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Land-use Change Modeling in a Brazilian Indigenous Reserve: Construction of a Reference Scenario for the Suruí REDD Project

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Abstract Interactions of indigenous peoples with the surrounding non-indigenous society are often the main sources of social and environmental changes in indigenous lands. In the case of the Suruí in Brazilian Amazonia's "arc of deforestation," these influences are leading to deforestation and logging that threaten both the forest and the sustainability of the group's productive systems. The Suruí tribal leadership has initiated a proposal for an economic alternative based on Reducing Emissions from Deforestation and Degradation (REDD). This has become a key case in global discussions on indigenous participation in REDD. The realism of the baseline scenario that serves as a reference for determining the amount of deforestation and emissions avoided by the proposed project is critical to assuring the reality of the carbon benefits claimed. Here we examine the SIMSURUI model, its input parameters and the implications of the Suruí Forest Carbon Project for indigenous participation in climate mitigation efforts.

Keywords Amazon · Deforestation · Baseline · REDD · Carbon · Global warming · Climate change · Tropical forest · Rainforest

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Introduction

Potential of the REDD Mechanism in Amazonian Protected Areas

In the Brazilian Amazon, the protected areas that are most susceptible to deforestation are generally those that are currently surrounded by cleared areas and are located in the Arc of deforestation. These protected areas have substantial potential for REDD (Reducing Emissions from Deforestation and Degradation). The purpose of the REDD mechanism is to finance conservation through carbon payments based on a defined future time period. REDD is usually conceived as paying for the greenhouse gases that would have been emitted with no REDD implantation based on a land-use and land-cover change (LULCC) baseline (flow method). An alternative is to pay for carbon storage (stock method), this method being appropriate in forested areas that store a considerable amount of carbon but are distant from deforestation threats (Cattaneo 2010; Fearnside 2012a, b). Forest sites that have large carbon stocks and are at risk of deforestation (because of external or internal causes), as is the case for the 24 indigenous lands in Rondônia in the western portion of the Legal Amazon, represent good candidates for REDD projects based on the flow method.

In addition to the establishment of a LULCC baseline, proponents such as non-governmental organizations (NGOs), regions or states (depending on the scale of implementation of the mechanism), have to deal with other thorny methodological points in order to implant REDD and insure a future climatic benefit. These include the "leakage" that corresponds to deforestation escaping as a result of project implementation, including both "in-to-out" and "out-to-out" leakage and "permanence" of climate benefits that insures that mitigation will be effective over time (Fearnside 2009; Yanai *et al.* 2012).

The Case of the Sete de Setembro Indigenous Land: The Suruí REDD + Pilot Project

The Sete de Setembro Indigenous Land (SSIL) [*Terra Indígena Sete de Setembro*], which is the focus of the present study, is the first indigenous site in Brazil to develop a REDD project. The 250,000-ha pilot site is located in a consolidated portion of the "arc of deforestation" (the crescent-shaped strip along the southern and eastern edges of Amazon forest where forest clearing has been concentrated). The SSIL has experienced recent deforestation inside its limits that could counterbalance the retention effect exercised since its official demarcation in 1983, when Brazil's military dictatorship (1964–1985) promoted the occupation of Rondônia. The Suruí indigenous tribe was officially contacted in 1969, but they had previously migrated from Cuiabá to Rondônia to escape persecution (Mindlin 2003). In 1974, 5 years after contact, half of the group died, mostly from influenza and measles (Greenbaum 1989). Although the territory was initially demarcated in 1976, successive invasions by colonists continued to occur, and the invaders refused to leave the land (Mindlin 2008). The successive interventions of public entities such as FUNAI (National Indian Foundation), INCRA (National Institute of Colonization and Agrarian Reform) and the Rondônia state government delayed ratification of the demarcation decree until 1983. This delay was part of a broader pattern during this period, where policies were almost entirely concentrated on economics and the stimulation of occupation (Pedlowski *et al.* 2005).

The development dynamics of the municipal seat of Cacoal, located 40 km from the SSIL, motivated many Suruí to leave the territory to live in the town. After 40 years of contact, although many Suruí are integrated into the local society (which is mainly composed of the descendants of Southeast Brazilian colonists), they still suffer severe discrimination based on their origin. Suruí are seen as privileged people because of their rights guaranteed by the Brazilian constitution, which recognizes the right of indigenous populations to permanent possession and exclusive usufruct of their land (Mindlin 2003). In the territory itself, logging activity has contributed to shaping a new distribution of villages. Suruí families moved to strategic points near the edges of the territory and created new villages as a way of preventing the theft of timber and to protect their natural resources. In 1979, 700 Suruí were living in six villages, whereas in 2009 there were 1231 Suruí in 26 villages (Metareilá 2010).

The Suruí point to poor attention of the government regarding indigenous people and their needs, particularly health and inclusion in the local market, as leading to a situation where FUNAI agents encouraged indigenous leaders to sell timber to loggers illegally (Metareilá 2010). Income from the sales was used to pay for the new customs of the indigenous people, such as a new diet of manufactured products like sugar, in addition to use of health services. In 1992, the Ecumenical Center of Documentation and Information (CEDI) calculated that almost US$2 million worth of timber had been removed from the SSIL (Mindlin 2003). Forty years of logging have impoverished the stocks of commercial timber species in the indigenous land and have led to progressive reduction of revenues from this activity. As an adaptive process in response to decreasing logging capacity, part of the Suruí population has converted forest areas to cattle pastures and coffee plantations in order to compensate for economic losses (Metareilá 2010).

Recent Modification of Suruí Land-Use Patterns: Forest Degradation and Deforestation

Coffee cultivation and cattle ranching are the main economic activities in the Cacoal region (Brazil, IBGE 2011). Historically, Cacoal (the largest town near the SSIL) has been one of the most important coffee production areas in the state. Livestock has increasingly predominated over coffee growing for several reasons. One is the shrinking labor force in the region, which affects coffee production more than cattle. Another is the stimulation of cattle ranching as a result of the strategic geographical position of Cacoal (located on the BR-364 Highway), coupled with financial incentives to attract enterprises such as tanneries, dairies and slaughter houses (Kemper 2006). The Suruí were originally hunters, fishers, and subsistence cultivators; they have now learned to adapt to the commercial norms of the majority society. They began to practice coffee cultivation in the 1980s when they legally obtained coffee plantations from the colonists who had invaded the southern part of the territory. Today, coffee is an important source of revenue in the Suruí economy (Metareilá 2010). Coffee is a perennial crop that follows an initial 3 years under annual crops such as maize and beans. Cattle ranching is also important, even though only a few families own pasture. Since 2000 the Suruí have been reinvesting revenues from illegal logging in their own productive systems (cattle ranching and coffee production). As an aggravating factor, almost no forests remain in the properties that surround the reserve; the traditional low-cost implementation of pastures motivates ranchers and farmers to exert external pressure to establish pastures and agricultural plantations in the reserve. As a result of interdependence, some Suruí have recently illegally leased land to these actors and established sharecropping agreements as an additional economic alternative to the decreasing revenues from logging. Since no direct invasions have been observed, this can be considered as an indirect deforestation process, where the Suruí agent decides on the fate of the land. These agreements are threatening the environmental integrity of the territory. The law states:

> "Estatuto do Índio, Lei 6001, Art. 18 – As Terras Indígenas não poderão ser objeto de arrendamento ou de qualquer ato ou negócio jurídico que restrinja o pleno exercício da posse direta pela comunidade indígena ou pelos silvícolas"
> [Statute of the Indian, Law 6001, Art. 18 – The indigenous lands cannot be leased or be the object of any act or legal business arrangement that restricts the full exercise of direct possession by the indigenous people]

Confronted with this situation of increasing forest conversion, the Metareilá association (formed in 1989 to defend the SSIL and the Suruí people against outside threats and to promote the welfare of the Suruí), mobilized several socio-environmental NGOs in 2009 to develop a conservation project: the Suruí Forest Carbon Project (SFCP). The SFCP includes a fund that integrates different types of conservation finance, including carbon incentives under the REDD voluntary carbon market mechanism. The objective is to develop economic activities that are environmentally less impacting as alternatives to those that generate deforestation. The reference scenario of the SFCP was based on a 30-year LULCC projection, developed from a 2-year study. A specific model was developed based on a preliminary analysis of deforestation drivers by the Institute for the Conservation and Sustainable Development of Amazonas (IDESAM) that integrates information on local LULCC strategies generated using a participatory approach (IDESAM and Metareilá 2011). The present study examines the utility of developing a LULCC model as a land-use projection tool and as a planning tool for REDD activities.

Methods

Study Area: An Island of Forest in the Arc of Deforestation

The study area is the Sete de Setembro Indigenous Land (SSIL), which is located in the western Amazon region straddling the border between the states of Rondônia and Mato Grosso (Fig. 1). This region comprises the western flank of a long corridor of indigenous lands surrounded by consolidated agricultural areas. The area is located at the intersection of the municipalities of Cacoal (which covers most of the SSIL) and Espigão do Oeste in Rondônia and the municipality of Rondôlandia in Mato Grosso. The municipality of Cacoal had 78,061 inhabitants in 2011 (Brazil, IBGE 2011). In the 1970s, the Cacoal area had the fastest deforestation in Rondônia (Fearnside 1986, 1989), and the intense exploitation of natural resources has now resulted in the loss of 65 % of the forest cover in the municipality. Pasture and agriculture predominate in the deforested areas (Brazil, INPE 2010).

