Deforestation and Carbon Emissions in Amazonia: Simulating the Impact of Connecting Brazil's State of Roraima to the "Arc of Deforestation" by Reconstructing the BR-319 (Manaus-Porto Velho) Highway

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The BR-319 Highway, connecting Porto Velho, Rondonia to Manaus, Amazonas, was the main migration link to Roraima from 1975 until closure of the highway in 1988. Reconstruction of the highway is included in the Brazilian federal government's Program for the Acceleration of Growth (PAC) along with the construction of the Santo Antônio and Jirau hydroelectric dams in Rondônia. Rondônia, in the southeastern portion of Brazilian Amazonia, is part of what is known as the "arc of deforestation." The dam-building projects are expected to attract approximately 100,000 people to Rondônia during the construction period. When construction of the dams ends in 2013 these people will further increase the demand for arable land. In the arc of deforestation the advance of agribusiness and extensive cattle ranching has made land increasingly scarce. Therefore, we assume that reopening the road will lead to a new flux of migrants from the arc of deforestation to central and northern Amazonia. The state of Roraima lies in the far north of Brazilian Amazonia and the southern part of Roraima has 70,500 km2 of primary forests. About 35% of these forests lack any legal conservation status and are accessible from Manaus via the BR-174 Highway. This region may attract the large migratory flux that is expected if the BR-319 Highway is reconstructed because the soils in Roraima are more fertile and productive than those in central Amazonia. Based on these premises and using the DINAMICA-EGO land-use and land-cover change simulation and modeling software, we have built three future scenarios of deforestation and carbon emissions from 2007 to 2030. A baseline scenario, which assumes no reconstruction of the BR-319, follows the deforestation trend observed between 2004 and 2007. The other two scenarios were built by taking into account the reconstruction and paving of BR-319 Highway. In one of these, called BAU (business as usual), a large migratory flux occurs into southern Roraima with a consequent increase in deforestation. In the other, a conservation scenario, public preservation policies negatively influence the deforestation rate. In the baseline scenario, cumulative deforestation reaches 3478 km2 in 2030, emitting de 59.1 × 106 tons of carbon. The BAU scenario results in 5100 km2 of deforestation and 86.5 × 106 tons of carbon emission. In the conservation scenario, 2966 km2 of deforestation are avoided as compared to the BAU scenario and 1343 km2 are avoided as compared to the baseline (no road) scenario.

Key words: Environmental modeling, Land use Land-use change, Amazon, Deforestation, Spatial analysis, Simulation

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Introduction

The extensive deforestation that has taken place along the southern edge of Brazilian Amazonia has been possible because of a series of factors, especially the improvement and expansion of the road network in this area in the 1970s and 1980s. Road access allowed a large population of migrants to move to remote areas in Amazonia, leading to rapid and uncontrolled deforestation in the area.

In the mid-1980s deforestation assumed alarming proportions when the main connections were paved between Amazonia and the major national population centers in the southern and southeastern parts of the country (Fearnside, 1989, 2005; Oliveira, 2005). Prominent events in this process were the paving of the portion of BR-163 (Cuiabá-Santarém) Highway in Mato Grosso and of the BR-364 Highway linking Cuiabá (Mato Grosso) to Porto Velho (Rondônia) (Fearnside, 1989) and later from Porto Velho to Rio Branco (Acre). These highways allowed more and more migrants to move to Amazonia, increasing pressure on the biome and on its resources, and, more recently, these roads facilitated the entry of soybean agribusiness (Oliveira, 2005; Carneiro-Filho, 2005).

These new forces are added to the processes of forest degradation already present from cattle ranching and logging in the area known as the "arc of deforestation." Both capitalized soy farmers and poor landless peasants (*sem terras*) are contributing to a new pulse in deforestation in Amazonia. Vast areas of forest are felled to establish new ranches for cattle, soy farms, and for holdings from illegal appropriation of public lands (*grilagem*) by large operators and through invasion of land by small farmers. An indication of the strong pressure that these economic activities exert on natural resources in Amazonia is the fact that prices for soy and beef strongly correlate with the pace of deforestation (Barreto *et al*., 2008).

In this context, the Brazilian government, under the aegis of the Program for Acceleration of Growth (PAC), plans to build a series of infrastructure projects in Amazonia. Among these are the Jirau and Santo Antonio hydroelectric dams on the Madeira River, upstream of Porto Velho, capital of the state of Rondônia. Also included is the reconstruction and paving of the BR-319, linking Porto Velho to Manaus, the capital of the state of Amazonas (Viana *et al*., 2008; Fearnside *et al*., 2009).

