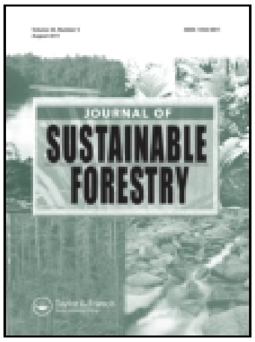

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Journal of Sustainable Forestry

ISSN: 1054-9811 (Print) 1540-756X (Online) Journal homepage: https://www.tandfonline.com/loi/wjsf20

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To cite this article: Ricardo Mello & Peter Hildebrand (2012) Modeling Effects of Climate Change Policies on Small Farmer Households in the Amazon Basin, Brazil, Journal of Sustainable Forestry, 31:1-2, 59-79, DOI: 10.1080/10549811.2011.565714

To link to this article: https://doi.org/10.1080/10549811.2011.565714

Published online: 30 Jan 2012.

Journal of Sustainable Forestry, 31:59–79, 2012

ISSN: 1054-9811 print/1540-756X online
DOI: 10.1080/10549811.2011.565714

Modeling Effects of Climate Change Policies on Small Farmer Households in the Amazon Basin, Brazil

RICARDO MELLO[1,2] and PETER HILDEBRAND[2]
[1]*Center for Latin American Studies and Tropical Conservation and Development Program, University of Florida, Gainesville, Florida, USA*
[2]*Amazon Environmental Research Institute (IPAM), Belém, Pará, Brazil*

Despite discussions on the effectiveness of carbon trade to reduce deforestation in the tropics, significant deforestation is expected to take place in the Amazon forest. Brazil is the fourth largest carbon emitter in the world, and nearly of 40% of its emission from deforestation come from smallholders. Smallholders can play a fundamental role in the conservation of carbon stocks due to their ability to adopt a highly diverse production system that does not require clearing of forest for production in the same way as soybean barons or cattle ranchers. This study analyzes potential effects of carbon trade policies on a typical 100-ha-smallholder farm located in the Transamazon highway, near Altamira in the eastern Brazilian Amazon. Land use change was estimated using an ethnographic linear programming model over a 5-yr period. Carbon trade increased their income by 9% and avoided the emission of 347 t of carbon, demonstrating the potential of climate

The authors would like to acknowledge research support from the Instituto de Pesquisa Ambiental da Amazônia in Brazil (IPAM) and the Amazon Conservation Leadership Initiative and Tropical Conservation and Development Program at the University of Florida. They are deeply thankful to the following colleagues from IPAM: Edvan Carvalho, Luzabeth Assunção, Rosana Gisele, Lucimar Lima, Marcos Rocha, and Erika Pinto for their support in this research, valuable information, and insights; to their friends of the FVPP—Ana Paula de Souza, Marta, and Guilherme Brito—for their belief that a new world is possible. The authors are also grateful to Dan Nepstad, Paulo Moutinho. and Robert Buschbacher for their insights. Last, they want to thank all the wonderful people who live in the Altamira region. This article is for them.

Address correspondence to Ricardo Mello, Center for Latin American Studies and Tropical Conservation and Development Program, University of Florida, PO Box 110240, Gainesville, FL 32611-0240, USA. E-mail: ric1965@ufl.edu

payments with economic improvement of marginalized populations. The methodological approach could be used by decision makers to project the land use change of small farmers for more accurate analyses of cost and benefits of forest carbon projects to these important actors in the Amazon.

KEYWORDS Amazon, carbon emissions, fire control, linear programming, REDD, small farms

INTRODUCTION

Importance of the Brazilian Tropical Forest to the Global Climate Change

As primary causes of climate change, the Intergovernmental Panel on Climate Change (IPCC) report (United Nations Framework Convention on Climate Change [UNFCCC], 2005) highlights fossil fuel use and land use change, the latter accounting for roughly one fifth of total anthropogenic greenhouse gas emissions. Forests play a double role in climate change: sequestering large quantities of carbon as growing trees absorb carbon dioxide from the air and storing it. Thus forests can become a major source of carbon emission when the stored carbon is released into the atmosphere by means of fire, forest degradation, and deforestation activities.

Brazil is the fourth largest carbon emitter in the world. The annual emissions in the Brazilian Amazon are estimated at 200 million t per year from deforestation (Houghton, 2005) plus the accidentally burned area that emits from 10 to 150% more carbon than deforestation alone (Nepstad, Moreira, & Alencar, 1999). Studying 152 cases in tropical areas with high deforestation rates, Geist and Lambin (2002) found that carbon emissions in the Amazon are mostly due to anthropogenic activities of converting forests to non-forested area. The actors vary over time depending on internal and external factors such as currency exchange rate, commodity prices, and subsidies. In the 1980s and 1990s, smallholders and cattle ranches emitted almost the same amount of carbon; however, since 2000, emission from deforestation for large farms producing soybeans for export increased (Nepstad et al., 2006).

The main international forum about climate change was organized by the United Nations in the Framework Convention on Climate Change (UNFCCC), which was adopted at the Earth Summit in Rio de Janeiro in 1992. The main agreement negotiated as an amendment to the convention was the Kyoto Protocol, under which industrialized countries agreed to reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990. Yet credit for forest maintenance was excluded in the agreement until 2012 (UNFCCC, 2005). This spawned the voluntary market for carbon stocked in tropical forests, though still in a limited scale.

