Research article - Analysis

Economic impacts of payments for environmental services on livelihoods of agro-extractivist communities in the Brazilian Amazon

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ABSTRACT

Rural communities in the Brazilian Amazon rely on manioc, produced in a swidden-fallow system that uses land cleared from forest areas. Increased agricultural production could reduce fallow period length with implications for manioc flour (farinha) production. We hypothesize that payments for environmental services (PES) programs may exacerbate reduction of fallow periods, thereby reducing per stem farinha productivity. To understand the household scale economic impacts of avoided deforestation under PES programs, we conducted interviews in 200 households from 32 communities in the Brazilian state of Amazonas. Using regression models, we assessed which variables most influenced farinha production, and calculated production costs and total revenues, with and without a PES program. Manioc yield increased by 22.83 kg per household per year for each additional year that the forest was left to recover before being cleared. Although production costs were higher for land cleared from older secondary forests, net profits on land cleared from primary forests were still higher. Total income from PES programs, when added to the secondary forest manioc profit, were higher than the foregone production in primary forest areas. However, when we considered only direct cash payments, we identified potential trade-offs. We conclude that PES programmes should consider possible long-term effects of payments on the livelihoods of participants.

Keywords; Agriculture, Bolsa Floresta, Bolsa Verde, deforestation, manioc, PES.

1. Introduction

Payments for environmental services (PES) have been proposed as an economic tool to help alter land use behavior, such as inhibiting deforestation (Wunder et al., 2005; Pagiola et al., 2013) often while aiming to reduce rural poverty (Wunder, 2005; Pagiola et al., 2005; Zilberman et al., 2006; Grieg-Gran et al., 2008; Muradian et al., 2010; FAS, 2017a). PES programs offer financial rewards to landowners and land users who adopt practices to conserve natural resources, and have been extensively implemented in developing countries as an economic alternative to activities that result in tropical deforestation (Wunder et al., 2005). PES programs that focus on carbon sequestration are increasingly common in tropical forest contexts, in part as a result of Reducing Emissions from Deforestation and forest Degradation *plus* forest management (REDD+) programs that aim to both protect forests and improve the livelihoods of local communities (Pacheco et al., 2012). However, in protecting primary forests from further agricultural expansion, PES programs could also incur detrimental economic and environmental costs by increasing competitive demand on previously cultivated agricultural plots (hereafter, *roçados*)

Integrating conservation and development objectives is a challenge for PES programs (Pereira, 2010): although there are some successful examples of PES meeting tangible benefits, many often fail to meet local subsistence needs due to either market volatility or underestimated payments (Martin et al., 2008; FAS 2017a). There are multiple responses from local PES participants, which may range from program withdrawal, increased swidden-fallow rotation, reduced fallow period, changes in livelihood strategy, and migration.

Whether or not a PES program provides a ‘win-win’ solution for conservation and development will depend in part on fine-tuning its design with respect to local context. PES programs in the Brazilian Amazon therefore need to consider the complexities and idiosyncrasies of each socio-ecological system in which they are to be implemented in order to effectively compensate local opportunity costs and address social justice (Newton et al. 2012b). For example, opportunity costs vary dramatically between the Amazon agricultural frontier, where the payoffs for forest conversion into pasture or cropland can be high, and more remote areas, where there is little immediate threat (Börner and Wunder, 2008; Börner et al., 2010). The motivation for payments in the latter case, may instead be related to the compensation of management practices that contribute to the provision of ecosystem services over time. This type of payment approach may result in high efficiency, but its success will therefore depend in part on whether PES programs can maintain or improve local livelihoods (Newton et al., 2012b). Given the complexity of the economic system in rural Amazonian communities (Futemma and Brondízio, 2003), the importance of manioc cultivation, and the large number of households affected by PES programs across the region, it is important to assess the economic impacts of these programs (Börner et al., 2013).

Manioc or cassava (*Manihot esculenta* Crantz) is the staple food crop for rural communities in the Brazilian Amazon, representing up to two thirds of all agricultural income (Souza, 2010; Newton et al., 2012b). Manioc is cultivated using swidden-fallow (or slash-and-burn) agriculture, and its tuberous roots are processed locally into a dry flour (hereafter, farinha) (Clement et al., 2010). This widely used tropical swidden-fallow system (Scatena et al., 1996) consists of alternate cropping (*roçado*) and fallow second-growth (capoeira) phases, after which often young secondary forests are cut and allowed to dry before being burned or removed to begin a new cropping cycle (Silva-Forsberg and Fearnside, 1997; Metzger, 2003; Fraser et al., 2012). Additional manioc plots (*roçados*) may also be created by clearing primary, rather than secondary, forest plots.

Biomass burning releases nutrients for the next cropping cycle, thereby re-establishing soil fertility over the fallow period (Nye and Greenland, 1960; Fraser et al., 2012). The longer the fallow, the greater the forest biomass and the more nutrients will be released after clearance and burning, directly influencing manioc production. In typical low-nutrient Oxisols and Ultisols, which account for 75% of all Amazonian soils (Irion, 1978), longer fallows are even more important to maintain crop yields (Fraser et al., 2012). Successive uses of the same agricultural plot or shortened fallow periods may therefore reduce crop yield (Silva-Forsberg and Fearnside, 1997). In addition, soil nutrient loads take even longer to recover in plots used over consecutive years without fallow periods (Styget et al., 2007).

Greater intensity of agricultural activity has been occurring in the Amazon since the 1990s due to increased population density and market integration, increasing demand over farinha products (Jakovac et al., 2017). Agricultural intensification can contribute to shortened fallow periods and increased frequency of swidden-fallow interchanges (Mazoyer and Roudart, 1998; Jakovac et al., 2016; Jakovac et al., 2017), and has been observed in swidden cultivation around the globe (van Vliet et al., 2012). These processes are potentially exacerbated by the voluntary participation in a deforestation-avoidance PES program that restricts primary forest clearance. Prohibiting access to new agricultural plots may be a driver of agricultural intensification.

There are several reasons why a PES program can accrue financial benefits to participant households. Although the measure of opportunity costs is dynamic in the long term, and some PES programs aim to improve livelihoods rather than compensate for losses, households may not be willing to comply with the program if payments to households and/or communities do not match or exceed their opportunity costs, which are largely determined by manioc yield and the availability of land for cropping (Nepstad et al., 2007; Newton et al., 2012b). In other words, achieving more sustainable practices may disrupt local livelihoods.

In this paper, we assess the economic impacts of PES programs in the Brazilian Amazon and evaluate their likely effectiveness by (i) understanding how environmental factors affect manioc production; and (ii) assessing whether payments will compensate likely production losses from reduced fallow periods. We considered two existing PES programs – the Bolsa Floresta (BF -

Forest Stipend) and the Bolsa Verde programs (BV - Green Stipend). Our hypotheses are that (i) farinha production will decrease as a function of younger age of the forest stands that are converted into manioc plots, and (ii) household scale profits from farinha production will be reduced if old-growth primary forest cannot be cleared and manioc plots are restricted to increasingly younger secondary forests. We expect that PES programs may reduce fallow periods, since prohibition of clearing old-growth primary forest is a central compliance criterion of both of these PES programs, and that PES programs could thus act as drivers of agricultural intensification.

2. MATERIALS AND METHODS

2.1 Case studies – Bolsa Floresta and Bolsa Verde programs

Bolsa Floresta and Bolsa Verde are two PES programs that have been active across the Brazilian Amazon since 2007 and 2011, respectively (Table 1).

