies to understand household decisions regarding deforestation or forest clearing in rural settings [32,33,36,69]. Farm households in our study sites illustrate what Ellis [70] calls a “peasant economy”; their livelihoods rely highly on agricultural production, and households are partially engaged into imperfect markets [58]. When markets are perfect and well-functioning, production and consumption decisions can be separated and household production decisions, including land-use, can be modeled as a profit-maximizing problem where households maximize their objective function based on net economic gains [68,71,72]. However, in the context of imperfect markets, as is the case of our study sites, households are both producers and consumers of goods, meaning that consumption and production decisions are interdependent, hence non-separable. In the presence of non-separability, the assumption of profit maximization does not entirely hold and the framework of utility maximization serves as a basis to assess households decisions [68,73]. In this context, besides market prices, consumption demands and resource distribution may play a key role in production and land management [73], implying that characteristics related to the household (e.g., age, family size, education) are also relevant to understand land-use decisions and therefore deforestation [74].



Farm households maximize their objective function subject to limited endowments of labor, land, and capital, as well as factors beyond the household control such as the natural capital and the presence of institutions [31,75]. In consequence, under the utility maximization framework, the determinants of deforestation include both household internal and exogenous factors [31,34,45,76,77]. Household-specific factors include land, labor and capital endowments, and demographic characteristics (e.g., family size, age or sex composition, and education). Exogenous factors comprise the natural resource base (e.g., quality of forest resources) and the institutional environment (e.g., policies oriented to improve infrastructure, health and education, and property rights) [34,45]. Studies on deforestation at the household level have focused mainly on the household-specific factors [33]. However, variables related to the natural resource base and the institutional environment are less common in these assessments [78].

With these considerations, the econometric model we used to evaluate the aspects influencing deforestation at household level in the Central Amazon and the Chocó-Darién of Ecuador is a logit model of the following form [79]:

$$\text{logit}(Y) = L_i = \ln\left(\frac{P_i}{1 - P_i}\right) = \alpha + \beta X \quad (1)$$

where  $Y$  is the binary response variable, which takes a value of 1 if the household cleared forest and 0 if otherwise (during the survey application, households self-reported whether they had cleared forest within their farm, and this information was used to build our dependent variable);  $L_i$  is the log of the odds ratio;  $P_i$  is the probability of clearing the forest, and  $(1 - P_i)$  is the probability of not converting forest into alternative land-use;  $\alpha$  is the  $Y$  intercept;  $\beta$  is the regression coefficient, and  $X$  is the vector of explanatory variables (Table 1 presents a description of variables used in the model). Our emphasis is to explore whether household decisions to deforest are influenced by the quality of the natural resource base and the institutional environment. These two elements have been previously hypothesized to influence deforestation [41,45,46,72] but have not been explicitly evaluated in the Ecuadorian context.

The quality of the natural resource base can be seen as a “straitjacket” that may exacerbate the constraints (e.g., lack of technology) that farm households deal with. As the quality of natural resources varies from farm to farm, farmers can face distinct constrictions [34,45]. The quality of soils and forest resources are important factors that can motivate farmers to deforest. Since data on soil quality at the appropriate disaggregation level were not available, we used the timber volume potential as a proxy for the quality of the natural resource base. In areas with higher availability of timber, farmers could perceive that forest resources are unlimited and could feel more motivated to deforest [80].

Farmers can also respond in different ways depending on the institutional environment that surrounds them. We focus on three policies within the institutional environment: (i) forest conservation strategies including the incentive-based program SBP and a command and control policy such as PAs; (ii) property rights measured through titling; and (iii) governmental grants for poverty alleviation. In tropical regions, the influence of conservation strategies can vary according to the context and location [81–84]. Negative results have been observed when conservation comprises strict protection or when conservation policies do not contemplate the participation of local people [18,85]. The ongoing deforestation close to conservation areas impacts on the integrity and functionality within conservation areas; therefore, it is necessary to evaluate the role of conservation strategies in the buffer zones [86,87]. More empirical evidence is needed to understand the contexts in which conservation strategies can result in a win–win situation, i.e., less deforestation inside and outside the conservation areas. Policies regarding property rights can also determine the way households perceive forests. Titled lands are associated with long-term decisions, which may include better management of forest resources and more sustainable production systems [88]. Although, no direct connection seems to exist between governmental grants and environmental goals, recent evidence suggests that cash transfers to poor people have the potential to create synergies with deforestation reduction [39]. In developing countries, many poor people live in or near forests and often rely on forest resources to overcome cash and credit

limitations and to cope with shocks [89]. Cash transfers for poverty alleviation can influence land-use decisions, for example by reducing the need to extract timber as a means to obtain immediate cash, or by substituting more agricultural expansion to produce food crops [39]. Since, in our study sites, there is a considerable number of households that receive governmental grants (between 56% and 68%), evaluating the relationship with household deforestation decisions is worthwhile.