Because of emerging knowledge about global warming and the urgency felt by governments, the role of tropical forests to alleviate global warming is attracting more attention as a target of international financial flows for conservation than are other environmental services such as biodiversity maintenance. During the UNFCCC 13th Conference of Parties (COP13) held in Bali in 2007, the “Road Map” to the next commitment period after 2012 was established. This included tropical forests in Brazil, which holds the greatest area of tropical forest in the world and could potentially gain carbon credit in this new, currently negotiated system. This carbon credit can compensate tropical countries for their nationwide reduction in emissions from deforestation and degradation (REDD; Moutinho, Santilli, Schwartzman, & Rodrigues, 2005).

Forest-Based Carbon Trade for Smallholders

There are two major reasons to consider smallholders as a main actor to be involved in the REDD mechanism. One is the socioeconomic importance of this social segment. Between 0.5 million (Instituto Brasileiro de Geografia e Estatistica [IBGE], 2006) and 2 million (Confederacao Nacional dos Trabalhadores na Agricultura [CONTAG], 2004) smallholder families live in the Amazon biome. Excluding Mato Grosso transition forest, they altogether control 31% of land, generate 71% of the total rural production aggregate value, and grow 89% of daily food (IBGE, 2006). They also produce about 93% of cassava flour, 95% of rice, 100% of beans, and 58% of cattle in the Amazon region (Costa, 2000). On the other hand, most of the smallholders in the Amazon live on less than US$2 per person per day: the poverty line established by the World Bank (Instituto Nacional de Colonização e Reforma Agrária/Food and Agriculture Organization [INCRA/FAO], 1999).

The other and the most important reason for the importance of smallholders in carbon trade is the linkage between production and carbon emissions from deforestation. This is due to the intense use of fire as the widespread tool of clearing forests for farming (Hedden-Dunkhorst et al., 2003). Nepstad et al. (1999) found equal contribution of small and large farms to the total deforestation, although such an estimate typically varies with the methodology used. For example, Pacheco (2003), using census data and satellite imagery, estimated that the deforestation by small farmers constituted only 1% of the total area deforested between 1985 and 1995. On the other hand, Sawyer (2001) theorized that if each of the 2 million families living in forested rural areas deforested 1 ha, carbon emissions by smallholder farms could reach 65% of the total carbon emitted by land use change in the Amazon.

Many researchers see that an effective way of reducing deforestation rates on smallholders is to make agriculture more productive and sustainable and forests more valuable. Agriculture will continue to be an important activity for large populations in the tropics. An increase in productivity through intensification, for example, can lessen the pressure on the agricultural frontier and thus reduce deforestation. Von Amsberg (1998) argues that agricultural improvements will reduce deforestation only if they do not increase the profitability of agricultural activities in newly cleared areas. Yet it has been suggested that livelihoods of many settlers arriving in the Brazilian Amazon region as poor colonists have improved and that some achieved it at markedly higher rates than other populations in Brazil (Braz et al., 1988; Reynal, Muchagata, Topall, & Hébette, 1995; Vosti, Witcover, & Carpentier, 2003). This suggests that the most profitable strategy for farming may be to clear forest for agriculture and ranching. Still, with increases in the intensity of land use, it may be possible reduce these incentives to clear forest (Vosti, Gockowski, & Tomich, 2005).

It has been also argued that technologies of intensifying agriculture could slow deforestation; however, the link between the two is ambiguous. In the Amazon, the main possibilities for agricultural intensification for smallholders include cultivation of perennial crops, pasture management, silvopastoral systems, forest management, and fire management and control (Carpentier, Vosti, & Witcover, 2000; Mello & Pires, 2004). All of them can potentially lessen the pressure on conversion of forests.

Other researchers suggest that deforestation in poor tropical communities will be reduced if forests become economically attractive to local populations. Timber forest management practices (Food and Agriculture Organization of the United Nations [FAO], 2005) and management of forests for non-timber forest products (Nepstad & Schwartzman, 1992) have been considered the best ways to raise forest-based incomes of local people (Perez & Byron, 1999). Yet more recent views have documented that forests with high biodiversity—such as tropical forests—are not ideal for commercial harvesting, because harvesting is difficult and yields are seldom economically viable (Neumann & Hirsch, 2000). In contrast, the REDD mechanism can achieve both an increase in the value of forests through payments for carbon stored in biomass and reduction in carbon emission through a shift from the slash-and-burn agricultural system to low carbon emission systems such as agroforestry and rotational cropping. Thus, it can be a new, potential method to control deforestation in the tropics.

A carbon market for forest is yet to be regulated, and there are still methodological issues that make implementation difficult. For the purchaser of carbon offsets, it is essential to be able to monitor and measure the net reduction in carbon emissions to enforce the agreements. The problems of measurement revolve around calculation of the net emission effect: the difference in carbon emissions over time between the "project scenario"' and the "baseline scenario" (without project; Moutinho et al., 2005; UNFCCC, 2008). Another measurement problem stems from the Kyoto Protocol's "additionality" principle: initiatives to mitigate greenhouse gas emissions must be considered additional to existing practices and governmental environmental laws. For smallholders, this implies the necessity to define carbon emissions for each parcel of land use in the property (Achard, Eva, Mayaux, Stibig, & Belward, 2004).

This article contributes to the REDD discussion by evaluating the potential costs and benefits when smallholders change their production systems to those of low carbon emission. This study was carried out in an eastern Amazon smallholder area, in which the first governmental project of payment for environmental services started in 2004. We simulated the effect on land use and family income over a 5-yr period from the start of the payment. Our focus was on evaluating the effectiveness of the new carbon income on reducing deforestation and improving family welfare.