To date, Bolsa Floresta operates within 16 protected areas (hereafter, PAs): one Environmental Protection Area, one State Forest, two federal Extractive Reserves and 12 state Sustainable Development Reserves (FAS, 2017a). These PAs are managed by the Amazonas state government and collectively cover 10.9 million hectares of Amazonian forests (FAS 2017a). As of September 2017, this program had 9,601 enrolled rural households who have agreed to a voluntary commitment term to avoid primary forest clearance, enrol children in school, and to participate in workshops on climate change and ecosystem services.

The benefits provided by BF are divided into four different components (Table 2), comprising a direct monthly household payment of R$ 50.00 (US$ 15.50; R$ 1.00 = US$ 0.31, March 2017) (Bolsa Floresta Familiar component - BFF), and three other community-based payment components: the Bolsa Floresta Income component provides an annual transfer to each community of R$ 395.80 (US$ 126.40) per household per PA for investment in activities such as the extraction of non-timber forest products; the Bolsa Floresta Social component provides an annual transfer to each reserve of R$ 350.00 (US$ 112.00) per household per PA for investments in education, health, and transportation services; and the Bolsa Floresta Association component supports PA cooperatives with 10% of the BFF total per PA (Viana, 2008; Börner et al., 2013). It is calculated that the combined value of all BF components is R$ 1,360.00 (US$ 421.60) per household per year (FAS, 2017a).

Bolsa Floresta is a state-level public policy administered and implemented by Fundação Amazonas Sustentável (Sustainable Amazon Foundation - FAS), a private non-governmental organization developed in partnership with the Amazonas state government and financially supported by private and public program sources (Table 1; FAS 2017b).

The Bolsa Verde program is run by the Brazilian federal government and, like the Bolsa Floresta, also pays smallholders inside conservation areas if they agree not to clear primary forests. Rather than having several payment types, the BV pays a cash lump sum of R$ 100 (US$31.00) per month directly to each eligible household (MMA, 2013) (Table 1). Its aim is to incentivize environmental conservation practices, diversifying peoples' livelihoods while increasing income. Currently, there are more than 48,000 households benefiting from this program across Brazil (MMA, 2017) (Table 1).

Neither BF nor BV currently incorporate robust monitoring or enforcement practices that guarantee that their conditionality requirements are met. In terms of monitoring, both rely on national programs operated by the federal government that can detect deforestation and forest degradation through satellite imagery (Prodes, 2018; Deter, 2018). However, these methods are of limited use as they cannot reliably detect small-scale deforestation. Some participants of the Bolsa Floresta program actively contribute towards monitoring by personally informing of any deforestation, although there are no formal arrangements (Newton et al., 2012b). There is no strong enforcement strategy for either program, and program expulsion due to non-compliance is therefore highly unlikely in our study region.

Overall, these two programs have some differences in design and governance, but are broadly similar in objectives and approach (Table 1). Most importantly, they share similar conditions and challenges: whether their payments will ensure local livelihoods for their beneficiaries (Viana, 2011).

2.2 Study area

Data were collected across two contiguous sustainable development reserves in the municipality of Carauari, in the state of Amazonas, Brazil. The two reserves are bisected by the Juruá River, a large white-water tributary of the Solimões River (Fig. 1). The Reserva Extrativista Médio Juruá (Médio Juruá Extractive Reserve, hereafter ResEx Médio Juruá, Portuguese acronym) is federally managed and was decreed in 1997, whereas the Reserva de Desenvolvimento Sustentável Uacari (Uacari Sustainable Development Reserve, hereafter RDS Uacari, Portuguese acronym) is state managed and was decreed in 2005. These two adjacent reserves cover a combined area of 886,175 ha and are inhabited by ~4,200 residents, distributed among 60 forest communities spread along 380 km of the Juruá River floodplain (Governo do Estado do Amazonas, 2010; Newton at al., 2012b). Communities are located both in unflooded upland (terra firme) and in seasonally-flooded lowland (várzea) areas, closer to the main river channel, which are inundated between January and June every year (Hawes et al., 2012).

Post-columbian settlements in our study area resulted from government incentives to secure frontier rubber exploitation lands in the late 19th century, with the development of traditional agriculture. The creation of these legally occupied reserve types (ResEx and RDS) within the public domain resulted from post-rubber boom grassroots demands and conflicts between settlers and the government (Santos, 2015). This historical context has influenced present-day tenure rights and types of land domain, which are critical for the effective implementation of PES programs (Duchelle et al., 2014). In the case of our study reserves, which are under government jurisdiction (state or federal), communities are afforded usufruct rights to access and manage resources, according to the management plan of each reserve (Corbera et al. 2011). In cases of non-compliance with the reserve management plan, the government holds the prerogative of requesting the land back (MMA 2018). Individual households do not have legal tenure rights over individual plots of land, including *roçados*. Therefore, each household and community has the right to use a communal area, rather than hold land titles. In addition to these formal land rights, tenure also relates to informal definitions of land use access (Fortmann, 2000). For example, the allocation of *roçados* to be used by each household depends on informal agreements among community members. In general, *roçados* are inherited along kinship lines, and in cases when reallocations occur between households, this is discussed within the community.

Residents of the two study reserves are offered access to either one of two different PES programs (Bolsa Verde in the federally managed ResEx Médio Juruá; and Bolsa Floresta in the state managed RDS Uacari). Both reserve types have similar objectives (protect natural resources and traditional practices), with the difference that properties have to be regulated in the ResEx (MMA, 2018). Although these two reserves diverge in their governance structure, their residents share environments and similar economic and livelihood characteristics (Newton et al., 2012b). These overarching similarities allowed us to merge the two data samples (from ResEx Médio Juruá and RDS Uacari) in the same analyses, but are further tested in our models (see section 2.3).

2.3 Data collection and analysis

We conducted semi-structured interviews with the head of 158 households distributed across 32 communities within the two study reserves (RDS Uacari: 69 households in 23 communities; ResEx

Médio Juruá: 89 households in 9 communities), between March and May 2012. Interviews lasted approximately one-hour.

The unit of analysis for our study was an individual *roçado*. Each interview thus collected specific data about the history and productivity of individual *roçados*. We recorded data with respect to (i) number of manioc stems planted, and resulting farinha production volume, (ii) farinha production costs, (iii) the fallow history of *roçados*, and (iv) travel distance to the community. In most cases, interviews were conducted in situ at each *roçado* plot, rather than at the interviewee's house, so that the respondent could more easily recall accurate site-specific information. This approach can yield reliable quantitative data on agricultural practices, with owners of small-hold agricultural plots in the Amazon capable of accurately recalling information on crop production and fallow periods from previous years (Coomes et al., 2000; Mertz, 2002), since agriculture is often their main source of income-generation (Silva-Forsberg and Fearnside, 1997).

In total, we collected data from 223 terra firme *roçados* (in many cases there were more than one *roçado* per household), of which 170 were visited in person and 139 were included in the analyses. The remainder were excluded due to missing data (e.g. no response given) for certain variables, since our analysis required data from all predictor variables (see below). All *roçados* recorded in the surveys were located in red or red-yellow argisols, characterized by low fertility due to a lack of mineral nutrients and high levels of aluminium (EMBRAPA, 2006; Souza, 2010). We collected data only on *roçados* that had been converted from upland (terra firme) forest, rather than *roçados* created in lowland (várzea) areas, since households in terra firme areas engage significantly more heavily in manioc production and associated forest clearance (Newton et al., 2012b).

2.3.1. Farinha production volume

The volume of farinha produced in this system is a result of a combination of land and natural resources (S), capital (K) and labor (L). In traditional agricultural systems, land and natural resources and labor are usually the most important factors that determine production. Substitution of a metal axe by a chainsaw represents the transition from labor to capital by reducing the number of person-hours and increasing the efficiency of forest clearance for cultivation.