As control variables, we included household-specific characteristics related to land, labor and capital endowments, and demographic characteristics that have been reported in other studies to determine deforestation decisions. In order to account for the potential effect of households nested within sites, we run our models with robust errors clustered at site level. We examined the presence of multicollinearity through a correlation matrix, and we found that the number of crops, cattle ranching, off-farm jobs, and vehicle access were correlated with important variables in our model. For example, we observed that raising cattle is an activity dominated by non-indigenous families, who on average, have 6.5 cows compared with 0.3 for their indigenous counterparts. The number of crops was positively correlated with timber volume potential, our variable of interest, and with the indigenous group, showing that indigenous households tend to have a more diversified crop production. Off-farm jobs were correlated with distance and farm size; whereas vehicle access was correlated with the conservation strategy. The model presented in the Section 3 has a variance inflation factor (VIF) of 1.29 for the Central Amazon and 1.36 for the Chocó-Darién. According to the literature, VIF values of 5 to 10 suggest moderate multicollinearity, meanwhile when values exceed 10, they correspond to high multicollinearity [90]. The variables included in our model and their expected effects are presented in Table 1.

**Table 1.** Predictors selected for the logit model to evaluate household deforestation decisions.

Variable	Description	Expected Sign
Household characteristics		
Age of the head of household	Age in years	Older households are less likely to be physically able to clear forest [33], therefore we expect a negative sign.
Indigenous group	0 = the head of household does not belong to an indigenous group 1 = otherwise In the Central Amazon, 1 corresponds to Amazonian Kichwa, whereas in the Chocó-Darién, it corresponds to Chachi.	There are mixed results on this topic. On the one hand, non-indigenous people, “settlers”, have been pointed out as agents of deforestation [34,66]; however, some studies mention that indigenous people can also engage in unsustainable practices when they have access to a market economy [31,91,92]. Overall, we expected a negative correlation between indigenous households and deforestation.
Education of the head of household	0 = the head of household completed at least the primary school 1 = the head of household has little or no education	More education increases household consumption and production, leading to more deforestation [34]. In addition, educated people have more opportunities to obtain agricultural loans and access markets, promoting agricultural extension [42].
Number of males in working age	Number of males living in the household between 15 and 65 years.	A higher number of adult males living in the household is related with more deforestation [42,43].
Commercialization rate	Percentage of income coming from the sale of agricultural produce.	Commercially oriented households are more likely to deforest to increase their agricultural lands [33].
Credits	0 = the household received a credit 1 = otherwise	There are mixed results related to the influence of credits; however, literature indicates that people tend to invest credits into activities that provoke more deforestation [41,77].
Physical asset index	Comprise physical assets owned by the household (e.g., car, motorbike, bike, telephone, TV, radio, refrigerator).	Asset-rich households tend to clear more forest since they may have more means to develop expansive agriculture [33,42].
Land endowments		
Farm size	0 = farms with less than 5 ha 1 = farms larger than 5 ha	Having a smaller farm leads to a more intensive use of the soil, which is translated into more forest clearing [34].
Forest area within the farm	Percentage of forest area within the farm boundaries prior to the deforestation occurred in the last five years.	A higher proportion of forest area could give the feeling that forest resources are unlimited, motivating people to consume more forest derived products and to convert more forest area into other uses [80].
Quality of forest resources		
Timber volume potential	Average timber volume between old-growth forests and logged forests in m <sup>3</sup> /ha, which can be legally harvested following the minimum cutting diameter specified in the Ecuadorian forest law for each species [93,94]. Its estimation considers the tree height, diameter at breast height, and a form factor of 0.7, as recommended by Segura et al. [95].	There is no empirical evidence on the effect of timber potential on deforestation. Our assumption is that the more timber volume available, the more attractive it is for farmers to deforest.
Natural resources governance		
Land titling	0 = the household does not have land titling 1 = otherwise	Formal tenure is linked with less forest converted to agricultural lands [34,96]
Presence of conservation strategy	In the Central Amazon, four selected sites are influenced by Socio Bosque program (SBP), whereas in the Chocó-Darién, two sites are influenced by a protected area (PA).  0 = no conservation strategy is present in the landscape  1 = otherwise	On the one hand, strict protection with very few participation of local actors, such as PAs, is reported to be insufficient to disincentive deforestation outside the areas under conservation [86]. Conversely, when protection is accompanied by incentives, such as the SBP, people are more engaged in conservation and have higher environmental awareness [22], suggesting less deforestation in neighboring farms. Despite these mixed results, we hypothesized that households near conservation strategies have lower odds to deforest than those with no conservation strategy in their proximities, implying that the presence of a formal conservation instrument, regardless of whether it is command and control or incentive-based, has the potential to reduce pressure on forests beyond the limits of the areas that are under conservation.