We hypothesized that participation in the carbon market affected the smallholder system in two ways: (a) the extensive agricultural system will lose economic competitiveness to higher carbon systems such as perennial crops and forest management; and (b) livestock and agricultural systems will be intensified. It is due to reduced availability of land for agricultural expansion plus fund available through the carbon market to invest in technological improvements.

METHODS

An ethnographic linear program (ELP) was used to analyze potential effects of REDD policies on land use decision and farm income of small-scale farmers in the Transamazon settlement project near Altamira, in the eastern Brazilian Amazon. The model is briefly described below, and the effects of REDD policies on land use, farm income, and carbon stocks were simulated.

Linear programming can be mathematically described as:

$$\text{Max (or Min)}: Z = \Sigma_j C_j X_j \ (j = 1 \ldots n),$$

$$\text{Subject to}: \Sigma_i A_{ij} X_j \leq R_i \ (i = 1 \ldots m),$$

$$\text{and } X_i \geq 0.$$

Z is the variable objective to be minimized or maximized; C_j is the cost (debit) or returns (credit) of each of the n activities X_j; A_{ij} is the set of input or output coefficients for each activity j and resource or constraint i; and R_i is the set of m minimum or maximum constraints or restrictions.

Study Area

This study was conducted in Anapu County, State of Pará, in a settlement area located near Xingu River in the eastern part of the Brazilian Amazon, 600 km or 12 hr by car from Belém, the state capital (Figure 1). The area receives annual precipitation exceeding 1,700 mm with five dry months a year with less than 50-mm precipitation (Agência Nacional de Águas [ANA], 2006). This seasonal rain pattern defines the agricultural cycles and the high inflammability of the forest in the dry season (Nepstad et al., 2004). This area was colonized in 1972, when the Transamazon highway was opened in the heart of the Amazon tropical rain forest. The settlement was designed as a "fish-bone" with secondary roads (*travessão*), each of which is 5-km long and running perpendicular to the highway. The total population of Anapu is 9,407 and the demographic density is less than 0.79 inhabitants/km^2. Most of the population (67%) are smallholders. According to the Brazilian Institute of Geography and Statistics (IBGE, 2006) census, 62% of the population older than 10 yr is involved in either agriculture, animal husbandry, forestry, or fishing activities. The smallholder living within 10 km from the Transamazon highway had been settled by the government 20 yr ago, while migrants farther from the highway moved in without official permits. The former received subsidies and technical assistance to grow cacao and develop pasture and deforested more area than the latter (Rocha, 2003).

Economic Analyses of REDD Project Using Ethnographic Linear Programming

Studies of smallholder systems require an understanding of complexity in their livelihood production and reproduction activities. The conceptual framework to study small farmers places a family at the center of decision making in resource allocation and consumption (Hildebrand, Breuer, Cabrera, & Sullivan, 2003). All fluxes of inputs and outputs associated with production converge at and diverge from the family. Then complexity including the effect of carbon policies and their constraints on the livelihood system is added. To work on this dynamic and complex multi-year scenario, we chose ELP as a tool. Diverged from traditional linear programming, this method incorporates sociocultural parameters, changing nutritional requirements, evolving household composition, and other factors to enhance the dynamism, representing a real-world livelihood system (Hildebrand et al., 2003).

Our model was created in Microsoft Excel© with the standard Frontline System Solver© add-in, which maximizes the sum of the gross margins for all activities included in the model, following the objective function $Z = \sum_j c_j X_j$; where X_j is the production or other activities in a smallholder; c_j the forecast gross margin of X. Each activity is subjected to constraints R_i: the use of the resource i needed to operate an activity j cannot exceed the available amount of the resource held by the household (Mudhara & Hildebrand, 2004). The equation form of constraints in the model is $\sum_j a_{ij} X_j \leq b_i$; where b_i is the amount of resource i available.