To test how the age of the forest cleared for manioc cultivation influenced subsequent farinha production, we recorded the following variables for each *roçado*: age of the forest stand cleared to form the *roçado* (age, in years); annual farinha production (production, in kg/ha); travel distance from the community to the *roçado* (distance, in km); number of consecutive years in which manioc had been planted in the same *roçado* without a fallow period (crop cycle, in years); number of days necessary for weeding (weeding, in days); number of working adults in the household (adults above 16 years old, in number/household); number of manioc stems planted in each *roçado* (stems, in stems/ha), and frequency of chainsaw use (chainsaw, in number of uses/year, (1) if the chainsaw was used once a year, and 0 otherwise; (2) if the chainsaw was used at least twice a year; (3) if the chainsaw was used at least three times a year, and 0 otherwise). Two of these variables are indicators of agricultural intensification: *age of the forest stand cleared to form the roçado* and *number of consecutive years in which manioc had been planted in the same roçado without a fallow period*. The former represents continuous reduction of the fallow; the latter represents the number of times the fallow was equal to zero. Repeating agricultural plots without fallow regrowth between cultivation cycles was recorded in 11% of the *roçado* samples in our dataset.

Farinha production was recorded as the number of sacks produced per *roçado* per year, and converted into kg, assuming that each sack contained 50 kg of farinha as widely standardised in the Juruá region and elsewhere in the Brazilian Amazon. The variable ‘stems’ is a powerful measure of *roçado* area since the density of manioc stems planted is constant (1 stem/m^2) and the number of stems predictably scales to *roçado* size, so that 10,000 stems corresponds to approximately one hectare (Newton et al., 2012a). Variable units in time (minutes), for the travel distances to *roçados* (by boat, canoe, or on foot) were standardized as in Newton et al. (2012c).

We had a high degree of confidence in the recorded age of secondary forests, as interviewees were reliably knowledgeable about the last time they had clear-felled any given plot for manioc cultivation. However, interviewees referred to old-growth forests only as "mata bruta", leaving some ambiguity between primary and mature secondary forests. Since the biomass of 50-100 year-old secondary forests can be considered equivalent to that in primary forests (Silva-Forsberg and Fernside, 1997; Mazoyer and Roudart, 1998; Guariguata and Osterag, 2001; Chazdon et al., 2007), we randomly imputed ages for the entire 'mata-bruta' forest category (hereafter, 'mature forests') ranging from 50 to 100 years since the last clear-felling event, repeated the model 1000 times, and used the average of the obtained (Bayesian) coefficients.

These variables were then included in a regression model to test the effect of fallow period (age), a proxy of land (S), on farinha production (production), while controlling for the number of manioc stems, and proxies of labor (L), and capital (K) (Fig. 2). Finally, in order to test the robustness of the previous fallow period as a determinant of farinha production, we ran another model using productivity (py) as the dependent variable, calculated as $py_i = p_i/stems$, while retaining all the explanatory (Right Hand Side, RHS) variables except for the number of manioc stems. We assumed that all harvested manioc was processed into farinha (Börner et al., 2013), and that no manioc was left unharvested. This assumption is likely to be accurate in the majority of cases, unless production was lost due to floods or crop-raiding (Abrahams et al., 2018), as reported in only two of our interviews. Further, we assumed that manioc was not imported or sold to or from other areas before manioc tubers were processed into farinha (no net import of manioc tubers). We also assumed that any differences in the efficiency of farinha processing did not affect the quantity of manioc harvested, and that farinha production is therefore a robust proxy of manioc production.

The model developed is as follow:

(1) $p\_i = ß\_0 + ß\_1\ age + ß\_2\ stems + ß\_3\ crop\ cycle + ß\_4\ weeding + ß\_5\ adults + ß\_5\ distance + ß\_6\ reserve + β\_chainsaw1 + β\_chainsaw2 + β\_chainsaw3$

Where:

p_i = farinha production (kg)

age = age of forest stand at the time of clearance for manioc cultivation (years)

stems = number of stems (unit)

Weeding – number of days required to remove weeds (days)

Adults – number of adults (above 16 years old) in the household (adults);

Distance – travel distance from the community to the *roçado* (km)

Reserve – qualitative variable (dummy), which identifies the reserve where manioc was cultivated

Chainsaw 1 – if the chainsaw was used once a year (1 if yes, 0 if not)

Chainsaw 2 – if the chainsaw was used at least twice a year (1 if yes, 0 if not)

Chainsaw 3 – if the chainsaw was used at least three times a year (1 if yes, 0 if not)

The reserve term is a dummy variable that identifies the reserve in which each *roçado* was developed (and consequently which of the two PES programs was implemented), with RDS Uacari = 1.

Based on the regression results, we then modelled potential increases in farinha production, according to variations in *roçado* area and age of forest stand at the time of clearance for manioc plantation. *Roçado* area for our sample ranged from 0.04 to 24.0 ha (mean = 0.76 ha ± 0.5; 7,626 stems) and each household typically harvested one *roçado* plot per year. Production revenue was calculated assuming a farinha price of R$ 1.11/kg (US$ 0.34/kg), the average price from February to May 2012 (ASPROC, 2012).

2.3.2. Farinha production costs

Farinha production cost was calculated in a different model from the above described. It considered the following variables: number of days required to clear forest stands of different ages, with and without chainsaw (labor) input; number of days required to remove weeds (weeding); number of adults (above 16 years old) in the household (adults); and number and type of implements required for production (tools). These four variables were calculated taking into account the daily work effort of one person at one hectare of *roçado*, projected for a year (annual costs). We assessed total farinha production costs for three forest stage categories: mature (MF; >50 years); old secondary forests (OSF; 11 - 50 years); and young secondary forests (YSF; 0 – 10 years) (Table 3).

Costs related to clear-cutting and weeding took into account local labor costs, for which observed transaction values were typically US$ 15.50 per day at the time of the study. All manioc was cultivated without external inputs such as fertilizers or herbicides. The price of agricultural tools, such as axes and hoes, was based on prices in the nearest market town (Carauari, Amazonas) at the time of the study. The wear-and-tear depreciation of each type of implement was included in the analysis, and was higher in high-biomass older forest plots than in younger forests. Chainsaw costs included all associated requirements such as gasoline, oil, chains (prices from local suppliers at the time of the study), and an skilled assistant (US$ 23.25 per day) but not the market value of a chainsaw since, in most cases, this tool was shared with other households within and even between neighbouring communities. Because not all households used a chainsaw in the clear-cutting process, the sum of chainsaw costs was weighted according to the proportion of chainsaw users per forest type (MF: 55%, OSF: 24%, YSF: 19%).

2.3.3. Farinha profits and PES programs

Profit from farinha production was calculated as total revenue minus average costs, according to the age of forest stand that had been cleared and the area of *roçado* planted, based on our regression coefficients. In cases where forest stands were younger than 50 years (i.e. secondary forests), we calculated the total annual income per household including the additional Bolsa Floresta or Bolsa Verde payments. We present the farinha profit results in US$ per hectare considering the collected data. However, the BF and the BV programs award their payments per both community (BF) and household (BF and BV), rather than per hectare. Thus, we have standardized all the results per household (including the community level payments, averaged over households) in order to be comparable.

Results comparing farinha profit and PES programs are presented based on modelled data (see section 2.3.1) in US$ per household per year. We calculated the total annual profit per household considering only the Família component of BF, and the total amount of BV, which represents the only direct household-level cash incentive from the program . In a second analysis, which we ran separately, we considered the combined payments from BF (combining direct and indirect payments), in order to evaluate what would be the likely direct benefits of having the total amount paid by FAS to each household if the community-level non-cash payments were converted to per-household direct cash payments. Although local participants allocated time and effort into other supplementary income activities other than farinha production, such as fishing, and timber and non-timber forest resource extraction, these were not considered as potential opportunity costs since they were independent of land availability and therefore not directly influenced by the restrictions imposed by the PES programs.