The Suruí territory is located in both the Madeira and Tapajós River Basins and has high biological diversity (IDESAM and Metareilá 2011). The SSIL has many attributes classed as "high conservation value" and almost the entire territory is rated as "extremely important" for biodiversity conservation (Brazil, MMA 2001). The SSIL is part of a broader ethno-environmental corridor that includes several indigenous lands and conservation units. The predominant topography is gently undulating with a slope between 3 % and 12 %. The soil is predominantly red-yellow podzolic (Ultisol or Acrisol). A variety of human land uses are present in the SSIL, including pasture, agriculture and secondary vegetation in fallow fields, in all representing 2,417 ha in 2009 or 1.4 % of the territory. The average rate of deforestation between 2000 and 2009, calculated based on the clearing of mature rainforests existing in 2000, was 0.07 % per year, or 157.4 ha/yr. Most of the uncleared area is tropical forest vegetation, specifically open sub-montane rain forest (IBGE code: Asp [Brazil, IBGE 1992]), together with a lesser proportion of dense sub-montane ombrophilous forest (IBGE code: Sde); some small patches of non-forest natural vegetation (IBGE code: Sd) are also scattered around the territory. The ombrophilous forest area has suffered most of the selective logging, reducing the original stock of commercial tree species and the corresponding biomass. Logging tracks cross almost the entire area. A forest biomass inventory was done throughout the SSIL, resulting in the assumption that the entire area has reduced biomass (IDESAM and Metareilá 2011).

SIMSURUI: Combining Systems Dynamics with a Participatory Approach

The LULCC model developed in this study, called SIMSURUI, is composed of two models. The first is a non-spatial systems model that calculates annual land-use and land-cover change transition rates and specifically the transition from forest to deforested land. The non-spatial model has been developed in Vensim software (Ventana Systems, Inc.). The systems approach has been chosen because of its capacity to integrate different types of components and its ability to represent socio-ecological systems in order to analyze management (Dougill *et al.* 2010; Sendzimir *et al.* 2011). The SIMSURUI model includes components that are specific to the Suruí socio-ecological system, including interactions among demography, economy and landscape. Land use reflects the strategic development of productive

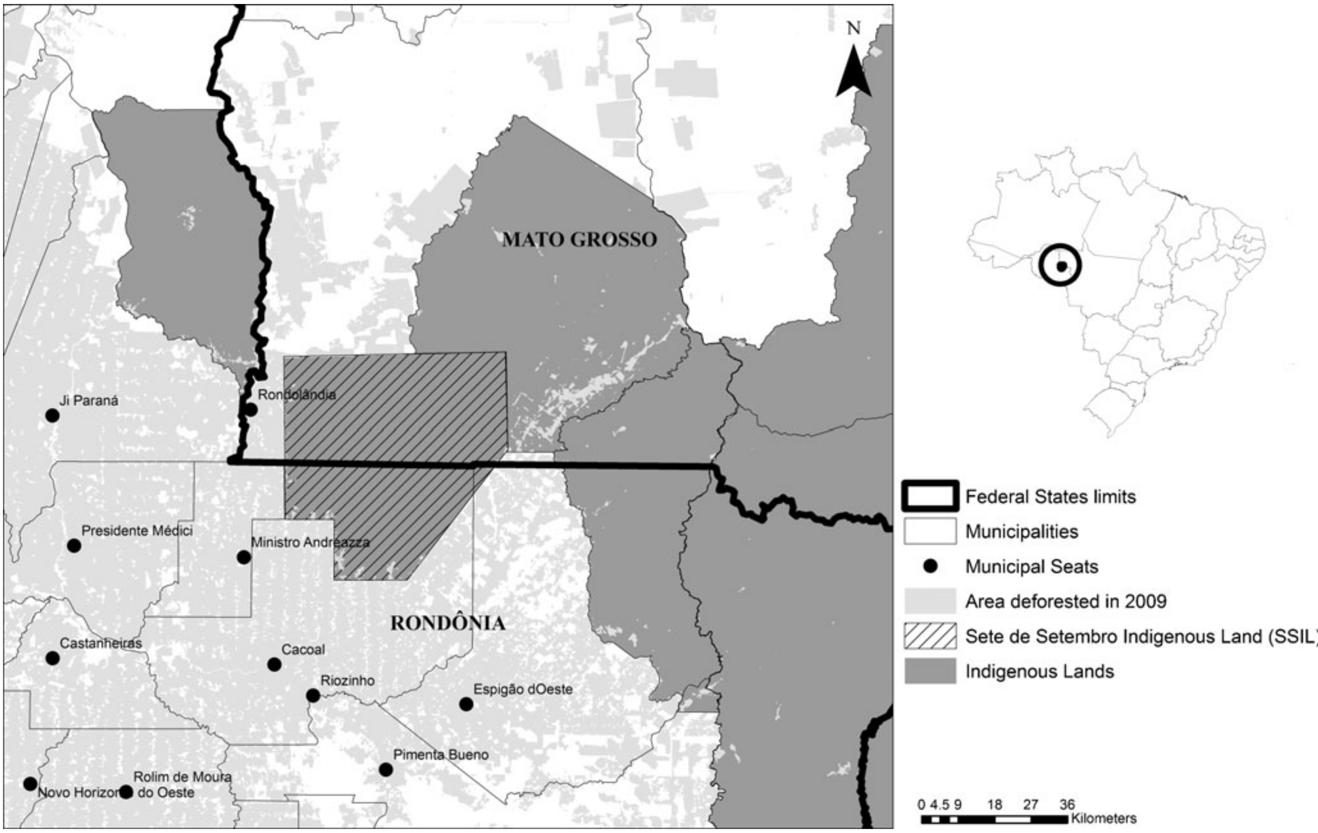

Fig. 1 Map of the Sete de Setembro Indigenous Land (*Terra Indígena Sete de Setembro*) showing other indigenous lands, surrounding towns and the area that had been deforested previous to 2009

activities by different Suruí agent groups. Vegetation dynamics are inferred from these interactions. The systems model was coupled with a cellular automata model to spatially allocate the modeled deforestation rate. This spatial model uses the DINAMICA-EGO modeling platform (Rodrigues *et al.* 2007; Soares-Filho 2013), which allocates land-use and cover change transition rates to a landscape composed of land-use/cover classes over grid cells. We only present the non-spatial systems model in this paper.

Steps in establishing the Suruí REDD reference scenario were:

1) Analysis of the available data related to the Cacoal region's historical deforestation drivers and Suruí land-use
2) Characterization of historical and recent Suruí land-use drivers, prospective identification of key future land-use drivers with discussion of the construction of a SFCP counterfactual scenario during a participative workshop organized by the SFCP NGOs with eleven Suruí leaders in February 2010 in Porto Velho
3) Conceptual model construction and preliminary version of a systems model with identification of feedback loops
4) Participative validation of the model structure, including interactions between key variables, quantification of parameters and selection of the most probable scenario during a second workshop in Cacoal in August 2010
5) Statistical validation and
6) Monte-Carlo sensitivity analysis

The SIMSURUI Vensim systems model is composed of five sub-models (Fig. 2):

1) Demography
2) Groups of productive agents in the Suruí population
3) Economic investment strategies of the groups of productive agents
4) Subsistence farming
5) Landscape dynamics of the Suruí territory

The historical reference period (2000–2009) was used as the basis for projecting the most-probable future loss of forest cover over a period of 30 years (2009 and 2038). The subsequent calculation of greenhouse-gas emissions was based on this most-probable scenario, making it possible to generate financial carbon benefits to conserve the SSIL.

The model incorporated data derived from the literature, from participatory workshops and from a parallel study that was conducted to determine the vegetation cover of the SSIL in 2009 and the evolution of LULCC in the SSIL during the 2004–2009 historical period. Household economic data were obtained from a census conducted by Metareilá in 2009. The census visited all of the Suruí households that lived in or used resources in the SSIL, of which 65 % had responses complete

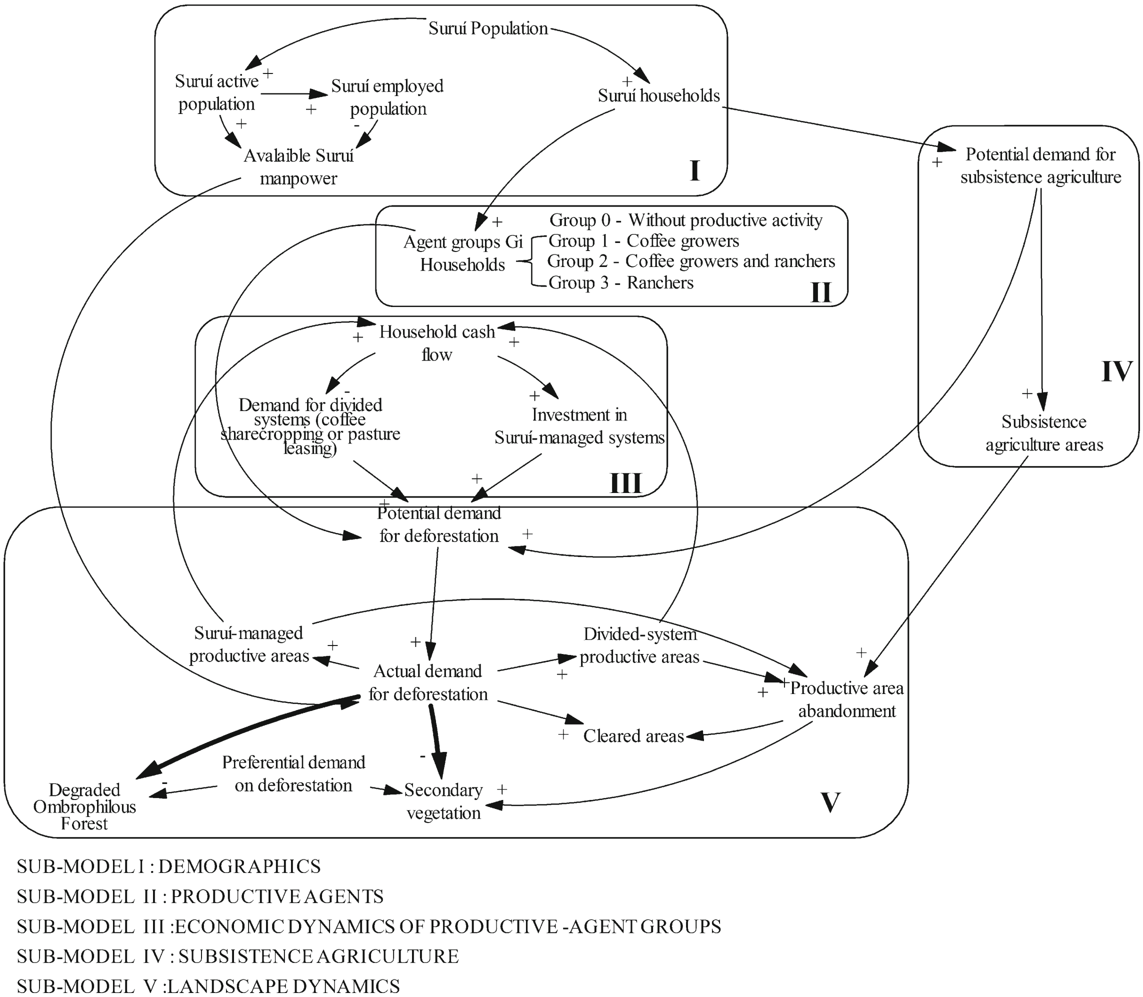

Fig. 2 Dynamic systems model of the Sete de Setembro Indigenous Land socio-ecological system. Sign next to each arrow (+ or -) indicates whether the relation is positive or negative as classed from interviews and/or available data analysis

enough to use in our study of approximately 90 % of the Suruí households (Table 1).