During the construction phase of the dams about 100,000 people are expected to be attracted to Rondônia and they will increase the pressure for arable land. Considering the fact and that the rural population in the arc of deforestation can no longer find land available for colonization or logging due to the expansion of agribusiness and of extensive cattle ranching, we assume that the reopening of the BR-319 Highway will provoke new migratory flows from these areas to the central and northern Amazon (Fearnside & Graça, 2005; 2006; Viana *et al*., 2008). The BR-319 Highway was the principal migration route to the state of Roraima from 1975 until lack of maintenance resulted in this economically unproductive highway being closed in 1988.

The southern portion of the state of Roraima still has over 70,500 km² of primary forests. We believe that this area could attract a large part of the expected migratory flow if the BR-319 is re-opened. This is because southern Roraima has more fertile and productive soil than does the central Amazon and because the highway will facilitate access to the area from the "arc deforestation".

The principal objective of our study was to simulate three future scenarios of deforestation for the southern part of the state of Roraima from 2007 to 2030 and to estimate the emissions of carbon to the atmosphere resulting from this.

Significant changes are taking place in Latin American in the way in which rights to land and forest resources are being granted to local people, and also in who is gaining access to these resources. As a result, an important portion of indigenous and traditional people, and other smallholders are consolidating their control over forest lands at a scale that was unthinkable in the past. This process, which begun in the mid 1980s, may have even more decisive outcomes on land tenure than previous agrarian reforms implemented in the region. The unfolding land reform, labeled here 'forest tenure reform' differ in several ways with agrarian reforms of earlier years where lands – including forest lands – were transferred to peasants for agricultural purposes, in keeping with the dominant rural development paradigms of that time (Delgado, 1965; Thiesenhusen, 1995).

Forest tenure reforms takes place in forest landscapes, and are devised to recognize land and forest rights to a diversity of local people making a living on such landscapes (e.g., indigenous people, traditional settlers, and smallholders). These reforms are expected to reconcile both conservation and livelihood needs. Land reforms tend to be differentiated between those reforms prompted by states or originated 'from above' from those being promoted 'from below' or community-led reforms (Sikor and Müller, 2009). It is not clear who is the main actor that drives tenure reform, though mostly they emerged from complex interactions between states and community-led reforms. Multiple motivations underpinning forest reforms reside on the implementation of land administration programs, in growing global concerns for biodiversity conservation, and in local demands for tenure rights, mainly from indigenous people.

Methodology

Study area

The study area includes the whole of the southern part of the state of Roraima encompassing five municipal districts: Caracaraí, Rorainópolis, São Luiz de Anauá, São João da Baliza and Caroebe. These municipal districts have a total area of 99,634 km², or 44% of the total area of Roraima (Fig. 1). The area is cut by the BR-174 Highway in the north-south direction and by the BR-210 Highway in the east-west direction. These highways were built in the 1970s during Brazil's military regime and have served as access for migration and recent colonization of the area. The area deforested by 2007 in the area totals 3723 km², or 3.7% of the total area of the southern part of the state and about 5% of the area of remaining forest in this region (Brazil, INPE, 2008). Please see Fig. 1.