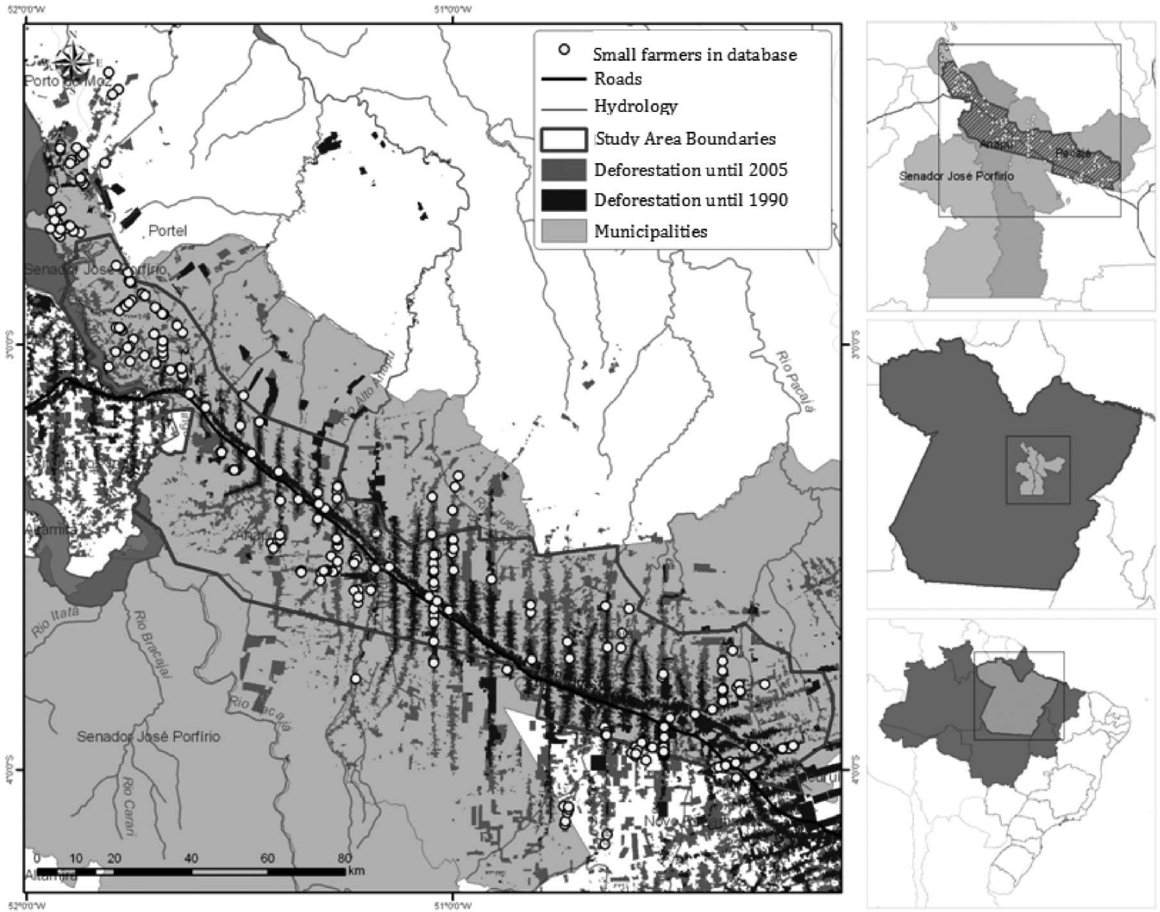

FIGURE 1 Location of the Rural Settlement area in Anapu, Pará State. The dots are the interview locations (Source: IPAM remote sensing lab).

The objective of this model is to maximize the sum of annual cash available for discretionary spending over 5 yr. Each year is subdivided into halves to account for seasonal household activities. The mixture of products sold in the market, non-farming activities, such as social security benefits and temporary work, and consumption requirements, such as purchase of food, clothes, or spending on leisure define the cash flow. The ELP model keeps track of sizes of forested areas and areas of other land uses in a farm in any year, as well as the time length of different land-uses. Using this information, carbon stock in a farm is calculated for each year, providing a basis for evaluating the impacts of REDD policies. In this scenario we assumed annual payments of REDD during the project period.

This model has four main constraints: (a) farm size: the area used for all farm activities cannot exceed the farm size; (b) labor: the labor needed for activities vary in semesters and gender, and households use primarily family labor, but can hire people if cash is available, or to work for others to earn cash; (c) cash: a household must have money for farming operation and for the necessary household expenditures each year. The surplus generated in any semester is transferred to the next semester as income; and (d) consumption requirements: some staple crops grown primarily for household consumption requires minimum level of production to meet family needs.

Two special constraints were introduced to simulate household livelihood changes in a REDD project. The first constrain is that deforestation is not allowed. All activities related to deforestation were adjusted to incorporate new technologies developed locally by small farmers and experimentation systematized by Amazon Institute for Environmental Research (IPAM) and Brazilian Agricultural Research Corporation (EMBRAPA; Veiga & Serrão, 1990; Mello, Gomes, & Rocha, 2008). The other constraint is that fire is not allowed without rigid control and management, which increases production cost. The equation for the cost and efficiency of fire prevention and control techniques was defined by the IPAM fire project (Mello & Pires, 2004; Carvalho, Mello, Assunção, & Souza, 2008) for each type of vegetation and area where fire will be used. For this study, we included cost to control accidental forest fires while building firebreaks around the forest area.

The model is validated to a set of initial conditions that define the model's starting point in terms of available resources (land, labor, and capital), existing land uses, and prevailing technology and prices.

Data Collection

Development of ELP requires data of input and output details for all the livelihood activities related to the livings of smallholder. The aggregate data available from the Brazilian demographic census were inappropriate to the lot level, thus we used the database generated by the Brazilian Ministry of Environment and Fundação Viver Produzir e Preservar (FVPP), a grassroot organization with a program of payments for environmental services, and IPAM, an NGO with experiences in climate change policies. This data set contained information for 307 lots collected in 2004 and 2007 (Figure 1). The data were collected in a 1-day period for each lot. The procedures of data collection included structured interviews, vegetation sampling along transect to survey main land uses, and handwritten diagrams to collect information about production strategies and plans for the future. The data included information on land use, family life history, livelihood activities, and prices.

Due to the high variability of land use dynamics in smallholders, calculating the carbon stock using direct measurement is expensive and not viable for carbon trade on a large scale (Pagiola, Arcenas, & Platais, 2005). Remote sensing methods are becoming more accessible and accurate to measure carbon stocks through new algorithms. It can detect landscape changes with less interference from clouds, and estimate the amount of carbon in the landscape (Nepstad et al., 2007).

In this study, carbon stock was estimated with the type of land cover by associating a carbon value for each land parcel. The land cover was defined using a combination of satellite imagery interpretation and field survey, in which the smallholders delineated their property in printed satellite images. The regional deforestation baseline was defined using the Brazilian official deforestation monitoring system Instituto Nacional de Pesquisas Espaciais (INPE, 2008), which was freely available and had classification of forest and non-forested area.