Additional economic and ecological data were obtained from ground observations in 2009, combined with remote-sensing and GIS data and informal interviews applied to local entities. Some parameters were based on historical observations and are considered to be fixed during the simulations, while others are expected to change according to the prospective scenario selected (Table 2).

Simulation Assumptions

SSIL Landscape Composition

The composition of the initial landscape was estimated by classifying a Landsat 5 Thematic Mapper (TM) satellite image for 2009, the starting date of the project. Of the five initial land-use and cover classes that were obtained from the classification, we ignored the hydrography and savanna classes to consider only three classes for inferring land-use dynamics: 1) ombrophilous forest, 2) cleared areas and 3) secondary vegetation originating from pasture and agriculture. Two transitions were considered in the model: 1 to 2 and 3 to 2.

With the objective of validating the model, we compared the modeled and observed annual rates of LULCC for the historic 2005–2009 period using data obtained from the Landsat land-use change analysis. Landscape data for 2004, obtained by Landsat classification, allowed a specific model to be built for calibration.

Sub-Models 1and 2: Suruí Population Dynamics

The population structure used in the model is based on the 2009 population pyramid data that were derived from the household data collection. To model the population structure, three age categories were distinguished: 0–15 years, 15–65 years and > 65 years, accounting annually for births, deaths and the evolution between the age categories.

In the view of the leaders, and in accord with observed trends between 2000 and 2009, births are decreasing due to higher use of contraceptives and due to the higher cost of

Table 1 Data sources used in SIMSURUI

Type of data	Source
Suruí household socioeconomics	Metareilá (2010)
Demographic	FUNASA (2010)
	Metareilá (2010)
Productive areas and landscape dynamics	Landsat-TM imagery analysis between 2000 and 2009
	Metareilá (2010)
Suruí household financial investment	Interviews-Workshop with Suruí indigenous leaders (IDESAM and Metareilá 2011)
Prospective analysis of key deforestation drivers	Workshop with Suruí indigenous leaders (IDESAM and Metareilá 2011)

education for children. The simulations integrate extrapolated birth and death rates for 30 years using linear trends from historical population data. Based on information collected by FUNASA (National Foundation for Health) and Metareilá since contact in 1969, immigration rate was found to be positive at 0.026 % per annum. The number of weddings between non-indigenous women and indigenous men has increased over the past decades and now compensates for the emigration of families to the nearby towns of Cacoal and Espigão do Oeste (Appendix 4).

The available labor force was derived from the proportion of active adults between 15 and 65 years old, excluding those who are considered to be unavailable for productive activities because they have permanent jobs either in nearby towns or in the Suruí territory. We subtracted the employment rate of 9.7 % (derived from the household survey) from the total active labor force to estimate the labor available for land-use activities.

The population model was then transformed into household units, considering households to be composed by 5.85 persons. Households are divided into four different agent groups that are distinguished by their productive activities in the Suruí territory: "Without Productive Activities" (Group 0), "Coffee Growers" (Group 1), "Mixed-strategy: Coffee Growers and Ranchers" (Group 2), and "Ranchers" (Group 3). In order to be more conservative and to limit uncertainty, the choice was made to maintain the 2009 observed distribution of producer groups during the simulations, which allows analysis of how combinations of productive systems will influence the economy and the demand for forest clearing.

Sub-Model 3: Suruí LULCC Strategy

The socioeconomic behavior of the three productive-agent groups is modeled based on the annual financial flow or "cash flow", which is computed for average households and equals the difference between household income (i.e., timber, livestock, agriculture, government assistance, employment compensation, non-timber forest products and handicrafts) and annual fixed expenses (i.e., food, energy, transportation, health, clothing and leisure). When cash flow is positive, the financial surplus of the family budget is invested in productive activities, real estate and is spent on consumer goods (technological accessories and vehicles). The income and expense values for each producer-agent group were based on the data collected by Metareilá, but the annual revenues from productive activities were based on a financial cost-benefit analysis produced by IDESAM (IDESAM and Metareilá. 2011). This study found an average profitability of R$294.00 per hectare/year for Suruí coffee growing over a 15-year period and R$190.80 per hectare/year for Suruí cattle ranching based on a 20-ha area over an 11-year period, R$121.60 per hectare/year for coffee sharecropping and R$60.00 per hectare/year for leasing pastures to external agents. The exchange rate for the Brazilian real (R$) at the time of interviews with Suruí leaders in 2009 was 1.78 R$/US$. Annual revenues obtained from each activity account for the new productive areas opened during iterations of the model, in addition to the areas that existed in 2009. After the permanence period (considered to be 11 years for pasture and 15 years for coffee), abandonment and the associated regeneration of secondary vegetation decreases the productive areas. For coffee production, a decrease in productivity is assumed from the thirteenth year and for pasture from the sixth year until midway through the eleventh year when it is abandoned. The gradual reduction of capacity is important to conservatively model profitability. Income from logging was considered to follow a downward trend, starting with the income obtained for timber sales in 2009 from the household socioeconomic data collection. Based on field campaigns since 2009, an over-flight of the reserve and the inventory of forest biomass (both carried out by IDESAM), much of the Suruí territory has been selectively logged. The inventory results indicated that the remaining trees of commercial value would be insufficient to sustain a continuous logging operation for more than 10 years. Thus, the model assumes that income from timber decreases from 2009 until 2018, when it becomes zero.

Each productive-agent group has a different annual household cash flow, and each group has different investment patterns. All groups have the goal of maintaining an annual positive balance of R$1500, which is considered to be the minimum desired household cash flow that would be used for productive activities, consumer goods and real estate and (see parameter values for investment ratios in Table 2). These investment parameters were defined during the participatory workshops. IDESAM applied questionnaires to eleven Suruí leaders who were present in the first participatory meeting. The questionnaire was intended to define the investment proportions depending on the cash-flow value categories as considered in the model. However, because some Suruí leaders were unable to answer the questions on these financial

Table 2 SIMSURUÍ parameter values

Sub-model	Name	Parameter description	Value	Reference/Justification
Suruí age-pyramid demography	b	Birth rate	Varying [0.046–0.018]	Extrapolation of the 2009 Metareilá census assumed. See Appendix 4
	d	Death rate	[0.0024–0.0028]	Extrapolation of the 2009 Metareilá census assumed. See Appendix 4
	c_{a1}	Young age class	15 year	Assumed
	c_{a2}	Adult age class	50 year	Assumed
	i	Immigration rate	0.00026	Metareilá (2010) See Appendix 4
	j	Job recruitment	0.0097	Metareilá (2010) See Appendix 4
	pf	Number of people per household	5.85 people	Metareilá (2010)
Labor	d_w	Days worked per year	260 days/year	Assumed
	$l_{c,i}$	Labor demand for implementation of Suruí-managed coffee plantations	58.15 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
	$l_{c,m}$	Labor demand for maintenance of Suruí-managed coffee plantations	21.5 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
	$l_{l,i}$	Labor demand for implementation of Suruí-managed livestock	13.65 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
	$l_{l,m}$	Labor demand for maintenance of Suruí-managed livestock	5.66 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
	$l_{sa,i}$	Labor demand for implementation of Suruí-managed subsistence agriculture	14.65 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
	$l_{sa,m}$	Labor demand for maintenance of Suruí-managed subsistence agriculture	6 days/year/ha	IDESAM and Metareilá (2011) See Appendix 4
Distribution of households among productive agent groups	d_{G0}	Proportion of the households in the non-productive group G_0	0.091	Metareilá (2010) See Table 4
	d_{G1}	Proportion of the households in the coffee growers group G_1	0.44	Metareilá (2010) See Table 4
	d_{G2}	Proportion of the households in mixed-strategy (coffee growing and ranching) group G_2	0.4	Metareilá (2010) See Table 4
	d_{G3}	Proportion of the households in the ranchers group G_3	0.074	Metareilá (2010) See Table 4
Illegal logging revenues rt_{Gi}	rt_{G1}	Revenue from timber: coffee growers group G1	7120 R$/year/hh	Metareilá (2010)
	rt_{G2}	Revenue from timber: mixed-strategy (coffee growing and ranching) group G2	9984 R$/year/hh	Metareilá (2010)
	rt_{G3}	Revenue from timber: ranchers group G3	7875 R$/year/hh	Metareilá (2010)
Handicraft revenues rh_{Gi}	rh_{G1}	Revenue from handicrafts: coffee growers group G1	148 R$/year/hh	Metareilá (2010)
	rh_{G2}	Revenue from handicrafts: mixed-strategy (coffee growing and ranching) group G2	344 R$/year/hh	Metareilá (2010)
	rh_{G3}	Revenue from handicrafts: ranchers group G3	12 R$/year/hh	Metareilá (2010)
Fixed revenues rf_{Gi}	rf_{G1}	Fixed revenues (employment, government assistance): coffee growers group G1	6974 R$/y/hh	Metareilá (2010)
	rf_{G2}	Fixed revenues (employment, government assistance): mixed-strategy (coffee growing and ranching) group G2	6042 R$/year/hh	Metareilá (2010)
	rf_{G3}	Fixed revenues (employment, government assistance): ranchers group G3	5006 R$/year/hh	Metareilá (2010)
Fixed Expenses ef_{Gi}	e_{G1}	Expenses (transport, health, energy, etc.): coffee growers group G1	7026 R$/year/hh	Metareilá (2010)
	e_{G2}	Expenses: mixed-strategy (coffee growing and ranching) group G2	9060 R$/year/hh	Metareilá (2010)
	e_{G3}	Expenses: ranchers group G3	8423 R$/year/hh	Metareilá (2010)
Revenues of Suruí-managed productive systems r_{sps}	r_l	Net revenue Suruí-managed livestock	190.8 R$/ha/hh	IDESAM and Metareilá (2011)
	r_c	Net revenue Suruí-managed coffee	294 R$/ha/hh	IDESAM and Metareilá (2011)
Revenues of divided productive systems r_{dps}	r_{dl}	Net revenue leasing livestock	60 R$/ha/hh	IDESAM and Metareilá (2011)
	r_{dc}	Net revenue coffee sharecropping	121.6 R$/ha/hh	IDESAM and Metareilá (2011)