3. RESULTS

3.1. Farinha production volume

We found that forest age at clearance for manioc cultivation in *roçados* (i.e. fallow period) was the main determinant of farinha production volume. For each additional year that the forest was left to recover before clearance, there was a modelled increase in farinha production of 22.83 kg per household per year (eq. 1). This corroborates studies that show shorter fallow periods leading to lower production of farinha (Mertz, 2002) or other crops produced in swidden agriculture (slash-and-burn) systems in tropical forest settings (Boserup, 1976; Mazoyer and Roudart, 1998). Levels of capital and labor investments were similar among households, which suggested that any differences in farinha processing efficiency — which in any case was consistently derived from a standard processing routine — were negligible, and did not significantly influence production (Table 4).

3.2. Farinha production costs

The annual cost of farinha production was higher in *roçados* cleared from mature forests (US$ 373.50/household) than from those cleared from old (US$ 268.89/household) or young secondary forests (US$ 192.09/household) (Fig. 3, Table 3). The main cost associated with clearing older forest stands was the number of days required for clear cutting the much higher tree basal areas; followed by the amount spent on tools, which was also highest for clearing mature forests. In contrast, weeding cost twice as much in areas cleared from young or old secondary forests than in areas cleared from mature forests (Table 3), presumably because of the well-established seed and seedling banks of undesirable pioneer ruderal plants in second growth.

3.3. Farinha profit and PES programs

Although farinha production costs were higher in *roçados* cleared from older forests, this difference in costs did not outweigh the higher productivity of *roçados* created on older forestland, and so revenue and net profit earned from these areas was still higher than on plots cleared from younger second-growth. According to the modelled data, farinha production in *roçados* cleared from 5 year-old secondary forests provided producers with an annual profit of US$ 622.92 per 0.76 ha *roçado* per household (US$ 819.63 per ha per household), compared to US$ 1,184.14 per 0.76 ha *roçado* per household (US$ 1558.07 per ha per household) if a plot within a 100 year-old forest had been felled (Fig. 4).

When the Bolsa Verde payments were added to revenues from farinha production, the net profit from cleared secondary forest stand was similar to that obtained from cleared mature forest stands. However, when only the *Familiar* component of BF was considered, the net annual profit was reduced by ~20%, but was still sufficient to match potential profits from clearing forest stands up to 80 years old. When all combined payments from BF were considered, results are similar to the BV program (Fig. 4). For example, clear-cutting a 30 year-old forest stand yielded net profits equivalent to those from cleared 100 year-old forest stands (US$ 3,819). Even clear-cutting five year-old stands yielded net profits equivalent to cleared 75 year-old forest stands (US$ 3,350), assuming a linear increase in farinha production in even older forests. This is a conservative approach, as maximum yields may be reached earlier than from stands older than 75 years, further emphasizing the benefits from the PES programs.

4. Discussion

Our results showed a positive relationship between the age of forest stands at the time of clearance for manioc cultivation and farinha production volume in the resulting *roçados*. This indicates a negative impact of a shorter fallow period on farinha production. Although the costs incurred in cultivating *roçados* cleared from mature forest were higher, revenue and net profits from these areas were greater than in *roçados* cleared from secondary forest plots of any age. Although the BF and BV PES programs may restrict farinha production through fallow reduction, our analysis indicates that direct payments by the BV and the overall payments from BF may still be sufficient to overcome production losses under current conditions of village size and human population density.

Any immigration into the reserves may contribute even more to agricultural intensification and the reduction of fallow periods. However, the BF program discourages migration into the reserve by restricting payments to households settled in the region for at least two years (Wittemyer et al., 2008). No such mechanism was found for the Bolsa Verde. Further, the population of the region was largely stable over the last 20 years (~1.6% increase), being highly concentrated in urban rather than rural areas (IBGE 2010).

4.1. Farinha production volume

One of the likely reasons for the lower production in *roçados* with a reduced fallow period is the condition of Amazonian forest soils, which are typically acidic and leached due to low nutrient retention capacity (Cahn et al., 1993). The nutrient cycle in this system depends mainly on the stock in above- and below-ground phytomass, which is released for plant uptake during the burning process (Mazoyer and Roudart, 1998; Juo and Manu, 1996; Palm et al., 1996; Metzger, 2003). Younger secondary forests have lower vegetative biomass, resulting in lower nutrient availability for plant uptake from the mineralization process (Silva-Forsberg and Fearnside, 1997). We did not find any effect of the number of successive manioc plantings without any intervening fallow period on farinha production. However, soil fertility is reported to take longer to recover after several cutting cycles without intervening fallow periods (Styget et al., 2007), which may also contribute to reduced production over the long-term (Muchagata and Brown, 2000; Styger et al., 2007; Jakovac et al., 2016).

4.2. Farinha production costs

The choice of which age of forest stand to clear in swidden-fallow agriculture is a trade-off between the costs of clear-cutting and weeding, and the benefits of productivity, while considering the age of available forest in the vicinity, as well as labor availability and personal preferences (Boserup, 1976; Scatena et al., 1996). Recently established and smaller communities tend to have more primary forest within their effective travel radius, and are therefore typically more likely to clear primary forest than more-established, larger communities, which are typically surrounded by secondary growth forest (Newton et al., 2012b). Some individuals may have a personal preference for selecting secondary forest stands for conversion to avoid high labor inputs in clear-cutting mature forest. Others, on the other hand, may prefer primary forests to avoid the increased amount of time spent weeding in *roçados* cleared from secondary forests. Although it is hard work, the one-off investment of clearing primary forest may represent less overall labor input than required by regular weeding (Uhl and Murphy, 1981). Indeed, weeding has been identified by rural Amazonians to be their most laborious activity (Jakovac et al., 2016), as clearly illustrated by the response of one of our interviewees: *"The good thing about using secondary forest is that it is really easy to clear. The bad thing is that you are going to spend most of the year removing weeds, time which could have been used for many other activities if you had cleared primary forest instead"* (Resident of São Raimundo community, RDS Uacari).

4.3. Farinha profit and PES programs

The Bolsa Verde income was higher than the producers' forgone profit from cultivating cleared primary forests (Fig. 4), supporting results found in other Amazonian reserves (Börner, 2013). The same was observed if the combined payments from the Bolsa Floresta program were considered. *The Familiar* component of BF alone, however, may confer trade-offs on local households. Direct payments made at the household level can quickly and easily be used to acquire new assets, and are usually preferred by local communities (Viana and Salviati, 2018). Although rural Amazonians largely are self-sufficient in fish and farinha, they regularly need cash to buy food and other basic goods in market towns or, in the case of our study region, in small and recently implemented supply stores located in the communities.

Studies in other Amazonian reserves show that 88% of local participants buy basic supplies (Börner et al., 2013), and cash typically remains the most common form of payment by rural people for items including food, medicine, and educational materials (Grieg-Gran et al., 2005). Purchasing these basic supplies is supported only by the direct cash payments (*Familiar* component of BF and BV) and not by any of the other indirect BF components. Therefore, participants' decisions may therefore be based primarily on these direct benefits (Gebara, 2013; Lima, 2014; Sills et al., 2014). Thus, if only the *Familiar* component of BF is considered, there may be a more difficult decision for local participants between continued participation in the PES program or withdrawal from it and a return to optional clear-cutting primary forests.