The values of carbon stock in the biomass used in this study were obtained from the studies conducted in eastern Amazonia by the Center for International Forestry Research (CIFOR)/International Center for Tropical Agriculture (CIAT; Braz et al., 1988; Palm et al., 2000). The aboveground carbon stocks in tons are defined as follows—primary forest: 160 t/ha; managed timber forest: 130 t/ha; agroforestry systems: 55 t/ha; young fallow: 15 t/ha; old fallow: 25 t/ha; pasture: 5 t/ha; and annuals: 5 t/ha.

Even though the average production system used by small farmers generally leads to a decrease of forest area, the pattern is heterogeneous. Thus, the smallholders with similar income composition were aggregated to reduce variability of land use, making possible generalizations of the model. The smallholders were classified into three categories: cattle-dependent farms, perennial crops-dependent farms, and annual crops-dependent farms. The aggregate results were used to categorize and realize a descriptive statistic of the sample.

To solve the model, one smallholder was chosen from the category that had a higher rate of deforestation and a large area of forest stands—two most significant characteristics for implementation of REDD program. Within the households in the category, there were six households that were willing to participate in the research and that had deforestation rate, income, and pasture area that were close to the average of the farms in the category.

Among the six, a smallholder with the easiest access was selected as a model household.

Complementary data were collected to deepen information about family composition and history, market conditions, productive system, and forest degradation. The data collected and the model solved were validated with the family to confirm the simulations.

Five-Yr Model Estimation of Flux of Carbon Stocked in Vegetation

The goals of REDD projects in relation to carbon emission is, in the essence, to reduce deforestation and degradation in comparison with the past. Thus, what is to be negotiated is the difference in carbon emissions between the projection from the past and the actual value achieved. Establishing a carbon baseline for small farmers is difficult due to the small size and diversity among farms. In addition, each farm has different patterns of deforestation and degradation and will have different strategies to reduce deforestation and degradation during a project period.

To meet the diversity of smallholders, a three-step process based on ELP was proposed as a method to calculate the carbon to be traded was proposed. This method first determines the current land cover and land use of a lot to estimate the existing carbon stock. Validity of the model is tested by simulating the land use change in the recent past and comparing the result with the actual change occurred in the land. Second, two ethnographic linear programming scenarios are created to calculate projected carbon emissions with and without the project. The former assumes the conventional livelihood strategies of households in the study area and calculates carbon emissions without carbon trade. The latter scenario incorporates the expected effects of payment for the aboveground carbon stock. Both are solved for 5 yr. Third, the amount of carbon to be sold is calculated as the difference between the carbon emission in the business-as-usual (baseline) scenario and that in the new production system. Then the value of payment is calculated with two different prices for carbon.

RESULTS

Land Use and Deforestation Patterns in the Study Area

As of 2007 when the data were collected, the surveyed land was mainly used for cattle ranching and subsistence agriculture. Fifty-seven percent of the land was classified as standing forest, 16% fallow (of various ages), 21% pasture or crop fields, and 6% as “other.” Yet this region had suffered the loss of 30% of the standing forest over the previous 15 yr. The remaining forests were highly vulnerable to forest fires due to logging activities that make forest more flammable and frequent use of fire as a major tool for land management. About 30% of the remaining forests had been burned at least once by 2004. Between 1986 and 2004, 5,743,858 t of carbon per year were emitted from deforestation of 240,000 ha of forests alone. This figure equals to an average of 20.5 ha of deforestation per farm including accidental forest fires in 164,000 ha of land in total.

The typical smallholder in Anapu had an average size of 88 ha. The average annual family cash income was US$970 from the combination of perennial crops—mainly cacao and banana (US$446); annual crops—primarily cassava and rice (US$174); and other—off-farm employment (e.g., teacher, retirement, and other governmental sources)—US$350. Cattle were sold only on special occasions, such as family deaths or weddings; and the number was increasing in this area to an average of 26 heads per family, indicating an increase of deforestation. This region is a perfect place to start a REDD project because it has a large forest area with high deforestation pressure, serious problem of poverty, and a very well-organized social movement.

Among the three types of farms categorized by the sources of their income, Type-I farms (cattle-centered farms) had 46% of the annual income from cattle. Thirty-two percent of the farms belonged to this type, and they are mostly located within 10 km from the main road. They generally had poor soils. The average farmland consisted of 33% pasture, 8% annual crop, 2% perennial crops, 12% fallow, and 45% forest.

Type-II farms (perennial crop-centered farms) had the more diverse annual income, of which 38% came from perennial crops. They were situated in areas with the same level of accessibility as the former type and with good basaltic soils, and constituted 19% of the total number of farms. The main crops were coffee, cacao, and banana. Land cover was more diverse than the other types with 17% pasture, 4% annual crops, 5% perennial crops, 8% fallow, and 66% forest on average.

Type-III farms (annual crop-centered farms) were mostly located more than 10 km off from the main road and constituted 49% of the total farms. They had problems in accessibility in the rainy season and land tenure was typically not consolidated. These families had the lowest income that was mainly from annual crops, and characterized by a subsistence economy. Land cover consisted of 2% pasture, 6% annual crop, 1% perennial crop, 14% fallow, and 77% forest.