Table 2 (continued)

Sub-model	Name	Parameter description	Value	Reference/Justification
Productive system establishment costs	c_c	Coffee plantation cost of deployment	2465 R$/ha/hh	IDESAM and Metareilá (2011)
	c_p	Pasture: cost of deployment	931.1 R$/ha/hh	IDESAM and Metareilá (2011)
	c_d	Minimum desired household cash flow	R$1500/hh	Assumed
Investment proportions of the cash flow of productive agent groups in consumer goods - i_{cg}	$i_{cg > 10000}$	Investment proportion in consumer goods (if household cash flow > R$10,000)	0.312	IDESAM and Metareilá (2011)
	$i_{cg\ [5000–10000]}$	Investment proportion in consumer goods (if household cash flow is between R$5000 and R$10,000)	0.46	IDESAM and Metareilá (2011)
	$i_{cg\ <5000}$	Investment proportion in consumer goods (if household cash flow < R$5000)	0.47	IDESAM and Metareilá (2011)
Investment proportions of the cash flow of productive agent groups in real estate - i_{re}	$i_{re > 10000}$	Investment proportion in real estate (if household cash flow > R$10,000)	0.592	IDESAM and Metareilá (2011)
	$i_{re\ [5000–10000]}$	Investment proportion in real estate (if household cash flow is between R$5000 and R$10,000)	0.22	IDESAM and Metareilá (2011)
	$i_{re\ <5000}$	Investment proportion in real estate (if household cash flow < R$5000)	0.062	IDESAM and Metareilá (2011)
Investment proportions of the cash flow of productive agent groups in productive systems - i_{ps}	$i_{ps>10000}$	Investment proportion in productive systems (if household cash flow > R$10,000)	0.096	IDESAM and Metareilá (2011)
	$i_{ps\ [5000–10000]}$	Investment proportion in productive systems (if household cash flow is between R$5000 and R$10,000)	0.32	IDESAM and Metareilá (2011)
	$i_{ps\ <5000}$	Investment proportion in productive systems (if household cash flow < 5000 R$)	0.468	IDESAM and Metareilá (2011)
	$i_{psc\ <5000}$	Proportion of the productive-system investment in coffee production for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow < R$5000)	0.45	IDESAM and Metareilá (2011)
	$i_{psl\ <5000}$	Proportion of the productive-system investment in livestock for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow < R$5000)	0.55	IDESAM and Metareilá (2011)
	$i_{psc\ [5000–10000]}$	Proportion of the productive-system investment in coffee production for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow is between 5000 and R$10,000)	0.33	IDESAM and Metareilá (2011)
	$i_{psl\ [5000–10000]}$	Proportion of the productive-system investment in livestock for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow is between R$5000 and R$10,000)	0.67	IDESAM and Metareilá (2011)
	$i_{psc\ >10000}$	Proportion of the productive-system investment in coffee production for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow > R$10,000)	0.18	IDESAM and Metareilá (2011)
	$i_{psl\ >10000}$	Proportion of the productive-system investment in livestock for the mixed-strategy (coffee growing and ranching) group G_2 (if household cash flow > R$10,000)	0.82	IDESAM and Metareilá (2011)
Subsistence agriculture	hh_{sa}	Proportion of the indigenous families practicing subsistence agriculture	0.791 hh/year	Calculated from Metareilá (2010)
	T_{sa}	Time permanence of subsistence agriculture production	4 year	IDESAM and Metareilá (2011)
	A_{sa}	Land demand for subsistence agriculture	0.175 ha/year	Calculated from Metareilá (2010)
	$L_{sa,i}$	Indigenous labor necessary for traditional agriculture implementation	14.65 days/year/ha	IDESAM and Metareilá (Amazonas) and Metareilá 2011)
	$L_{tc,m}$	Indigenous labor necessary for traditional agriculture maintenance	6 days/year/ha	IDESAM and Metareilá (2011)
Land demand	$a_{dc,G1}$	Land demand in coffee sharecropping system (if household cash flow is above R$1500) coffee growers group G_1	0.0452 ha/year	Calculated from Metareilá (2010)
	$a_{dc\ G2}$	Land demand in coffee sharecropping system (if household cash flow is above R$1500)	0.0878 ha/year	Calculated from Metareilá (2010)

Table 2 (continued)

Sub-model	Name	Parameter description	Value	Reference/Justification
		mixed-strategy (coffee growing and ranching) group G_2		
	$a_{dl\ G2}$	Land demand in pasture leasing (if household cash flow is above R$1500) mixed-strategy (coffee growing and ranching) group G_2	0.336 ha/year	Calculated from Metareilá (2010)
	$a_{dl\ G3}$	Land demand in pasture leasing (if household cash flow is above R$1500) ranchers group G_3	0.432 ha/year	Calculated from Metareilá (2010)
	T_{cr}	Time permanence of livestock system	11 year	Luizão et al. (2009)
	T_c	Time permanence of coffee production system	15 year	Luizão et al. (2009)
SSIL landscape	d	Proportion of the annual total land demand in opening new areas of primary vegetation	0.78	Landsat TM imagery analyses
	c	Proportion of the annual total land demand in opening new areas of secondary vegetation	0.22	Landsat TM imagery analyses

allocations, it was considered preferable to average the data by cash-flow category to increase the sample size, making it impossible to obtain separate proportions for each group. The same average productive investment proportions were used for all four productive-agent groups because of the size of the sample available to calculate this parameter. We assumed that, in view of the reduction in timber revenue, agent groups would invest their net revenues in productive activities according to the average proportion informed by the leaders. The leaders argued that the clan population that they represented would follow the same investment patterns. Averaging the data could therefore have led to either an overestimate or an underestimate of the strategic productive investment of certain productive groups. Also, it was not possible to deduce an averaged investment rate linking the sizes of the 2009 productive areas and the ages of the systems because this information was not collected during the socioeconomic survey. We could not verify such information using Landsat satellite imagery and a geographic information system because productive areas were not mapped during interviews and the 30-m resolution of Landsat-TM does not permit distinguishing pastures from coffee plantations.

It was assumed that the proportion of investments in productive systems is higher when cash flow declines, as calculated from interviews and adjusted during the calibration parameterization (See Table 2 and Appendix 3). It was not assumed that there would be a continuous increase in the productive-investment proportions in response to the downward trend in cash flow; instead, the choice was made to strictly follow the results from the surveys as modified during the Monte-Carlo calibration. Categorizing these proportions led to the investment being modeled as a discrete phenomenon. This is especially important when approaching the limits of the cash-flow value categories, as the threshold could be considered to be a modeling artifact.

Depending on the annual household cash flow, the Suruí engage in two types of arrangement for income generation from productive activities. The first type is a Suruí-managed system (which is considered legal by the Brazilian constitution) in which Suruí agents alone invest in production and accumulate all income. The second type is a "divided" system based on either sharecropping or leasing (both considered illegal, but which do occur), where the Suruí grant the right to use an area of land in the indigenous territory to an external agent (lessee) who bears the costs of deployment, maintenance and harvesting. The revenues are shared between the tenant and the Suruí. We considered that when the cash flow is more than R$1500, a portion of the balance is allocated to establish a Suruí-managed system of coffee cultivation or livestock, depending on the productive-agent group. The productive area is cleared in accordance with the cost of deployment of each activity (R$931 per hectare for pasture establishment and R$2465 per hectare for coffee plantation establishment). When the cash flow is below the desired value of R$1500, each group chooses to increase the area allotted to sharecropping or rental in order to cover the difference between the cash-flow value obtained and the desired value. Thus, the group will earn revenue without investing in setting up and maintaining these productive areas. The area designated for sharecropping matches the amount required to generate enough income to maintain the household cash flow at the desired level. The annual demands of all productive groups for Suruí-managed productive areas are summed with the annual demands for sharecropping productive areas in order to obtain the potential demand for opening new production areas that generate profits at the landscape level.

Sub-Model 4: Subsistence Agriculture

Because slash-and-burn subsistence agriculture (manioc, sweet potatoes, etc.) is an activity that impacts forest cover but does not provide cash income, a constant area per household and per year is assumed to be cleared for this activity. The total potential demand for new areas is calculated each year by adding this demand for new areas of subsistence agriculture and the calculated potential demand for new areas that generate profits.

To calculate the effective demand for new production areas in any given year, the model considers the availability of labor needed to maintain the areas for productive use and the availability of labor to open up new areas. If the potential demand cannot be supported by the available manpower, the ratio of available to needed manpower is applied to calculate the effective demand for new areas. The effective demand for new productive areas can be satisfied either through deforestation (transition 1–2) or through clearing of secondary vegetation (transition 3–2).

Sub-Model 5: Productive Areas and Landscape Dynamics

The resulting total demand for productive area is translated into conversion of native forests (1–2) or reuse of secondary forests (3–2) and then integrated into the landscape dynamics. All three classes of land use and cover are affected by the two land-use and cover class transitions. Of the current demand for newly deforested areas, 72 % is associated with the ombrophilous forest stock and 28 % with the secondary vegetation stock, according to the averaged annual analysis of LULCC conducted using Landsat TM 5 images between 2000 and 2009. Annually, the converted area is added to the productive areas in use and the abandoned areas are added to the secondary-vegetation stock.