In this scenario, and depending on the availability of forest stands of different ages, it may become more financially attractive to clear-cut primary than secondary forest (Fig. 4). This is particularly true considering that robust monitoring and enforcement strategies are not operational in either the BF or BV programs. Furthermore, although a recent survey in five of the BF protected areas detected that households perceive the positive impacts of indirect benefits (FAS 2017b), some still report that they need technical assistance to use some of the equipment provided (Lima, 2014). This may further diminish the relative importance of the Income, Social, and Association components of BF to individual households. Such trade-offs were not observed in the BV program, as the payments were higher and not divided into indirect components.

On the other hand, indirect payments that contribute to improvements to social infrastructure may prove a more important incentive for PES participation and may act as an agent for behavioral changes (Gebara, 2013; Lima, 2014; Grillos, 2017). Whereas cash benefits only compensate for current production losses (Sills et al., 2014), indirect payments can provide more permanent, self-sustaining benefits (Gebara, 2013), help build local management capacity, and strengthen local leadership. The BF program has, through its indirect payments, somewhat replaced the role of government in supplying basic services (Börner et al., 2013), and may have other long-term benefits. Perceptions on the benefits of indirect components from participants of the Bolsa Floresta have increased between 2011 and 2015, corroborating its long-term importance (Viana and Salviati 2018).

The BV program, in contrast, has no such indirect payments to the households. Although the BF and the BV programs have similar characteristics regarding their conditions and requirements, they may have different impacts on local communities. On the one hand, the BF direct cash payment may not compensate for opportunity costs as fully as the BV payments in the short term, and could therefore negatively affect local livelihoods. On the other hand, steps to build capacity and strengthen long-term leadership through the indirect payments from BF may not be observed under BV.

Any decision to either substitute farinha production practices (e.g. reduce farinha production due to shortened fallow) or potentially withdraw from the program may depend on several factors and small differences in PES incentives may determine if, and how, participants can effectively capture value from their activities (Grieg-Gran et al., 2005). Important considerations include opportunity costs, influence on neighbours, the total revenue received, tenure insecurity, as well as overall perceptions of the program itself. For instance, PES participants often fear the possibility of programs limiting their current activities (Cromberg et al., 2014).

Opportunity costs are a major factor in driving decision-making by agricultural producers, and in many cases payments do not fully compensate for losses from foregone activities (Grieg-Gran et al., 2005). In some parts of Brazil the absolute value of opportunity costs are relatively high – e.g. in areas with high soybean production along the agricultural frontier – but are generally low in more remote regions of Amazonia, particularly in areas where the main livelihood activities are extensive cattle ranching or slash-and-burn agriculture (Börner and Wunder, 2008; Börner et al., 2010). Despite these relatively low opportunity costs, PES programs are not intended to become the only income source for participating households; it is therefore important that their value is determined relative to existing livelihood strategies amongst participants. Determining differential payments according to each household's livelihood activities would be a substantial administrative undertaking but could theoretically contribute to reduced financial deficits for those households most intensely disadvantaged by PES requirements (Börner et al., 2013; Newton et al., 2012b).

Increased diversification of livelihood activities is a stated objective of BF, with the hope that alternatives will eventually become more attractive than traditional agricultural practices (Börner et al., 2013). The central idea of the program is that provision of indirect payments will contribute towards a long-term shift from agriculture to the extraction of NTFPs, such as *Euterpe precatoria* (açaí) palm fruits and oil seeds, or even services (e.g., tourism), to reduce the pressure on primary forest conversion. The longer that PES programs are maintained, the more likely people are to explore extractive activities as an alternative to agriculture, though uncertainties over the long-term future of PES programs and on whether alternative activities can always be maintained given market elasticity and the lower competitiveness of extractive activities compared to manioc products such as farinha (Homma, 1995), may encourage people to continue with the relative guarantee of a reliable income and subsistence food security from manioc cultivation (Pereira, 2010).

Changes in livelihood activities and the increased amount of cash obtained through direct payments from BF *Familiar* and BV could also have consequences for food security and dietary norms among the communities. Piperata et al. (2011) observed behavioral changes and difference in food intake in communities that receive the Bolsa Família, a government allowance that increases household access to cash. In many cases, manioc was still the main source of carbohydrates, but was increasingly complemented by purchased substitutes. Further, if livelihood activities change up to a point where farinha production is reduced, cash may not offset the total amount of locally produced carbohydrates consumed (Piperata et al. 2011).

Continued agriculture production may be incentivized by increased successive rotation cycle, which may contribute to reduced production, even if fallow periods allow recovery to reach the age of mature old-growth forest (Mazoyer and Roudart, 1998). Assuming that no new primary forest areas will be cleared for cultivation for as long as the current PES programs run, and that the same *roçados* will be repeatedly used, production levels may be expected to decrease across all *roçados*. Two subsequent outcomes may be expected in terms of regional declines in farinha production: (i) prices may rise, thereby increasing the attractiveness to producers once more (Almeida, 1996); or (ii) net profits for producers will fall, increasing the attractiveness of the PES program.

Another possible consequence of prohibited primary forest clearance is that smallholders may travel farther to reach secondary forest areas, once in possession of new machinery and infrastructure (e.g. motorized boats and ox-wagons to carry materials). In general, agricultural plots are allocated to areas closer to households. In riverine communities close to the study area, it was reported that most *roçados* were located within 2 km from each household, and that farther areas were usually the ones with longer fallows (Jakovac et al., 2017). When cultivated, however, more distant areas had lower productivity and a higher workload (Sirén, 2007). Still, an extended travel distance is already apparent in other regions (Jakovac et al., 2017), as well as in the largest community in our study reserves, which is surrounded by larger areas of successional mosaics (e.g. community of Roque, ResEx Médio Juruá). Despite this development, it is unlikely that most communities will benefit from a comparable level of infrastructure in the near future due to considerable accessibility issues across the floodplain landscape, which usually necessitates a boat to reach *roçados*. In these cases, the costs associated with clearing forests farther from the community remain prohibitively high and these areas are typically avoided (Coomes et al., 2000).

Accessibility can, therefore, be one of the drivers of increased agricultural production and reduced fallow periods in these areas (Jakovac et al., 2017). As a result, we suggest that these PES programs are more likely to encourage people to travel less and to invest instead in alternative means of increasing farinha production.

Agricultural mechanization and the use of fertilizers are possible alternatives to increase production, often reducing costs and human labor. The Brazilian government research agency (EMBRAPA: Empresa Brasileira de Pesquisa Agropecuária) recommends 467 kg of fertilizer per ha for intensive manioc cropping in the Amazon but it is estimated that PES programs would only provide sufficient funds for 333 kg per ha to compensate for the nutrient input that fallow periods provide otherwise (Börner et al., 2013). Further, nutrient input from fertilizers heavily depends on soil texture, which in the Amazon is typically unfavourable to conventional means of fertilizer application. In this scenario, little or no money from PES would be left for social or personal needs. Finally, the potential for increased mechanization and fertilizer use raises concerns over environmental impacts that do not currently occur in the region, such as eutrophication, runoff, and cascading impacts on biodiversity (Schiesari et al., 2013), as well as human health (Damien et al., 2017).

Tenure conditions in our study area are based both on (i) formal ownership of the land by the government, and ii) informal allocations of *roçado* areas to each household). Tenure insecurity has been reported as one of the main barriers for PES implementation (Duchelle et al., 2014). In our study area, tenure arrangements are relatively stable, but individual households do not have autonomous control of demarcated plots. However, if land becomes scarce, we anticipate disputes over high-quality *roçado* areas.

As intended, payments from the overall Bolsa Floresta and Bolsa Verde programs were generally more financially attractive than the continued clearance of primary forests for farinha production.