The three classes had different deforestation rates; the rate was highest in Type-I, where pasture expansion was needed to accommodate an increasing number of cattle and to make up for a decline in pasture productivity. Between 2001 and 2005, the deforestation rate for this type measured by Real Time Deforestation Detection (DETER) coordinated by Brazilian National Institute for Space Research was 4.3% per year, while the rate was 2.1% per year for the Type- II. Type-III had an intermediate rate of 2.8%, mainly due to a lack of financial resources and more difficult market access that limits development. Thus, Type-I farms had the most suitable characteristics for REDD projects because they had the highest deforestation rates and a large area of threatened forest.

The Family-Level Model of a Type-I Smallholder

The farm of the selected smallholder was acquired in 1990 and the total area is 110 ha, consisting of 95 ha of forest, 3 ha of annual crops (rice), and 12 ha of fallow. The main production strategy was to make large areas of annual crops (principally rice) together with pasture. After rice was harvested, the land was converted to pasture. At the same time, they made a loan to grow cacao because this region had a profitable and well-established market for cacao. They also purchased cattle with a subsidized loan. The household acquired nine cattle, built fences, and a pen. The pasture has fences only on the boundaries of their property, and its management involves slash-and-burn practices. The cattle receive vaccines and salt throughout the year. The family raises chickens and pigs for consumption. Today, after 18 yr since the family move-in, the family has 22 head of cattle and the forest area has been reduced to 66 ha, with a deforestation rate of 4.3% per year in the last 5 yr.

The family was composed of six members, but only four work on the property (one adult female and one adolescent female live in the city 2 hr away on foot from the smallholder to study). The family had one additional adult male, who is now considered as a family member, living with them for the last 10 yr. One adult female received a wage for her work as a community health agent. Men worked 8 hr, 288 days a year, and women and children between 8 and 13 yr provide 6 hr of labor per day. The family annual income was US$4,310: 36% from off-farm activities; 18% from annual crops; 24% from cacao; and 22% from cattle and dairy products.

Modeled land cover change is presented in Figure 2. The comparison between the observed land use change and the modeled results confirmed the tendency of forest losses for the next 5 yr. The predicted forest area in the year 2012 is 59 ha, a reduction of 10.7% since 2007. The annual crop area was stable at 0.5 ha per year (ranging from 0.3 to 0.7 ha), only half of the average size for the Type-I properties. Seventy-five percent of the land for annual crop was in forest. The biggest change in the area was an increase in pasture, growing from 29 to 35% of the total smallholder area. The fallow area was reduced and perennial crop area did not change, staying at 3% of the total smallholder area. The model reproduced the loss of forest to pasture, a common situation for this type of producer. In the business-as-usual scenario, income increased from US$4,310 per year to US$6,758 due to the increase in cattle sales. Cattle revenue surpassed cacao and became the main income source by the 3rd yr. The present value of total income discounted with 6% for a 5-yr model period was US$22,974. The income consisted of 29% from off-farm activities, 11% from annual crops, 27% from cacao, and

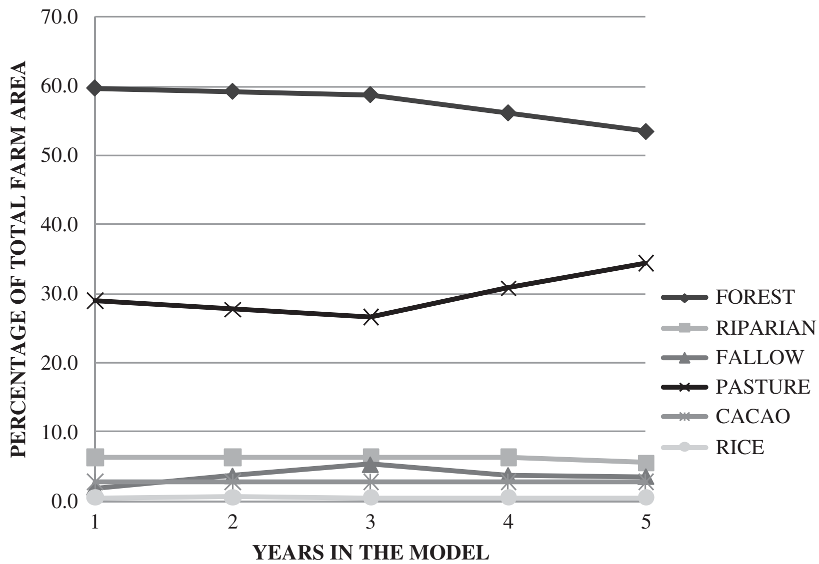

FIGURE 2 Changes in land use cover during the 5-yr model for a Type-I farm, in the business-as-usual scenario.

31% from cattle and dairy products. Forest products were collected sporadically, mainly fruit (*açai*; *Euthерpia* sp.) and *buriti* (*Mauritia flexuosa*), contributing 2% of the family income. Family labor was not sufficient at the end of the 3rd yr, so the family had to hire the equivalent of 4% of the total available family labor.

Carbon stock payment scenario

Under this scenario, the smallholder receives an annual payment equivalent to the difference in carbon retained on the farm in comparison to the baseline (Scenario 1). The payment is added to the model as beginning year cash, and has no restriction on its use. With the constraints of no deforestation, fire management, and no burning of pasture, the production cost increased by 18% on average. The model was solved with a ton of carbon valued in 5 and US$10, the average market price for forest carbon projects (Nepstad et al., 2007). The results are presented in the Table 1.