Table 1. Cont.

Variable	Description	Expected Sign
Governmental grants	0 = no household member receives a cash transfer 1 = at least one person in the house is benefited	Governmental grants tend to relax the constrained budget of poor people, reducing the need to deforest [39].
Infrastructure		
Distance to the forest	Distance in km from the house to the forest plot owned by the household.	Spatial assessments show that more deforestation occurs when forests are close to the house [13]. Our assumption is that higher distances relate to less deforestation.
Distance to market	Distance from the house to the main market in km.	Higher distance to markets reduces the likelihood to deforest [41,43].

### 3. Results

The results of the econometric analysis showed that the natural resource base and the institutional environment have a significant role on households' decisions to deforest (Table 2).

**Table 2.** Logit regression results of deforestation at household level for the Central Amazon and the Chocó-Darién of Ecuador.

Variables	Central Amazon				Chocó-Darién			
	Coef.	Robust Std. Err.	<i>p</i>	Odds Ratio	Coef.	Robust Std. Err.	<i>p</i>	Odds Ratio
Household characteristics								
Age of the head of household (years)	−0.087	0.050	*	0.917	−0.132	0.104		0.876
Age squared	0.001	0.000		1.001	0.001	0.001		1.001
Indigenous group (0/1)	−0.055	0.415		0.946	0.874	0.344	**	2.397
Education of the head of household (0/1)	−0.181	0.209		0.834	−1.503	0.459	***	0.223
Number of males in working age	−0.157	0.056	***	0.855	0.768	0.329	**	2.155
Commercialization rate (%)	0.001	0.002		1.001	0.000	0.007		1.000
Credit (0/1)	0.467	0.301		1.595	0.838	0.446	*	2.311
Physical asset index	0.289	0.359		1.335	−0.040	0.605		0.960
Land endowments								
Farm >5 ha (0/1)	−2.225	0.358	***	0.108	−1.809	0.060	***	0.164
Forest area within the farm (%)	0.043	0.006	***	1.044	0.045	0.021	**	1.046
Quality of forest resources								
Timber volume potential (m <sup>3</sup> /ha)	0.009	0.002	***	1.009	−0.048	0.016	***	0.953
Institutional environment								
Conservation strategy <sup>1</sup> (0/1)	−0.810	0.271	***	0.445	2.294	0.620	***	9.918
Land titling (0/1)	−0.171	0.486		0.843	−2.150	0.762	***	0.117
Governmental grants (0/1)	−0.985	0.297	***	0.373	−1.420	0.307	***	0.242
Infrastructure								
ln distance to the forest patch (km)	−0.200	0.078	**	0.819	0.317	0.105	***	1.373
ln distance to market (km)	0.093	0.111		1.098	−0.307	0.193		0.735
Intercept	−1.075	1.420			5.609	3.371		
Number of observations	486				215			
Hosmer Lemeshow goodness of fit								
$\chi^2$	7.83				9.43			
<i>p</i>	0.45				0.31			
VIF	1.29				1.36			

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.010$ . <sup>1</sup> For the Central Amazon, the conservation strategy refers to Socio Bosque Program (SBP), and for the Chocó-Darién, it corresponds to protected areas (PA).

Timber volume potential, used as an indicator of the quality of forest resources, showed a significant effect for the Central Amazon and the Chocó-Darién although in different directions. The increase of one cubic meter of harvestable timber is associated with about 1% increase in the odds of a household to deforest in the Central Amazon, and with 5% decrease in the Chocó-Darién. Concerning the institutional environment, our results indicate that conservation strategies have the potential to influence household decisions in the buffer areas; however, the magnitude and direction of this effect varies according to the context and the type of strategy implemented. Households in the Central Amazon living close to the incentive-based conservation, SBP, have a 56% lower odds of deforesting than those with no presence of SBP in the proximities. On the other hand, in the Chocó-Darién, the odds of deforestation were 9 times higher for households living around state-controlled PAs than for those with no PA in their surroundings. Titling was only significant for the Chocó-Darién and showed that households

with titled land have an 88% lower odds of deforesting than their counterparts. Governmental grants were negatively associated with deforestation; households receiving cash transfers had between a 63 (Central Amazon) and 76% (Chocó-Darién) lower odds of deforesting than those who do not benefit from this policy.