However, the context in which these programs were implemented may have additional consequences. Our findings show evidence that PES programs can contribute to a wider trend in agricultural intensification (Jakovac et al. 2017), even in the absence of other factors such as population increase or concerns over either Forest Code enforcement or land tenure. Further, the design structure of the two programs (e.g. BF having both direct and indirect payments), as well as the different governance types of the two reserves, may lead to divergent long-term consequences for communities in either reserve. Although direct payments from the Família component of BF does not compensate for losses, indirect payments may contribute to long-term behavioral changes, which may not be observed in the BV program. However, in both cases, any lack of insurance of long-term financial security for rural people may result in a shift back to traditional behaviors, and other unintended consequences such as fertilizer application to compensate for reduced yields (Jakovac et al., 2016, van Vliet et al., 2012).

5. Conclusions

Whether or not a PES program provides a 'win-win' solution for conservation and development will depend on its design with respect to local context. PES programs aim to induce behavioral changes among their participants, and the success of the programs will depend on the extent to which they can maintain or improve local livelihoods. In our study, farinha production, the staple food crop in remote Amazonian communities, decreased with reduced fallow periods. Considering that PES programs inhibiting clear-cutting of old-growth primary forest can exacerbate reduced fallow periods, local livelihoods could be compromised. The Bolsa Verde program appeared to effectively compensate for production losses, as did the Bolsa Floresta program when we considered all of its components collectively. However, when we considered only the direct payments made at the household level (i.e. only the Família component of BF), then BF may not be as effective at influencing livelihood decisions of PES participants. Livelihoods may nevertheless be improved by the BF, considering the indirect payments from other BF components, which aimed to encourage a switch in the production process from agriculture to other more sustainable resource management and extractive activities (that do not depend on clear cutting mature forests). The BV program, on the other hand, lacks those additional benefits resulting from indirect payments, and the success of this program therefore depends on the perceived benefits of direct payments. In addition, future studies could assess how the lack of monitoring and enforcement may influence program effectiveness. PES programs in the Brazilian Amazon should consider the complexities and idiosyncrasies of the socio-ecological system in which they are implemented, including short and long term benefits that effectively compensate local communities for current economic losses, while also contributing to local empowerment and improved local livelihoods.

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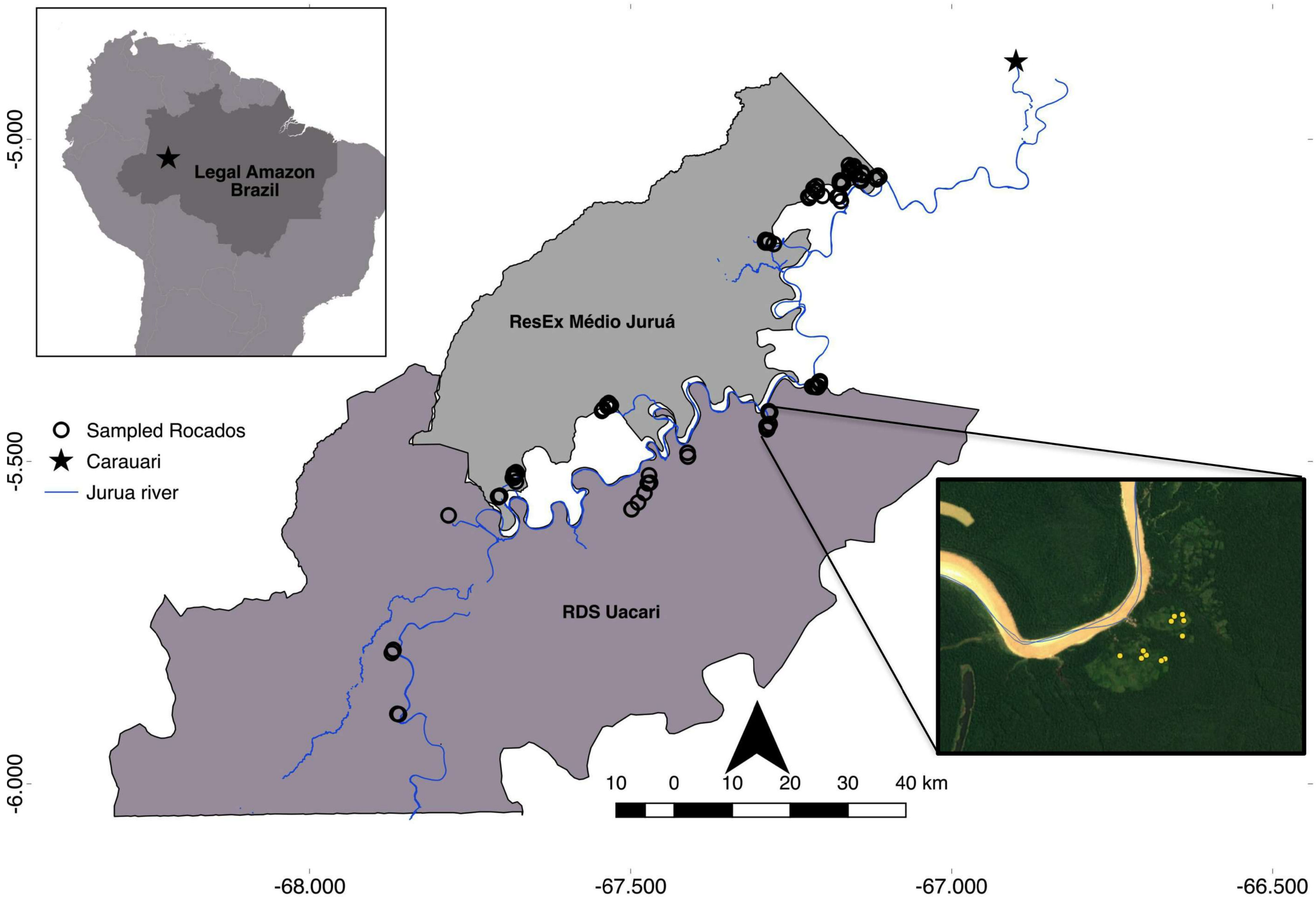
FIGURE LEGENDS

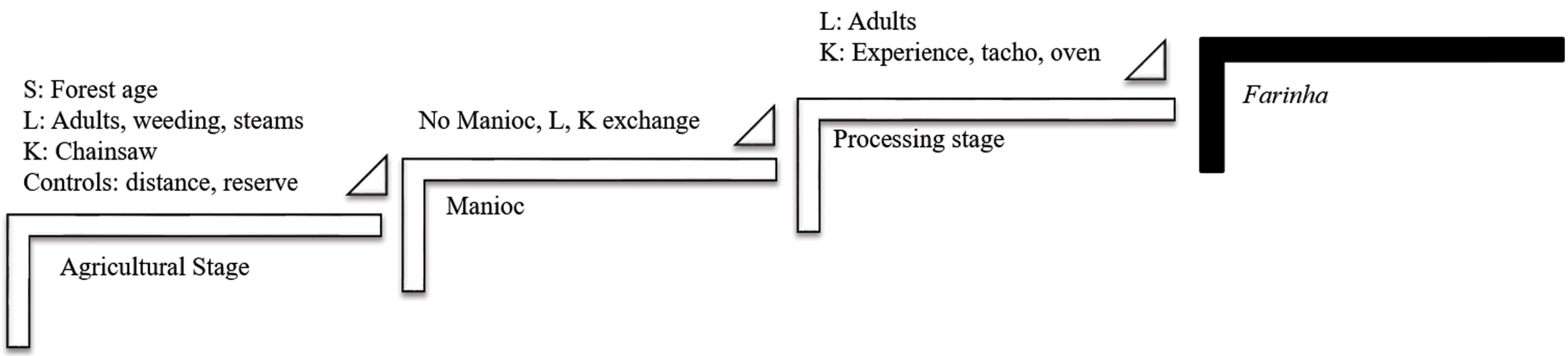
Figure 1. Location of surveyed *roçado* agricultural plots in the RDS Uacari and ResEx Médio Juruá, municipality of Carauari, where the Bolsa Floresta and Bolsa Verde PES programs were implemented, respectively. In the inset, yellow dots show an example of the spatial distribution of *roçados* around a rural community.