Calibration and Validation

A qualitative validation of the model was conducted with the Suruí leaders during two workshops, one to present a preliminary design of the model after studying data availability and the second to test and correct some of the assumptions in the preliminary version of the model and related outcomes. All of these steps are important for reducing uncertainties in modeling deforestation. A complementary quantitative analysis has been conducted to define the accuracy and uncertainties of the model in reproducing the historical patterns. To obtain the best match for the minimum payoff, a key-parameter sensitivity analysis of the model was conducted using the Monte Carlo method in the PLE Plus version of Vensim (Appendix 3).

Results

Accuracy and Uncertainties of the SIMSURUI Model

We obtained a correspondence of 93 % when the modeled "cumulative area of forest cleared" data were compared to the historical data for 2005–2009. The uncertainties of SIMSURUI are presented in Appendix 3.

Suruí Demographic Evolution

The model projected the Suruí population to 2504 persons in 2038, corresponding to 428 households. The 2038 projected labor force of 949 persons represents 37 % of the population (Table 3).

The increasing demographic projection based on the observed increasing trend (Appendix 1) indicates that internal pressure on natural resources would be higher in the future. The main productive-agent group in 2038 is the coffee growers with 187 families (Table 4).

Cash-flow Evolution and Productive Economic Return on Investment

All of the productive-agent groups had different economic configurations in 2009 because financial receipts vary among the groups (Fig. 3). All groups were similarly dependent on wood sales, which represented approximately 48 % of household revenues in 2009. In terms of productive income, Groups 2 and 3 were both similarly dependent (by around 20 %), whereas Group 1 was less dependent (4 %). Group 1 depended essentially on fixed revenues, representing 48 % of the gross income, whereas fixed income represented around 30 % for Groups 2 and 3. In 2009, expenses represented around 50 % of the income for all groups and net cash flow represented the remaining 50 % of the income. In this configuration, Group 1 is the only group that fully covers its expenses from fixed income. In addition to fixed income, Groups 2 and 3 have to rely on a part of the income from productive systems and wood to cover their expenses. At the end of simulations (in 2038), these proportions change significantly among productive groups; expenses represent 71 % of the income in Group 1, 88 % in Group 2 and 89 % in Group 3, reducing the net cash flow to 29 % of the income for Group 1 and 12 % and 11 % for Groups 2 and 3. Group 1 succeeds in having higher net cash flow (surplus) than the other groups due to its simulated investment in coffee cultivation. Group 1 raised its productive benefits by 341 % as compared to 2009 (R$2759 per household (hh) in 2038 against R$625/hh in

Table 3 SIMSURUI demographic input and simulated values

Demographic level state variables (number of individuals)	2009	2038
Suruí population	1142	2504
[0–15 years]	518	705
[15–65 years]	597	1266
[> 65 years]	27	532
Suruí households	195	428
Employed individuals	62	316
Labor available in Suruí territory	534	949

Table 4 Evolution of the SSIL productive-agent groups between 2009 and 2038

		Interviews	Suruí population extrapolation		
		Households	%	2009	2038
Group 0	Without productive activity/subsistence	11	9.1	18	39
Group 1	Coffee growers	53	44	85	187
Group 2	Mixed-strategy: coffee growers and ranchers	48	40	78	170
Group 3	Ranchers	9	7.4	14	31
Total		121	100	195	428

2009) as well as Group 3 by 20 %., whereas Group 2 lost 10 % of its 2009 productive benefits.

During the simulation, for all groups the household cash flow followed a downward trend from 2009 onwards (Fig. 4), following the downward trend in wood revenue, which falls to 0 % of the income in 2018. The household is also confronted with a reduction of existing productive-system revenues that depend on system permanence time. Of the three productive groups, only Group 1 had a cash-flow level in 2038 that exceeded the minimum desired value of R$1500, but this group's cash flow decreased to R$2854 in 2038 (Fig. 3), representing a decrease by 64 % as compared to the value in 2009 (R$7841). Groups 2 and 3 reached the minimum desired value around 2020 and respectively obtained cash flows of R$1103 and R$1196 in 2038, which represent 10 % and 14 % of the initial values, respectively. Since wood income decreases during the simulations, Groups 2 and 3 become more dependent on the productive systems to pay the portion of their expenses that is not covered by fixed income, this being reflected as a reduction of the financial surplus or cash flow. In the model, the reduction of cash flow leads to a reduction of productive investment, with the result that the Suruí's own productive investments decrease during the simulations for all Groups. On average, over the 30 years of the simulations, Group 1 invested R$45,687 in its own coffee production systems (R$1522/yr), whereas Group 2 invested R$29,889 in coffee production and cattle ranching (R$996/yr) and Group 3 invested R$28,737 (R$958/yr). Average returns on

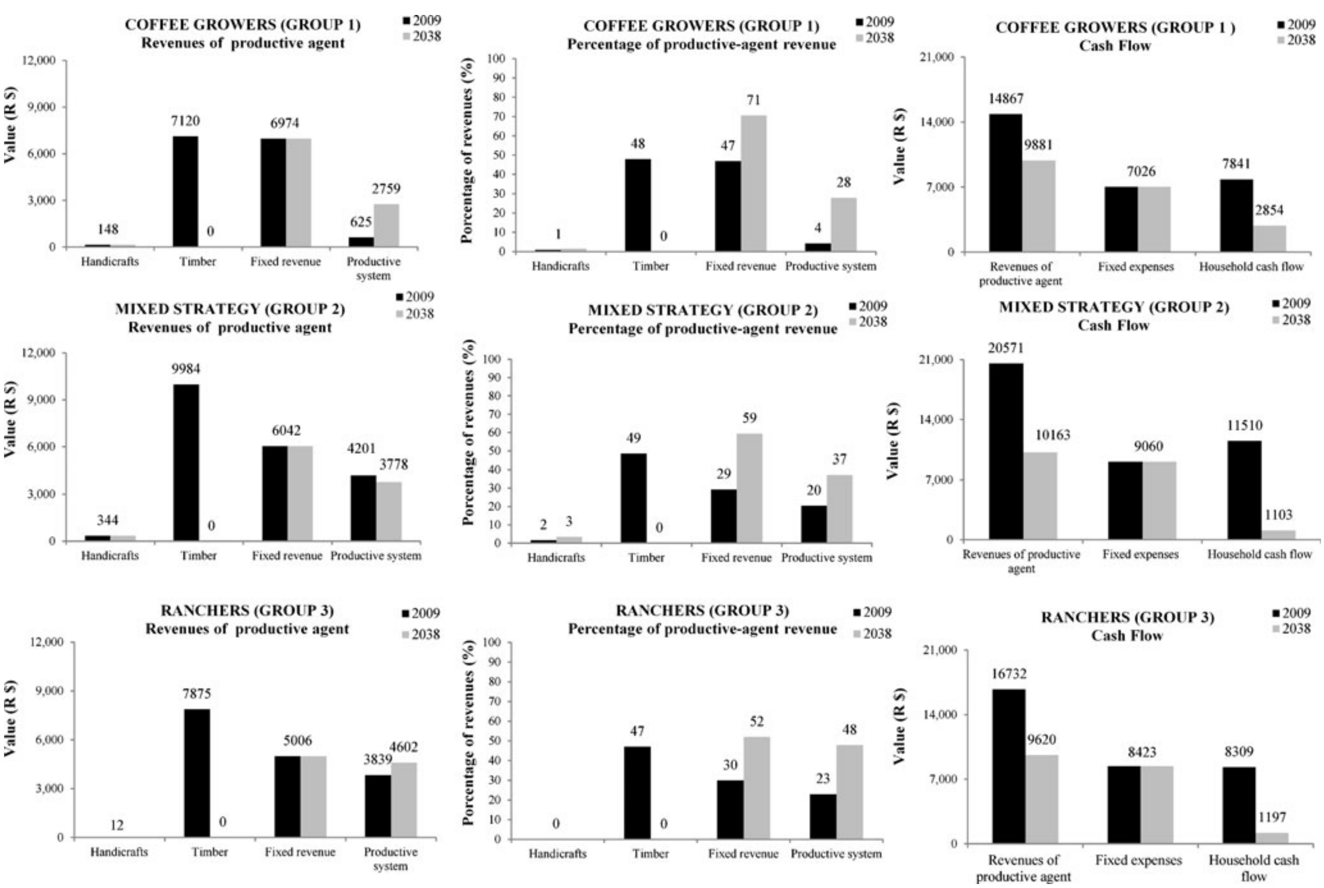

Fig. 3 Economic configuration of the Suruí productive-agent groups during SIMSURUI simulations between 2009 and 2038