The control variables included in the model indicate that household-specific factors also have an effect on households decisions. Land endowments showed a significant effect in both regions; households with farms larger than five ha have a 89% and 84% lower odds to deforest in the Central Amazon and in the Chocó-Darién, respectively. However, large forest areas have higher odds of being deforested. One additional percentage of forest increased the odds of a household to deforest by 4% in the Central Amazon and 5% in the Chocó-Darién. Household characteristics indicated that, in the Central Amazon, households with more manpower are associated with a 15% lower odds of deforesting; whereas in the Chocó-Darién, households with more males of working age are 2.2 times more likely to deforest. In the Chocó Darién, ethnicity, education, and credits were also significant. Indigenous Chachis are 2.3 times more likely to deforest than their non-indigenous neighbors. Little or no education is linked with lower odds of deforesting, which is in line with other similar studies [34,42,88]. Despite the fact that credits are only significant at 10%, it is important to note the magnitude (2.3 times higher odds) that credits have on deforestation. From infrastructure variables, only distance to forest was significant, showing that one increase in distance reduces the odds of a household to deforest by 0.20% in the Central Amazon but increases by 0.32% in the Chocó-Darién.

#### 4. Discussion

In Ecuador, ancestral populations and indigenous people own 7 M ha of forests, most of them in the Amazon and the Chocó-Darién [25,97,98]. Landholders have the power to decide how to manage their land in compliance with the law. The Environmental Organic Code (Código Orgánico Ambiental—COA in Spanish) allows landholders to use their forests, whether for subsistence or commercial purposes, as long as they follow the regulations established in the law [99]. According to the COA, no management plans are needed when landholders use the forest for subsistence or cultural reasons (Art. 109). In this case, harvesting forest products does not qualify as an infringement of the law, but the environmental authority is in charge to regulate the quantities to be used or extracted (Art. 315). However, for commercialization purposes, landholders need to present a management plan, following the respective guidelines (Art. 107, Art. 109); failing to do so is punished by the law (Art. 317, Art. 318). Deforestation within the farm creates negative environmental externalities (e.g., fragmentation, habitat loss, greenhouse gas emissions, and degradation of ecosystem services) that exceed the farm boundaries and affect human well-being [9,100]. Uncovering the factors related to household decisions to deforest is essential for the design of effective conservation actions.

As previously mentioned, the quality of natural resources that landholders have at their disposal influences their land-use decisions. In Central Amazon, livelihoods are characterized by small-scale agriculture, and farmers are limited by low fertile and acid soils, forcing them to expand agricultural fields to cope with productivity declines [101]. In this region, forests with high timber volumes are associated with a higher odds of deforesting. We estimated, on average, a timber volume potential of 176 m<sup>3</sup>/ha for the Central Amazon; however, timber in this region is considered a by-product of agricultural expansion and contributes less than 10% to the total household income [28,58,102]. During forest clearing, farmers extract timber species of high commercial value and sell them to intermediaries or to local markets, obtaining an additional benefit from forest conversion. In areas of high abundance of timber species, farmers sell standing trees to intermediaries and use the cash to finance more agricultural expansion [28], showing that their main interest is land instead of timber. In the Central Amazon, small-scale timber markets satisfy local and regional demands for construction and furniture; however, most of the timber is commercialized in the neighboring cities, while only 8% is locally consumed [28,65]. In the Chocó-Darién, on the other hand, we found an opposite relation between timber potential and deforestation decisions. We estimated that the timber volume potential

is 118 m<sup>3</sup>/ha for this region and timber extraction for commercialization purposes is an important livelihood strategy and has been noted as the main driver of deforestation [27,42]. Farmers begin by harvesting hard-wood species; when these are depleted, soft-wood species are sold. High intensity and frequent logging activities can result in degraded forests [103]. When tree species of commercial value disappear, farmers convert the already degraded forests into agricultural lands as an alternative livelihood strategy; this conversion does not occur in the short-term and it is not possible to capture with cross-sectional studies. In the Chocó-Darién, precious timber species are declining [104] and logged forests now have only half of the timber volume potential compared to intact forests [51], increasing the likelihood of a total forest clearing in the medium to long-term. With the decline of timber species in the Chocó-Darién, it is probable that timber markets relocate to the Central Amazon, which accounts for 63% of the legally harvestable timber volume [8]. It is urgent to encourage sustainable forest management (SFM) with reduced-impact logging techniques, and to promote fair participation of farmers within value chains. This must be accompanied by more control of illegal logging, which is a serious concern in both regions [58] and more post-harvesting monitoring. More resources are needed to strengthen the capacity of the environmental authority.