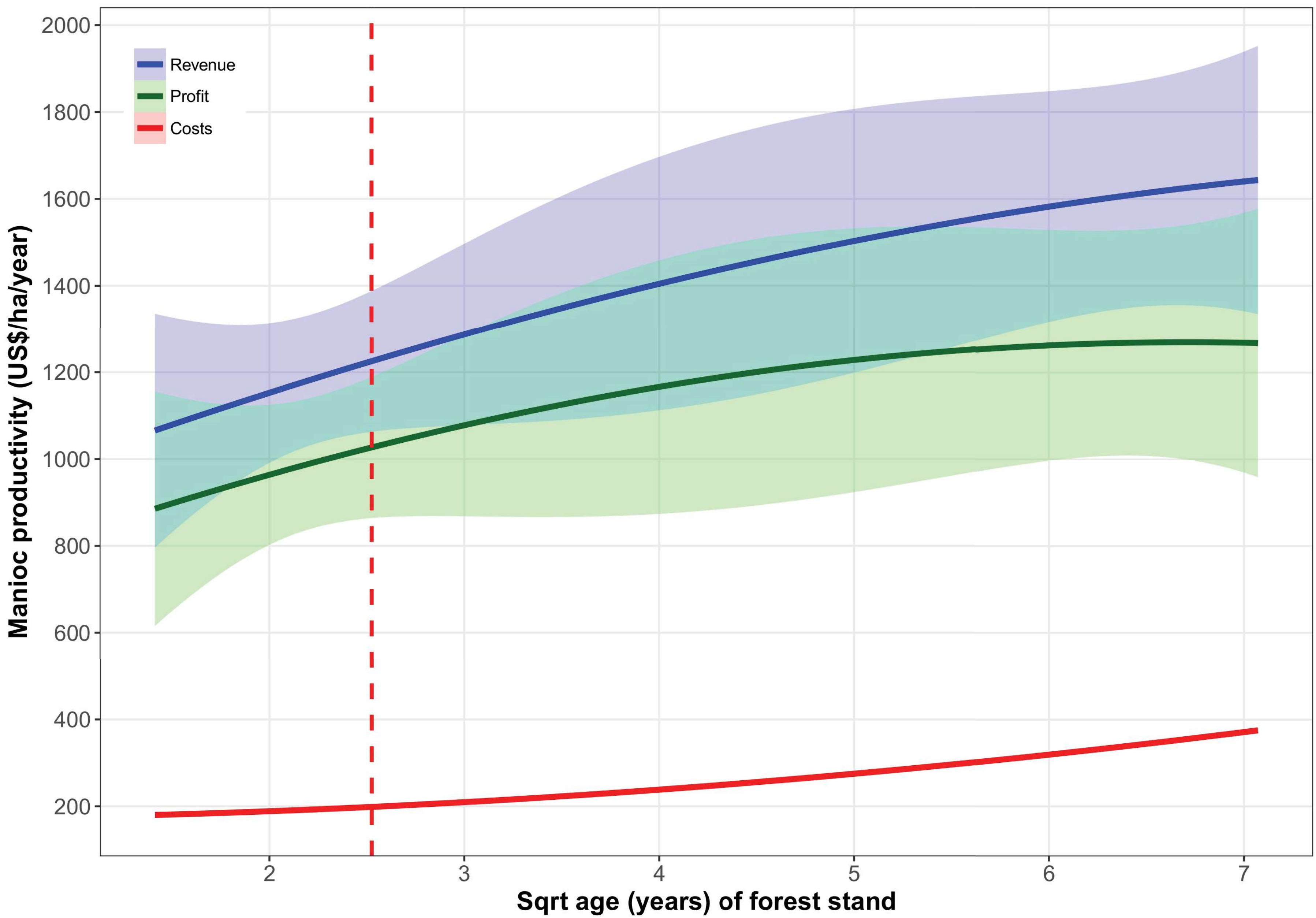
Figure 2. Scheme detailing the process for modelling farinha production, including variables used to represent land (S), capital (K) and labor (L).

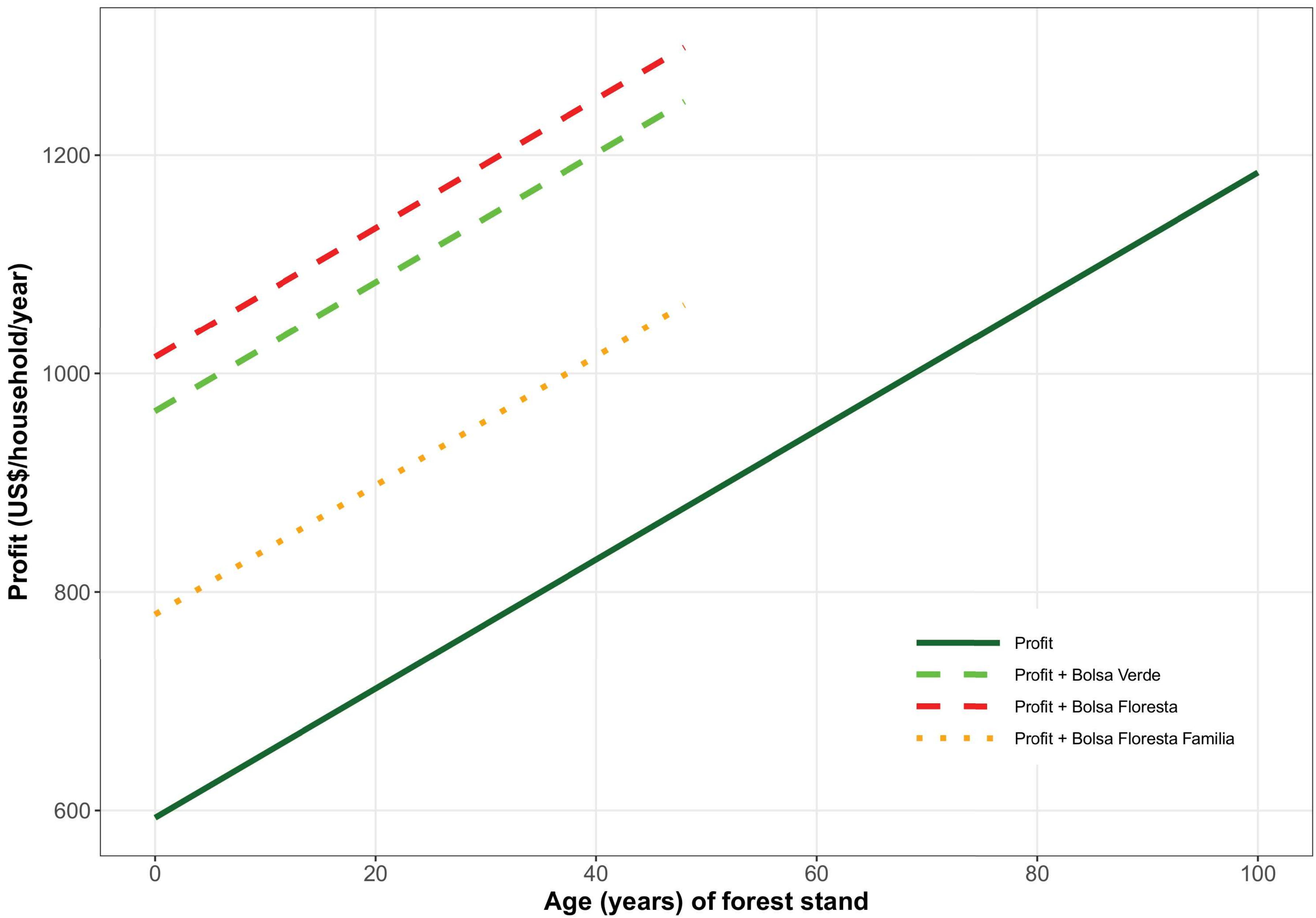
Figure 3: Revenue from farinha production, planting costs and total profit obtained by each household per year, according to the age of forest plots that had been clear-cut prior to manioc cultivation. Shaded regions represent 95% confidence intervals; dashed vertical line represents the mean age of secondary forests at conversion to *roçados*.