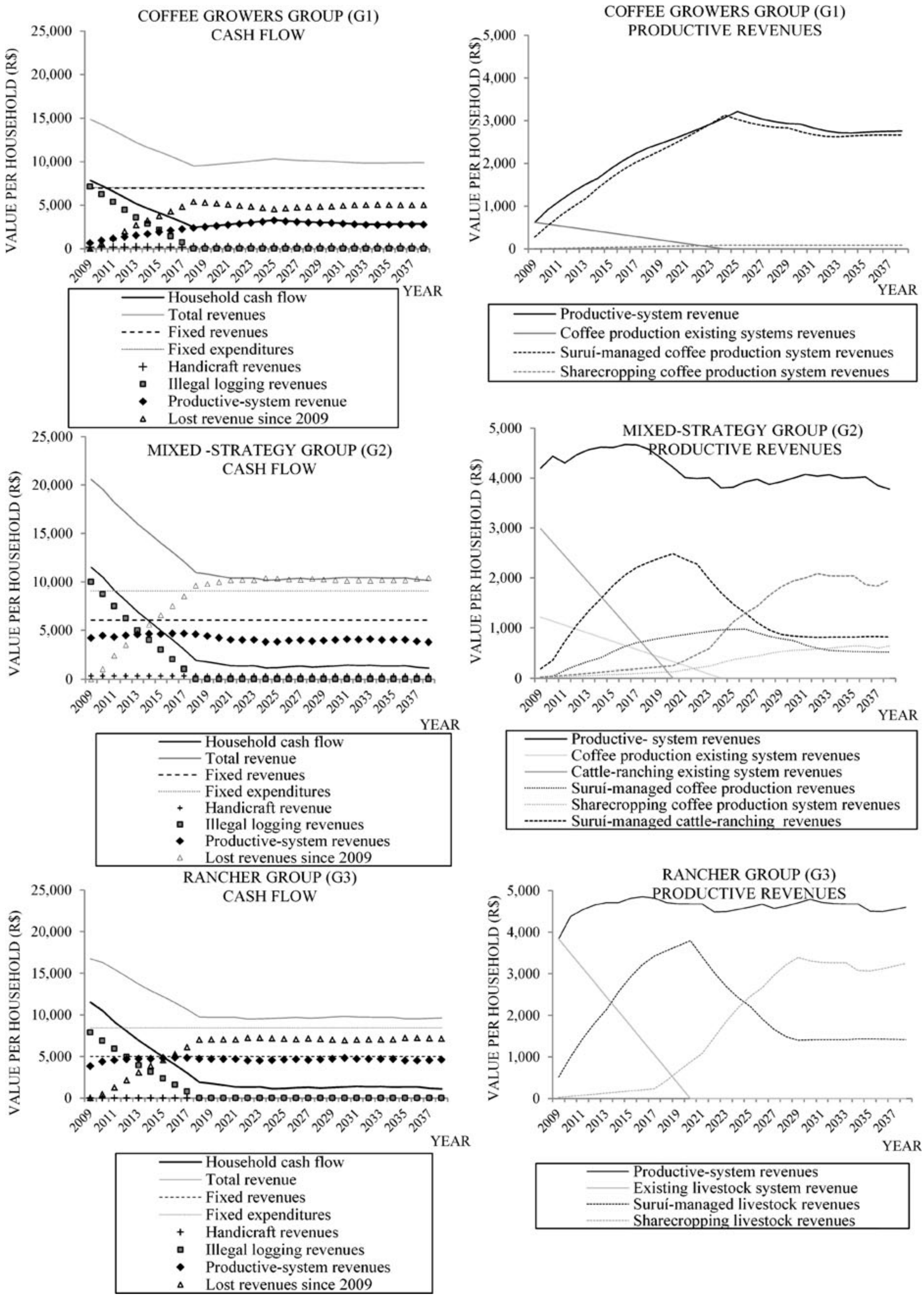

Fig. 4 Economic behavior of the Suruí productive-agent groups during SIMSURUI simulations between 2009 and 2038

investment were 48 % for Group 1, 96 % for Group 2, and 119 % for Group 3, indicating that cattle ranching is more interesting economically. The groups that practice cattle ranching (Groups 2 and 3) obtained averages of R$1955/yr and R$2101/yr, respectively, from funds invested in the Suruí-managed systems, whereas Group 1 obtained higher revenues with R$2257/yr, but having invested almost 50 % more than the other groups. When we consider the additional revenues of divided systems, Group 1 earned an average of R$2419/yr from productive systems. Groups 2 and 3 substantially increased their productive income by employing illegal productive partnerships obtaining average incomes of R$4163 and R$4616/yr, respectively.

Group 1 is the only group that significantly increased its income from its own productive activities during the simulations without favoring sharecropping systems. In contrast, Groups 2 and 3 succeeded in stabilizing their cash flows after 2020 because of the strategy of employing the share-cropping system, which brings revenues without costs. However, sharecropping systems are not sufficient to maintain cash flow at the desired level of R$1500. The cash flow results indicate that none of the groups succeeded in compensating for revenue losses from both wood and from existing productive areas through investment in their own productive systems combined with divided systems. If we compare the sum of annual revenues of both wood and productive systems with the corresponding sum applied to the 2009 data, we observe that increasing income from the productive systems only permits a partial compensation for the losses (Fig. 4). In 2038, Group 1 succeeded in maintaining 36 % of the 2009 summed revenues from wood and existing productive systems, whereas Group 2 maintained 27 % and Group 3 39 %.

Demand for New Productive Areas and Compensation for Loss of Timber Revenues

The potential demand for new areas was always met because labor was not limiting, the labor force being sufficient to maintain the existing productive systems and to implant new areas. The households in each group showed different annual rates of forest conversion and patterns of implanting productive areas (Fig. 5). These differences depend on the effective demand for new areas of Suruí-managed systems (which depends on annual cash-flow values attributed to productive investment and on the cost of implanting productive activities). The divided systems are also called upon when needed. Coffee growers in Group 1 opened, on average, 0.61 ha/yr for their own coffee plantations and 0.045 ha/yr for the sharecropping system. Group 2 households opened 0.16 ha/yr for their own coffee production systems, 0.26 ha/yr for the coffee sharecropping system, 0.64 ha/yr for their own pastures and 1.87 ha/yr for leased pastures. Finally, the most extensive areas were opened by Group 3, with 1.02 ha/yr opened for their own pastures and 3.37 ha/yr for leased pastures. In 2038, the largest productive area is attributed to the rancher group with 55.45 ha of pasture per family (Table 4). For each group, we compared the average annual profitability per hectare of productive area. Strict ranchers (Group 3) obtained R$123 per hectare, which is less than the mixed group of ranchers and coffee growers (Group 2) with R$187 per hectare; the best profitability per hectare was obtained by coffee growers (Group 1) with R$282 per hectare. Cattle ranching is economically more interesting because the return on investment is higher than for coffee growing, but cattle ranching demands more land to be profitable.

When we compare productive investment among groups during the initial simulations, we observe that Group 1 quickly increased its productive area at an average of 11 % per year during the first 10 years of simulations, whereas, during the same period, Groups 2 and 3 increased their areas at rates of 1 % and 4 %, respectively. Given these results, it is expected that Group 1 would invest more than in the past and would succeed in increasing its productive area and associated income. Since Group 1 is not dependent on productive activities during all iterations of the model because fixed income pays for expenses, the option of investing in productive activities allows this group to cover part of the reduction of wood income. The sudden increase in investment in the initial iterations compensates, in large part, for loss of production due to the smaller extent of the coffee and pasture systems (Fig. 3). In this configuration, all productive income is a financial surplus, and part of it can be reinvested in productive systems while the remainder is spent on consumption or is invested in real estate.

The productive configuration is different for Groups 2 and 3, which are dependent on productive activities to pay for their expenses; they need to compensate for economic losses from existing systems that are progressively abandoned, in addition to compensating for loss of income from logging. During the simulations, this investment proportion allows Groups 2 and 3 to succeed in almost completely compensating for the loss of income from productive areas, investing in their own systems in the initial iterations and then adopting the divided system around 2020 when wood incomes have fallen to zero. The maintenance of their income from productive systems permitted by the investment proportions associated with divided systems allows them to sustain their expenses for basic necessities but does not permit them to maintain a cash flow above R$1500. Therefore, they resort to shared and leased systems to cover the difference from the desired value; their cash flow remains very close to R$1500, but there is a delay before they approach this desired value since the demand for expanding these systems is economically satisfied after a delay of 1 year because of the causal chain loop and time step. Raising investment proportion rates could have led to increased revenues from their own productive activities, but increasing these

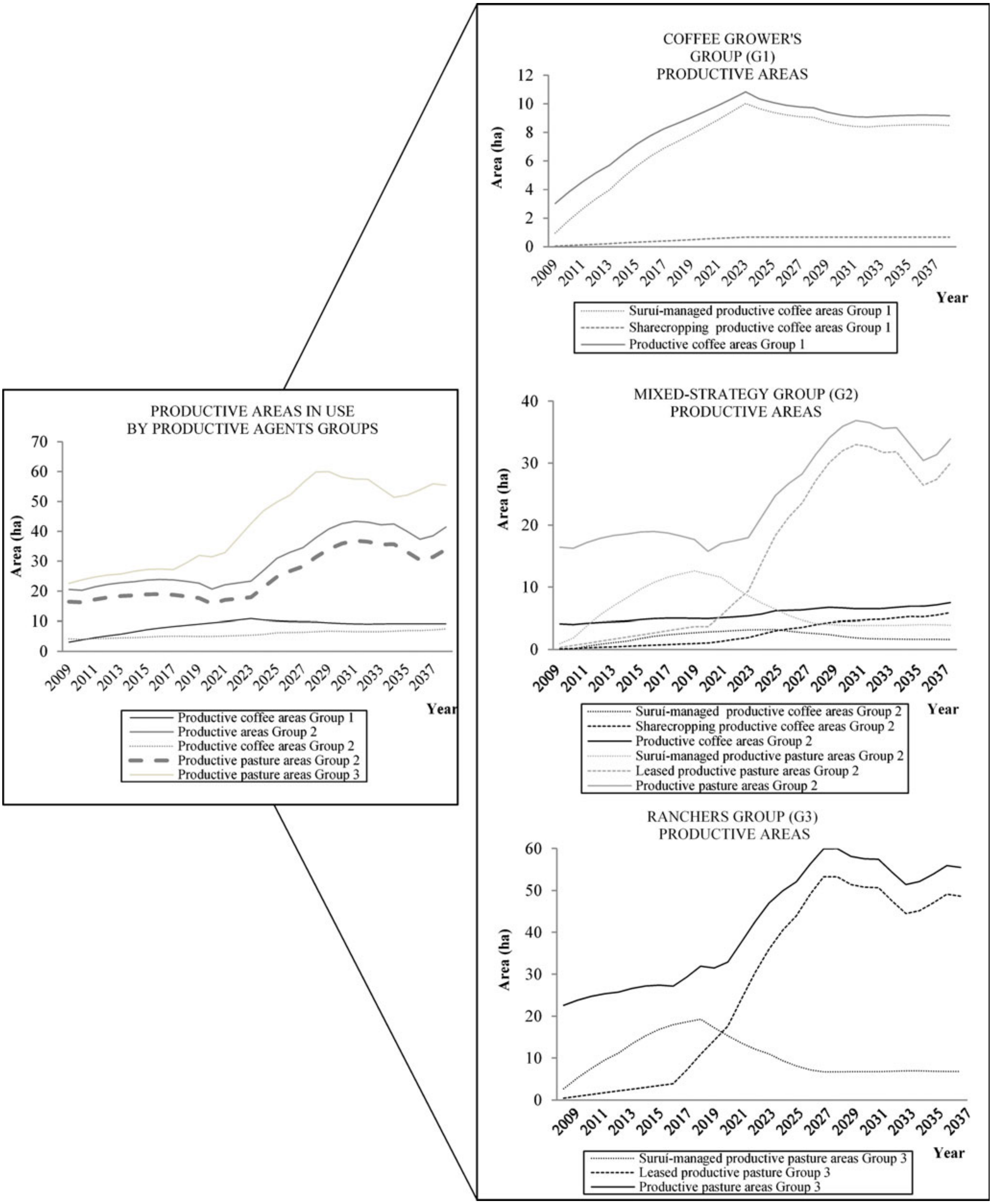

Fig. 5 Evolution of the productive areas of the Suruí productive-agent groups during SIMSURUI simulations between 2009 and 2038