Even when the primary goal of conservation strategies is to safeguard forests inside the areas under protection, land-use intensification outside them negatively affects the integrity and functionality of conservation areas [87]. Therefore, it is necessary to identify circumstances under which these policies can disincentivize deforestation beyond the borders of the conservation. Our results evidence that, in the study regions, deforestation is occurring close to conservation areas, calling for the inclusion of more local landholders in present and future conservation strategies. The presence of conservation strategies portrayed mixed results on household deforestation decisions across the regions in our study. Spatially explicit studies also have found contrasting results [105–110], supporting the fact that the effect of conservation policies on deforestation is context-specific. In our study, households in the Central Amazon, living close to the incentive-based conservation SBP had lower odds to deforest compared with their peers with no SBP in their surroundings. Likewise, assessments using ecological indicators quantified less deforestation inside SBP areas and less degradation in forests close to SBP [22,49,108,111]. Our results prove that incentive-based conservation has a promising potential for combatting deforestation beyond the limits of the conservation area. It seems that SBP is raising conservation awareness even in areas outside the program. Some studies show that local people enrolled in SBP conduct frequent surveillance and when they detect illegal activities, within and around the SBP area, they report it to the environmental authority [22,112]. Moreover, in zones with an SBP area, there is a higher presence of SBP staff that constantly monitors the compliance with conservation contracts [22,49,113]. Perhaps, these facts restrain neighboring households to deforest, as they may perceive higher probabilities to get caught in illegal activities.

Conversely, in the Chocó-Darién, households living close to a PA had a higher chance of deforesting than those with no PA in their proximities. This does not imply that PAs are driving more deforestation; it rather evidences that near PAs pressures on forests are high, and households clear their remnant forest despite the potential sanction they could receive if they are caught infringing the law. Our results indicate that in a context of high deforestation and a strong presence of timber markets, people living in the buffer areas need additional alternatives to reduce deforestation within their farms. Since around 69% of the tropical moist forest in surrounding PAs has experienced a decline in the forest cover [107], it is necessary to design mechanisms that enhance the role of such strategies in the buffer areas. The well-being of people living near PAs can be improved in different ways. For example, when tourism is promoted, PAs can help to generate additional income and reduce poverty levels; moreover, positive links have been found on children's health for those living close to PAs [114]. It means that to be effective in preventing forest degradation and deforestation in the long-term, the management of PAs does not have to be disconnected with the people living in the vicinity, and positive benefits can be generated when more holistic management approaches are considered.

The Ecuadorian Constitution of 2008 recognized legal rights over lands to indigenous and ancestral possessors [62], and with the new forest policy reforms, titling increased considerably in the country. Individual tenure rights were granted for individual landholders, and collective tenure rights were recognized for indigenous communities; these comprised land-use rights including forests [28]. From our sample, 86% of households reported having legal titling in the Central Amazon and only 40% in the Chocó-Darién. Precisely, in the latter region, titling was significantly associated with less deforestation. There is important evidence indicating that formal land tenure leads to less forest conversion [34,42,96,115], which was also corroborated with our findings. In this respect, solving land tenure issues is crucial to preventing more deforestation of fragile ecosystems such as the Chocó-Darién. Having land tenure security can bring additional benefits such as less timber harvested illegally [91], the adoption of more sustainable land-use practices [34,116,117], and the possibility of participating in governmental programs such as conservation programs or trainings [115].

The environmental effect of governmental grants is an aspect that has remained understudied. However, we are starting to see studies evidencing that poverty alleviation policies are not necessarily at odds with conservation objectives [39,114]. Results from our study also contribute to supporting this argument. Controlling for other aspects, we found that households receiving governmental grants had lower odds of deforesting. Our findings suggest that cash transfers to poor households can reduce the need of clearing more forest to obtain extra income or to produce food, indicating that governmental policies for poverty alleviation have the potential to support forest conservation. In this sense, these results could motivate more research in this area and the integration of people working in the natural resources conservation sector when social policies are designed.