The payment of US$5 per ton of carbon resulted in carbon emission reductions of 291 t in 5 yr as the result of preservation of 5.1 ha of forest compared with the business-as-usual scenario. The carbon credit received by the householder in 5 yr was US$835.69 (present value discounted insurance). However, even with carbon payment, family income was reduced to US$19,806.86: 14% less in comparison to the business-as-usual scenario. Thus, the payment for carbon emission reduction would be insufficient for a family to change the production practices using fire. The model gives the

TABLE 1 Simulation Results for Carbon Stock Payments and Business-as-Usual Scenarios

Scenario		Business-as-usual	Carbon payment US$5	Carbon payment US$10
Family income[a]	(US$)	22,974	19,807	25,151
Deforestation in 5 yr	(ha)	9.0	4.9	1.8
Fallow area change in 5 yr	(ha)	–0.3	+0.8	+1.9
Avoided carbon emission[b]	(t)	–	291	501
Increase in labor demand	(% hired)	–	4	14
Carbon credited[c]	(US$)	–	835.69	2,745.34

[a]Present value; [b]Included changes in all land use; [c]Present value.

option for the family to choose between the annual crop with fire and without fire, and the transition to annual crop without fire occurred only in 35% of the crop area.

With the scenario of an annual payment of US$10/t, 501 t of carbon emission would be avoided and an income of US$2,745.34 would be generated. The payment for carbon sequestration in only 5 yr reduce deforestation from 9 to 1.8 ha and increase carbon stocks in the smallholder by 1.2% from the start of the project, owing to a 15% increase in the fallow area. Unlike business-as-usual and US$5 scenarios, carbon stock would increase in the last year of the model, in spite of persistent carbon stock decline in the first 2 yr, mainly due to the period of production system changes (Figure 3).

The effect of carbon payment on family income and land use was significantly different at this carbon price. Family income increased to US$25,150.98, or 9.4% greater than the business-as-usual scenario. The

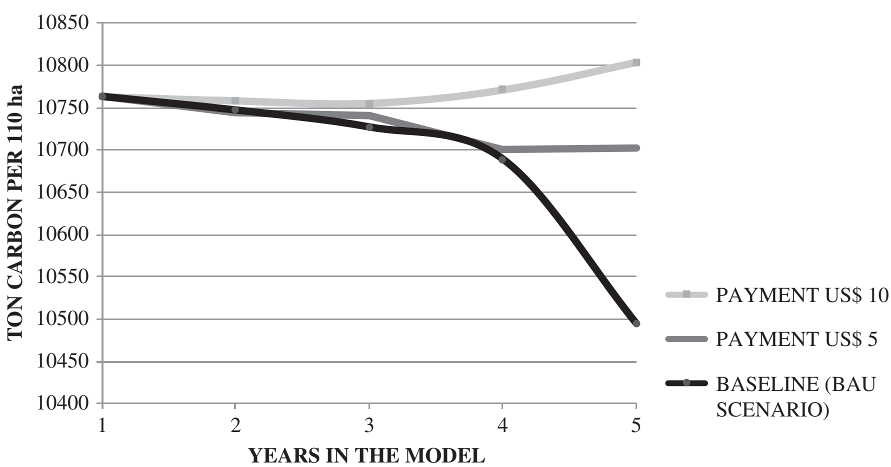

FIGURE 3 The 5-yr model using the business-as-usual (BAU) and carbon payment scenarios. The difference between the business-as-usual carbon scenario and the carbon stock in the carbon payment scenario is the avoided emission.

family could reduce fire dependence on the production system without a loss in income. At the end of the 5 yr of this analysis, the primary income continued to be provided by cattle, but the new production system provided additional income, which is low in the first 2 yr but became greater thereafter. Fire control enabled the use of *açai* and the collection of lianas viable in the riparian area, diversifying income sources. The contribution of these non-timber forest products to the total income increased from 2 to 18%. Other forest uses were not incorporated in the model because of the previous timber extraction in the area, and in a 5-yr model would be impossible to change the forest condition to allow more intense forest management. However, this is an important element to consider in models for longer terms.

The labor deficit increased from 4 to 9% in this scenario, and cash income was reduced by US$917 during the first 2 yr due to the investment needed to change the system in the short term. However, after the 3rd yr the income became 24% greater than the business-as-usual system (Figure 4).

DISCUSSION AND CONCLUSIONS

During the last decade, local smallholders, rural extension efforts, and national and international research centers developed new land management techniques, which are now adopted by smallholders in the tropics in the absence of carbon trade. These techniques had the goal of reducing deforestation while increasing forest value (Perz, 2003). Despite the relative success of these techniques, they have never been adopted widely to reduce deforestation. Part of the failure has been due to its high implementation

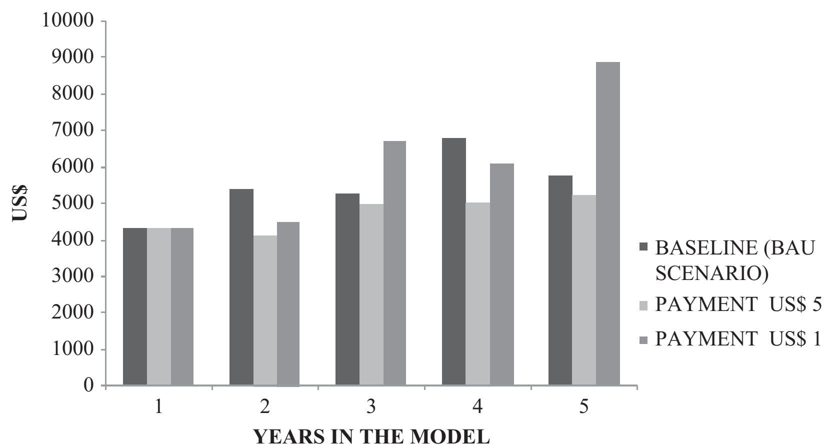

FIGURE 4 Change of annual income during the 5 yr of simulation for the models with and without carbon payment to Type-I smallholders in Anapú, Pará.

cost, which is particularly a burden to poor farmers (Almeida, Sabogal, & Júnior, 2006). The carbon trade can become an important source to finance this change on a large scale.