proportions would result in an exceedingly large reduction in the portion allocated to investments in real estate and to purchasing consumer goods. The three groups have, respectively, invested in real estate an average of R$398 per year (R$33 per month), R$1317 per year (R$110 per month) and R$1143 per year (R$95 per month). These values are relatively low as compared to the local price of real estate, which is why these outlays can be considered to be either expenditures for maintenance of the existing real estate or low progressive investments in new real estate. The possibility of Suruí soliciting personal bank loans to invest in real estate was not considered, as it seems that the lack of sufficient fixed income to serve as a guarantee for bank loans would restrict these investments to a small part of the population, especially to those who earn salaries. Moreover, we did not consider the economic return of the real estate in which some Suruí have already invested outside the indigenous land, especially in Cacoal and Riozinho, which could be a source of income in the future if sold when needed. This choice is believed to be conservative because it underestimates future financial revenues, but, as observed in the field, real-estate speculation in Cacoal is increasing because of the implantation of new infrastructure such as private faculties and hospitals, attracting professionals from southern Brazil (personal communications and the websites of real-estate agencies). In terms of acquisition of consumer goods, which is modeled from cash flow, the proportion attributed can be considered to be relatively conservative; expenditures of the three groups on goods were, respectively, R$1701 per year (R$142 per month), R$1317 per year (R$110 per month) and R$1143 per year (R$95 per month).

Landscape Dynamics

Concerning landscape dynamics, 13,575 ha of ombrophilous forest would be deforested by 2038, and 5279.3 ha of secondary vegetation would be re-used in the indigenous territory (Fig. 6). On average, we obtained a deforestation rate of 452.2 ha/yr during the 30-year simulation, which corresponds to 2.9 times the 2000–2009 historical rate.

Discussion

The Suruí Standard of Living and Consumption of Modern Goods in SIMSURUÍ

An important point in the SIMSURUI household economics model is the separation of basic economic needs or “expenses” (e.g., clothing, food, transport, electricity) from additional consumer goods such as technological products like cell phones, DVD players and vehicles. This makes it possible to investigate whether Suruí households would be able to sustain the 2009 observed standard of living based on fixed expenses, and how they would have to adapt their consumption of technological products to a new less-prosperous economic configuration when the SSIL forest no longer offers an abundant supply of timber. Fixed expenses also express the evolution of modernity because they include the use of electricity and landline telephones, which represent new customs that have progressively entered into the category that is considered to be basic necessities by the Suruí in the period since contact with modern civilization and Brazilian economic progress.

The Brazilian Institute of Geography and Statistics (IBGE) carried out a social study in 2010 in order to analyze the average Brazilian family budget, evaluating the current family expenses that include consumer spending (transport, food, housing, health, hygiene, clothing, education, leisure, tobacco and personal services) and other expenses (taxes, postal services, etc.). These results can be compared with the modeled Suruí economic data in order to assess the place of the Suruí population in the Brazilian context. A difference with our assumption is that IBGE also included as “housing expenses” the acquisition of electrical products such as freezers, washing machines, television sets and DVD players, and included as “transport expenses” the acquisition of vehicles, which we did not include in the Suruí fixed expenses. A way to make the methodologies comparable is to sum Suruí expenses and modeled acquisition of consumer goods (which include both technological products and vehicles). On average, Brazilian households spent R$2134 per month on consumer spending (Brazil, IBGE 2010). Our data indicate that, on average, the Suruí productive-agent groups spent R$796 per household per year on consumer spending over the 30-year simulations, or 2.67 times less than the average Brazilian household spent in 2010.

We therefore can conclude that the assumption that households would maintain an annual net cash flow or surplus of R$1500 in order to invest in real estate or to purchase consumer goods (in addition to expenses) is quite conservative as compared to the Brazilian living standard. However, assuming a desired cash flow value of R$1500 (which represents 19, 13 and 18 % of the 2009 cash flow for Groups 1, 2 and 3, respectively) could appear unreasonable because it does not presume that the Suruí households will be progressively included in modern life, as expressed by a higher basic standard of living and consumption of goods. We would expect a progression of inclusion in modernity among families because the rapid progression to modernity observed in the surrounding area of Cacoal, which is a symbol of social status and power. An indication of the potential for increased acquisition of modern goods is that only 6 % of the Suruí households own a car and 28 % a motorcycle (Metareilá 2010). Considering the difficulty of transport from the indigenous territory to surrounding towns, we could expect that the acquisition of vehicles would be a priority in order to facilitate the flow of agricultural products and for the Suruí’s frequent journeys to the surrounding towns. We expect that the economic constraint of decreased cash flow linked to the reduction of wood

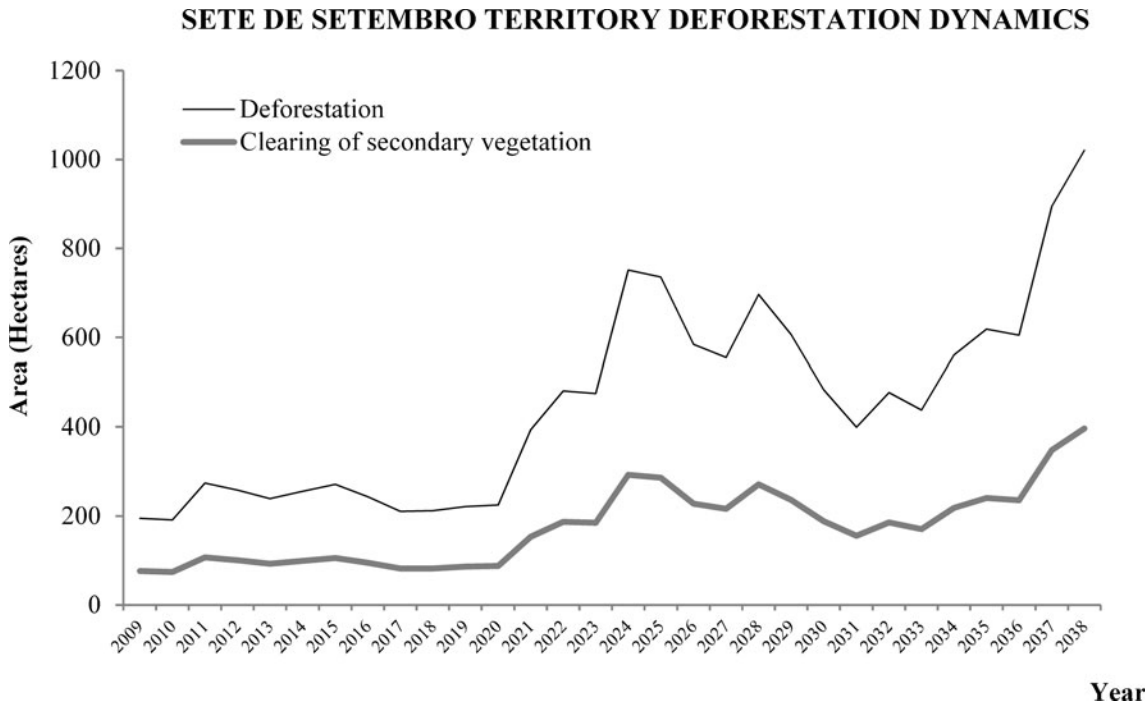

Fig. 6 Landscape dynamics through SIMSURUI simulations between 2009 and 2038

availability will have a preponderant role in shaping the evolution of modernity in the life style of Suruí households. As illustrated by Group 1, if fixed income increases and compensates for expenses among productive groups, then the level of consumption would be higher than the modeled level but lower than historical consumption because of a resulting downward evolution of cash flow. A desired cash flow could have been considered that corresponds to the average expenses of Brazilians, but, as observed in the model, this would have led to more reliance on divided production systems and consequent demand for deforestation to obtain productive revenues that could satisfy this level of financial demand. The SIMSURUI reference scenario would then sustain the Suruí standard of living for all productive groups, but for Groups 2 and 3 it implies relying on illegal agreements that lead to higher deforestation rates because they depend more heavily on income from the productive systems.

Land-use Trajectories in the SSIL: A Switch from Coffee Cultivation to Cattle Ranching?

One of the assumptions that is considered conservative is the fixed proportions of households among productive-agent groups, as observed in 2009. Since cattle ranching is economically more profitable (in terms of return on money invested), the model could have assumed a progression of households switching from Group 1 to Group 2 and from Group 2 to Group 3. This would be based on the maximization of profits, since the internal rate of return is higher for cattle ranching than for coffee production, and, consequently, the Suruí would progressively abandon their coffee plantations to establish pastures. However, arguments to the contrary suggest that there is no clear trend towards this distribution of productive groups. Both coffee and cattle ranching are linked to access to local markets, to historical insertion in the market, and to experience with these activities. An additional factor restraining pasture is a respect for forest by indigenous people that represents an additional value placed on the ecological impact of land-use practices. We are not able to evaluate the proportion of the Suruí who hold this more-conservationist value, versus individuals who are more opportunistic and would devalue the importance of environmental impacts. Indeed, the impact of cattle ranching is much higher because it demands more land to be as profitable as coffee production.