Besides discussing the results for our main variables of interest, we also briefly discuss some points concerning our control variables. The positive association between indigenous Chachis and deforestation evidences their high dependence on forest resources in a context of lack of technology, informal markets, and historic marginalization. Livelihoods in indigenous households are characterized by a higher crop diversification, mixed with the collection of forest products and a low engagement in cattle ranching; evidencing the role that ethnicity has on land-use decisions. As long as indigenous people are more integrated into markets, subsistence-oriented production systems are likely to transform into a cash-based economy; under the market imperfections, people can be pulled into a lose-lose situation in which environmental degradation comes hand-in-hand with poverty exacerbation [31,40,46,118–121]. More education is needed to provide local people the opportunity to participate in markets under more equitable conditions. So far, education is insufficient in our study sites; people who manage to finish primary school have serious economic limitations to continuing their studies. As suggested by Pichón and Bilsborrow [122], we believe that for the positive effect of education to be translated in less deforestation, there must be a significant increase in education levels in the forest frontiers.

Our results also reflected that the limitations given by a small farm size lead people to use the soil intensively [34]. In the Central Amazon, farmers have on average 26 ha of land, whereas in the Chocó-Darién, their counterparts have 23 ha. Continuous plot subdivisions to satisfy new demands for land have fragmented and reduced the size of many farms [123]. For households whose small farm is the only productive asset, policies restricting the forest use or forest conversion might be more oppressing. In contexts such as the Central Amazon and the Chocó-Darién, characterized by expansive production systems and poor agricultural technology [31,45], households clear the forest to extend their agricultural fields as the only option to compensate productivity declines or to cope with the depletion of forest resources, evidencing the role of land in supporting livelihood strategies. Higher percentages of forest cover within the farm can attract agricultural extension in the Central Amazon and more timber extraction in the Chocó-Darién, putting larger forest areas at a higher risk of conversion.

Finally, households in the Central Amazon are less likely to deforest if their forest plots are located at longer distances from homesteads, which is in line with our previous assumption; however, in the Chocó-Darién, we observed an opposite relation. Ninety percent of forest clearing in the Central

Amazon occurred within 4.4 km and within 5.5 km in the Chocó-Darién from the house to the forest plot owned by the farmer. A previous study analyzing deforestation with spatial techniques also suggests that in the Chocó-Darién deforestation occurs in more remote areas [40]. Forest areas near the house have already been converted to other land uses, and the remaining forests are located at longer distances. Palacios and Jaramillo [104] found that tree species with high commercial value are in severe decline and tree species with big diameters are less abundant for the timber market within short distances, forcing farmers to move longer distances [12,104].

## 5. Conclusions

Understanding the attributes that lead a household to convert forestlands to other land-uses can help to design better conservation policies. The quality of natural resources and the institutional environment are elements that significantly influence household deforestation decisions. In contexts where farmers depend more on agricultural production, valuable tree species can generate an additional incentive for forest clearing, since timber commercialization can finance agricultural expansion. When timber markets dominate the economy, continuous timber harvesting leads to forest clearing once valuable timber species are depleted; however, this effect is not captured in cross-sectional studies.

Conservation strategies have the potential to influence household decisions outside the areas under protection; however, the effects are context-dependent. On the one hand, SBP is associated with lower odds of deforestation in farms close to the program. This can be attributed to the higher awareness that SBP has created towards conservation. On the other hand, PAs need additional strategies to reduce deforestation in the buffer zones, especially in contexts with high deforestation pressures. This does not mean that PAs are not effective in reducing deforestation within their borders. There is a clear acknowledgment that without PAs in our study areas, deforestation could be much higher. As agricultural lands are getting closer to forests, deforestation risks are posed on new areas including those which are now under strict protection; therefore, lessons learnt from SBP and PAs can help to design or improve conservation strategies aligned to the current social demands.

Titling continues to be an important element for an adequate governance of the territory and for forests in particular. In places where land titles are scant, such as the Chocó-Darién, the effect of having secure property rights on deforestation is evident. The Ecuadorian government needs to facilitate the titling process in order to avoid more deforestation in the last remnants of the Chocó-Darién.

Governmental grants that aimed to alleviate poverty show good signs of helping to reduce deforestation. Undoubtedly, more research is still needed on this topic. However, in times of high uncertainty, high unemployment rates, and a continued demand for land, well-designed cash transfer schemes can help to create positive outcomes for the environment.

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