Figure 4: Profit from farinha production according to the age of forest plots when cleared for manioc cultivation compared to total profit when including payments from the two PES programs (Bolsa Verde and Bolsa Floresta), and from the *Familiar* component of Bolsa Floresta in isolation.


Legal Amazon
Brazil
ResEx Médio Juruá
RDS Uacari
Sampled Rocados
Carauari
Jurua river
10 0 10 20 30 40 km
-5.000
-5.500
-6.000
-68.000
-67.500
-67.000
-66.500


S: Forest age
L: Adults, weeding, steams
K: Chainsaw
Controls: distance, reserve
Agricultural Stage
No Manioc, L, K exchange
Manioc
L: Adults
K: Experience, tacho, oven
Processing stage
Farinha


Revenue
Profit
Costs
Manioc productivity (US$/ha/year)
2000
1800
1600
1400
1200
1000
800
600
400
200
2
3
4
5
6
7
Sqrt age (years) of forest stand


Profit (US$/household/year)
1200
1000
800
600
0
20
40
60
80
100
Age (years) of forest stand
Profit
Profit + Bolsa Verde
Profit + Bolsa Floresta
Profit + Bolsa Floresta Familia

TABLES

Table 1. Characteristics of the two PES programs and focal protected areas surveyed in this study in western Brazilian Amazonia (FAS 2017a; MMA 2013).

	Bolsa Floresta	Bolsa Verde
Administration	Private- partnership -Fundação Amazonas Sustentável (FAS)	Brazilian Federal Government Ministry of Environment (MMA)
Program established	2007*	2011
Program reach	9,601 households in 581 communities, in 16 protected areas (totalling 10.9 million ha) across the Brazilian state of Amazonas.	48,000 households in 877 federal rural settlements, in 68 federal conservation units (totalling 46 million ha) in 23 states across Brazil.
Eligibility	Non-opening of new cultivation areas within native primary forest, participation in workshops, training in climate change and environmental services, enrolment of children in schools, adherence to the reserve management plan, be living in the reserve for at least two years.	Residence in rural area, income of less than US$ 21.00 per capita, registration in other social programs, adherence to other social programs` rules and the reserve management plan.
PES value (US$)	US$ 186.00 direct payments per household annually + indirect benefits to community or reserve. Combined total = approx. US$ 421.60 per household per year	US$ 372.00 direct payments per household per year
Focal reserve in this study	Reserva de Desenvolvimento Sustentável Uacari (RDS Uacari)	Reserva Extrativista Médio Juruá (ResEx Médio Juruá)
Management	Amazonas State Governement - Secretaria do Estado do Meio Ambiente e Desenvolvimento Sustentável (SDS)	Brazilian Federal Government - Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio)
Year of decree	2005	1997
Reserve area (ha)	632,949	253,227

* Established and initially implemented by the State of Amazonas government.

Table 2. Description of the four *Bolsa Floresta* components (modified from FAS 2017).

Bolsa Floresta component	Benefit accrues to	Type of Payment	Value (US$/household/year)	Intended objective of the component
Bolsa Floresta Familia	Female head of family	Direct	186.00	Support education, and buy food
Bolsa Floresta Income	Community	Indirect	126.40	Improve infrastructure for sustainable livelihood activities
Bolsa Floresta Social	Reserve	Indirect	112.00	Improve education, health, and transportation services
Bolsa Floresta Association	Reserve cooperatives	Indirect	10% of total BFF for that reserve	Strengthen cooperatives
Total	Reserve, community and households	Both	421.60 (overall payment, including direct and indirect)	-

Table 3. Manioc production costs in mature forests, old secondary forests and young secondary forests in the municipality of Carauari, Amazonas, Brazil.

Variable	Details	Quantity	Value per Unit (US$)	Total Value (US$/year)
a) Mature Forests				
Clear Cut (day)		28.84	15.95	201.19*
Hoe (unit)		0.76	18.6	3.72*
Axe (unit)		0.76	25.11	5.02*
Chainsaw	Clear Cut (day-chainsaw)	4.95	15.50	76.80
	Chainsaw (unit)	10.94	6.79	5.16
	Gas (chainsaw) (litres)	3.39	1.08	11.87
	Oil 2T (litres/day)	0.2	3.72	0.84
	Oil (litres/day)	2.62	3.41	8.9
	Chains (unit)	1.08	12.4	13.47
	Assistant (n)	4.95	23.25	5.31
Total Chainsaw				127.77*
Weeding (day)		2.30	15.50	35.78*
MF Total				**373.50**
b) Old Secondary Forests				
Clear Cut (day)		14.50	15.95	170.86*
Hoe (unit)		0.76	9.02	1.62*
Axe (unit)		0.76	25.11	2.51*
Chainsaw	Clear Cut (day-chainsaw)	1.67	15.5	25.91
	Chainsaw (unit)	0.76	5.2328	3.97
	Gas (chainsaw) (litres)	5.87	1.085	6.37
	Oil 2T (litres/day)	0.14	3.72	0.54
	Oil (litres/day)	1.18	3.41	6.25
	Chains (unit)	0.75	12.40	9.32
	Assistant (n)	1.67	23.25	38.87
Total Chainsaw				21.90*
Weeding (day)		4.64	15.50	71.99*
OSF Total				**268.89**
c) Young Secondary Forests				
Clear Cut (day)		8.16	15.95	102.50*
Hoe (unit)		0.31	9.05	0.36*
Axe (unit)		0.76	25.11	2.00*
Chainsaw	Clear Cut (day-chainsaw)	0.76	15.50	11.78
	Chainsaw (unit)	0.76	4.29	3.26
	Gas (chainsaw) (litres)	1.59	1.08	1.73
	Oil 2T (litres/day)	0.06	3.72	0.22
	Oil (litres/day)	1.14	3.41	3.88
	Chains (unit)	0	12.40	0
	Assistant (n)	0.76	23.25	17.67
Total Chainsaw				7.32*
Weeding (day)		2.16	15.50	79.88*
YSF Total				**192.09**

* = total values used in calculation

Table 4. Farinha production volume model output, showing the coefficients of each variable, standard errors and P values. In addition to *Number of Stems,* only the variable describing the *Age* of roçados significantly influences farinha production ($p<0.05$).

Variables	Coefficient	Std. Error	P>-t-
Age	22.83	10.40	0.03
Stems	0.28	0.023	0.00
Weeding	8.06	114.21	0.94
Adults	-126.58	104.72	0.22
Distance	19.69	27.01	0.69
Reserve	-13.12	423.15	0.97
Chainsaw 1	112.25	427.65	0.79
Chainsaw 2	-100.56	630.60	0.87
Chainsaw 3	383.60	492.05	0.43
Constant	522.39	567.78	0.36
Number of Obs.	**F**	**Prob. F**	**R^2**
139	19.10	0.00	0.57