As reported by Metareilá (2010), households have recently opted to implant both coffee plantations and pastures, and the majority of coffee plantations are not yet productive, indicating that coffee cultivation is contingent on the choices regarding cattle ranching. Additionally, the Suruí have gained experience in coffee production since 1980, although the Suruí have not practiced this activity continuously in the intervening years due to fluctuations in the price of coffee (Metareilá 2010). Metareilá argues that coffee growing is the principal activity in villages that do not participate to illegal logging. During the participatory workshops, some participants argued that the households that used to only sell timber and that had abandoned agricultural habits would directly establish pastures. The pastures could be either as Suruí-managed systems or for leasing. It was argued that cattle ranching would be favored over coffee because pasture is economically more profitable and less demanding on manpower and time, is less dependent on climatic conditions, and is less subject to market volatility.

On the contrary, the current pressure of international environmental groups on slaughter houses to avoid purchasing cattle from Amazonian protected areas is stronger than before and could discourage some Suruí from ranching. If voluntary involvement of companies such as JBS (which has an almost-complete monopoly on cattle purchases in Cacoal) is effective, the Suruí would encounter serious problems in selling their cattle directly to the slaughter house. The profitability of indigenous cattle ranching would be significantly reduced if intermediaries were to enter the price chain in order to disguise the origin of the cattle. This might favor coffee production if the coffee market remains stable. However, it appears that, in practice, Suruí households succeed in selling cattle to the slaughter house in Cacoal (ABIEC 2012). Two years after the environment-friendly accord between JBS and Greenpeace to impede purchase of cattle originating from protected areas, the NGO attacked JBS for not respecting the agreement, especially for buying cattle from indigenous lands in Mato Grosso (Greenpeace 2012). JBS countered by claiming that Brazilian governance is not able to trace the origin of cattle from birth to final sale (JBS 2012). We can therefore doubt the effectiveness of the agreement between Greenpeace and JBS because JBS is well aware of previous failures in monitoring the cattle-ranching chain, especially the illegal contracts for leasing pastures in indigenous lands (Greenpeace, 2012). Since commercial cattle ranching by indigenous people is not a prohibited activity in indigenous lands, what would be questionable is the reduction of access to the market for the Suruí-managed cattle ranching. This could indirectly favor the illegal activity of pasture leasing unless there is total control over every step in the beef production chain, including the fattening of cattle in indigenous lands. Under the assumptions of the model, this situation could increase deforestation inside indigenous lands in order to meet the R$1500/hh/yr cash-flow target because the illegal practice requires three times as much land to generate the same income for the Suruí, as compared to Suruí-managed cattle ranching.

Another limitation of the SIMSURUI model is the constancy of the profitability of Suruí activities. The possible improvement of practices during the simulations is not considered. We can imagine that the Suruí would improve the yield of coffee cropping (e.g., space between lines of plants and reduction of invasive plants as reported in the socioeconomic survey by Meitarelá) and increase their return on investment in coffee cultivation based on the fact that surrounding colonists, who act in the Suruí systems as sharecroppers or as wage laborers, are sharing their knowledge coffee growing with the Suruí and influencing the improvement of practices. Cattle ranching is less demanding on agricultural techniques. Ranching could also be improved in the future, especially with respect to animal density per hectare and implantation of pastures based on slash-and-burn, but not necessarily meaning improvement of profitability. Since the IDESAM profitability calculation considered that the Suruí pay for foot-and-mouth disease vaccine and for all wage labor, it is possible that cattle-ranching profitability is slightly underestimated.

Defining a Local LULCC Reference Scenario for a REDD Project

One of the major criticisms of REDD reference scenarios is the uncertainty of the emissions calculation on which the financial calculation of REDD credits is based, and the creation of undeserved "hot-air" credits that could distort the carbon market (Olander *et al.* 2008, Huettner *et al.* 2009). Increasing complexity through inclusion of many variables to represent a socio-ecological system, as is the case in the SIMSURUI, can lead to increasing the uncertainty of a LULCC predictive model as compared to a simple statistical model. Associating variables implies combining their respective natural variability and the uncertainty of the methods from which the values were derived. Additionally, when no historical trends could be determined from data, we had to assume future trends of parameters and variables based on expert knowledge and the visions of the Suruí leaders expressed in the participative workshops. Relying on a statistical model with only one or two variables, such as population size or distance to market, can hide other variables that explain land-use dynamism at the level of productive agents. In order to project the future strategic behavior of productive-agent groups (as in SIMSURUI), combining economic, productive and landscape data may appear to have led to increased uncertainty in the LULCC model. However, the more complete representation of the socio-ecological system provided by systems modeling was useful in order to integrate different trends in the variables and to understand how the result influences land-use patterns, sometimes in un-expected ways.

In the SSIL case, integrating local variables in a LULCC model led to obtaining lower projected deforestation rates than those from hypothetical projections made by environmental NGOs and obtained by other LULCC models that project future deforestation throughout the Brazilian Amazon Basin. This includes the SIMAMAZONIA model in the DINAMICA-EGO platform by Soares-Filho *et al*. (2006) or the model of Brazilian Amazonia in the CLUE software by Aguiar (2006). The SIMSURUI SFCP reference scenario projects deforestation of 6 % of the territory by 2038, which is much lower than the hypothetical projection of ISA and Forest Trends (2010) that expects at-risk indigenous lands (such as the SSIL) to be approximately 20 % deforested by 2020. SIMAMAZONIA also projects higher deforestation, with 35 % of the SSIL deforested by 2038. Basing the deforestation rate calculation on a sub-region that encompasses several municipalities, the SIMAMAZONIA model allocated a higher deforestation rate in the SSIL. The parameter values in SIMAMAZONIA do not consider variables internal to the protected areas. Projecting deforestation based on internal factors related to local land-use activities together with the influence of agents in the surrounding area can produce more realistic results for protected areas than can applying a sub-regional deforestation rate that homogenizes the agents and drivers of deforestation.

In the case of the Juma REDD project (IDESAM 2009), developed in the southern part of the state of Amazonas, the land-use baseline was determined from the SIMAMAZONIA projection and consequently does not consider internal information from this sustainable-use reserve. The Juma project was validated both by the Voluntary Carbon Standard (VCS) and Climate, Community and Biodiversity Alliance (CCBA) norms in 2009. For a REDD project, the integration of local land-use dynamics in a protected area can be considered a progress in the sense that characterizes the inherent pressure on inhabited forest ecosystems.

The development of a specific LULCC model is only possible in well-studied sites such as the Suruí territory. Demographic data are available for almost all Brazilian Amazonian tribes because they have been monitored by FUNASA for decades, but land-use characterization and socioeconomic diagnostics are not usually available in indigenous lands. A few management and use plans exist in Brazilian indigenous lands (GEF 2009). In Rondônia, only three of 24 indigenous lands have such plans, all of which were produced by Kanindé and the Amazon Conservation Team (ACT) NGOs (see http://www.kaninde.org.br).

In the SIMSURUI model, socioeconomic data are the core of the land-use strategy modeling. Developing LULCC models based on demographic trends and historical deforestation rates is possible but less precise if the model does not include realistic land-use dynamics, which are first characterized by socioeconomic surveys coupled with spatial analyses. Specific prospective studies are needed to plan territorial and environmental management in protected areas, indicating zones where deforested land uses would be developed depending on demography and population needs and other zones that would be strictly preserved to guarantee environmental integrity.

Analyses such as that of cash flow in Suruí households are useful to indicate how a REDD project will deal with benefit-sharing incentives. Without this information on the economic standard of living it is likely that cost-opportunity calculations will fail to represent the true situation of the community. Local specificities must be included in the baselines for REDD projects if this mechanism is to have a role in countering the real threats to indigenous lands and other protected areas. The Suruí REDD project baseline studied here was developed in accord with current procedures for site-specific projects and was certified by the standards VCS and CCBA in 2011 (United States, USAID 2013).

However, Brazil is currently constructing a federal REDD framework, and some of the state governments in the Legal Amazon region are also developing independent frameworks (Brazil, MMA 2012). At the same time that mitigation is being done at the project level, it is also being done at the national level under the Amazon Fund (Brazil, MMA 2009). National-level emissions reductions are calculated based on the total decrease in deforestation indicated by the PRODES dataset, including the (currently very small) portion of this decrease that occurs inside REDD projects. At present climatic integrity is not jeopardized by the same emissions reductions being doubly rewarded (once in the projects and again based on the national accounts) because REDD currently does not generate carbon credit (certified emissions reductions: CERs) at either level. If future negotiations result in carbon credit for REDD, then it will be essential to avoid double counting of the emissions reductions. A "nested approach" has been proposed (Zhu *et al.* 2010) that would guarantee that a project baseline for deforestation (such as the present one) could be integrated into a national baseline, thus avoiding double counting of emissions reductions. A variant of this is the Jurisdictional and Nested REDD + Initiative (JNRI) (VCS 2012). Whatever procedure is adopted, it will be necessary to maintain a registry of project emission reductions to be deducted from the national accounting (Fearnside 2012a).

Conclusions

The land-use change modeling for the reference scenario of the proposed Suruí Reduced Emissions from Deforestation and Degradation (REDD) project has a wide variety of features that contribute to its realism and conservative nature in estimating baseline deforestation rates.

Modeled scenarios of future developments are inherently uncertain, although the model developed for the Suruí baseline (SIMSURUI) uses the most reliable information available from a 2-year data collection effort with wide participation of tribal leaders and organizations. Most indigenous groups lack this level of information.

The data and modeling demands of REDD baselines represent significant, but not insurmountable, barriers to wider implementation of indigenous REDD.

The increasing threats to indigenous areas from deforestation and logging, as in the case of the Suruí, indicate the need for economic alternatives that reward forest maintenance for environmental services. REDD is currently the alternative of this type that is closest to providing a source of such support. This justifies considerable effort to continue improvement of data and models for REDD baselines. SIMSURUI provides a starting point for these efforts.

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