This work simulated the effects of carbon trade as a means of achieving a low carbon emission system for small producers in Anapu, in the eastern part of the Amazon. The region is classified as a highly potential area for REDD projects because of relatively well-defined land tenure, well-structured social organization, and a highly threatened forest with the loss of 30% of forest cover, mainly in the last 15 yr (Soares-Filho *et al.* 2006; Wunder, Börner, Tito, & Pereira, 2008).

We used ethnographic linear programming to seek answers to the effects of potential carbon trade on a smallholder's livelihood system. This article showed that carbon trade could be economically viable, improve food security, and simultaneously increase carbon stock in livestock-based smallholders. Such smallholders that are dependent on livestock constitute 32% of the smallholders in this region and have the highest deforestation rate among the types analyzed. However, if carbon prices are not high enough to cover the transition costs to an intensive productive system and good environmental protection practices, the model predicts a negative effect on the family livelihood. This result suggests the risk to smallholder's farmers when Brazil enforces environmental laws to reduce deforestation without implementing policies to change the production system. This trend became evident in Brazil with recent efforts to reduce deforestation, where fines for violation of environmental regulations increased and credit was restricted to farmers who complied with environmental laws.

In our single farm model at a fixed carbon price of US$5 per ton of carbon, a REDD contract will reduce agricultural production and collapse the livelihood system with a negative cash flow. On the other hand, the production system reacted positively at US$10 per ton of carbon with a value twice as much as those found in other studies of smallholders (Börner, Mendoza, & Vosti, 2007; Wunder et al., 2008). Such differences in opportunity cost to reduce carbon emission from smallholders arise from different methodological approaches used. In our case, the opportunity cost is defined for the whole property by hectares, not for each activity that is affected by limiting deforestation. This accountability is complex and is only possible using models such as ELP. Additional new forest uses—such as vegetable oil extraction, fruit collection, or any other forest-related production—can lead to new profit that reduces the carbon cost. This way the opportunity cost as defined here is more linked with the introduction of new technologies to reduce forest conversion than mechanisms of compensation for preserving the forest.

ELP models capture changes in established production systems as a consequence of an intervention—REDD policy in our case—as their main objective. It is possible to use ELP output to generate regional tendencies, but it was not done in this article, as it was not the objective here. A quick simulation using the results for cattle-centered smallholders showed that the emission of 501 t of carbon was avoided in 110 ha of land during the 5 yr. Since the study area has 2,000 Type-I producers (cattle specialists) holding an average of 100 ha, the simple calculation from the result yields 182,000 t of avoided carbon emission per year in the total area of 200,000 ha.

Regardless of how the carbon market will be established—whether at a project level as the volunteer market is supposed to operate, or at the national level, as Brazil proposed—the effective transformation of production systems from high to low carbon emission will happen when the income of families living in forest areas increases. Our model can assist carbon contractors decide how to elaborate the contract clauses—such as the definition of yearly goals for a household, changes in the production system, the cost and revenues, as well as carbon stored in the property.

The results show that it is possible and feasible to establish a new level of discussion about REDD with small landholders in the Amazon by conditioning payment for carbon on change in productive systems. ELP models, once refined with better data, could be incorporated in programs like Proambiente, one of the most advanced PES-like schemes that include the effect of deforestation and other environmental services such as fire control and water quality (Hall, 2008). Yet this PES program has been failing to attract buyers, mainly due to the difficulty of the certification process that does not clearly shows the amount of service generated (Wunder et al., 2008). Nor does it have a monitoring system to ensure that the services are being processed and a new low carbon emission system has been developed. Both of such limitations can be minimized with the ELP method.

Another good case where the methodology could be applied is the Amazonas state "*bolsa floresta*" program, that makes a fixed payment of US$25 per month per family for not deforesting, as well as for community improvements such as building schools, health centers, and providing training. However, when an understanding of the family livelihood system is insufficient, a disconnection between environmental service rendered and payments can reduce the success in changing productive systems. The application of ELP methodology can facilitate the negotiation of a common platform between program managers and communities. ELP model data collection and output of the simulations are helpful in planning and implementing production system changes needed to reduce deforestation and increase income. This way, the remuneration for environmental service could receive better estimation.

These two Brazilian PES programs are examples where ELP can be used to improve results of the REDD program to reduce carbon emission. The methodological tool used in this article can be applied, with small adjustment, to the rural extension system in order to reduce uncertainty about the carbon transaction.

In this preliminary work, we only examined the effect on one household. In the future, a large number of different households should be analyzed to improve the validity of the model to measure potential effects of carbon trade on smallholders living in tropical forests. Additional smallholders can be modeled with relatively few changes in the model, mainly to account for smallholder size, current land use, and household composition. In the whole Brazilian Amazon region, there are nearly 2 million smallholders with high emission production systems. With a little support, such a system can be changed to systems with less carbon emissions.

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