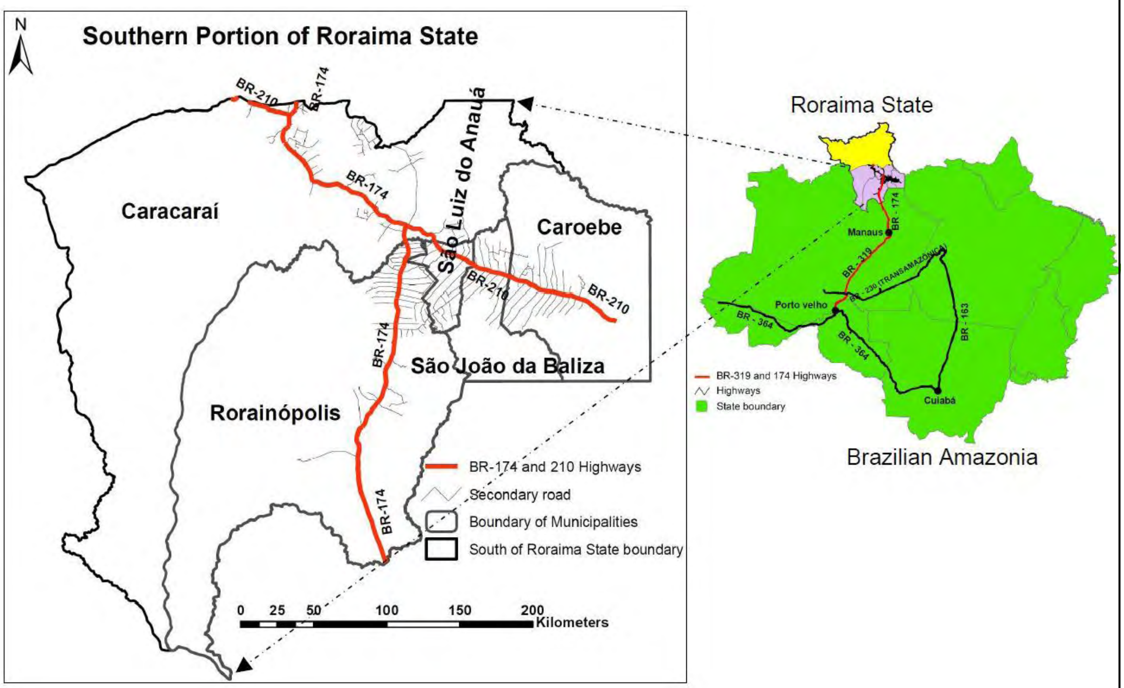

Figure 1. Location of the study area

Spatial data for input to the model

The spatial model of land use was based on the DINAMICA-EGO software (EGO stands for "Environment for Geoprocessing Objects"), developed in the remote-sensing laboratory of the Federal University of Minas Gerais by the group lead by Britaldo Soares-Filho (Soares-Filho *et al*., 2006). DINAMICA-EGO uses as input data maps of land use (Fig. 2), maps of static and dynamic variables and maps of transition probabilities or of weights of evidence. More information on DINAMICA-EGO can be obtained at www.csr.ufmg.br/dinamica. Please see Fig. 2.

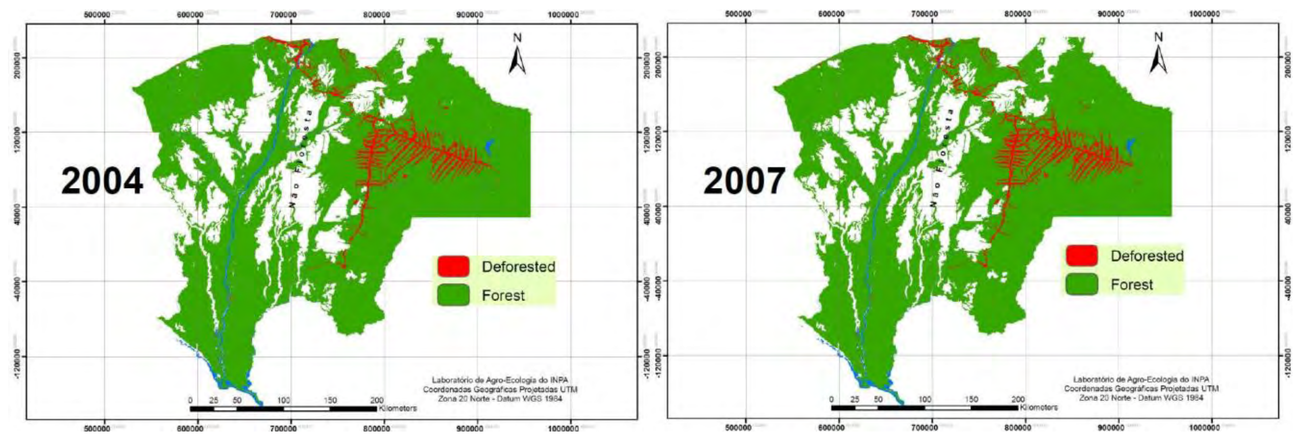

Figure 2. Maps of land use and land cover in the study area in 2004 (a) and 2007 (b) used as initial maps and for calculation of the rates of transition for 2004-2007

Static and dynamic variables

As static variables (Fig. 3a) we used digital maps of altitude, relief, rivers, soils, vegetation, friction (or cost), favorability, indigenous areas and conservation units (Brazil, SIPAM, 2008) and maps of the settlement projects (Brazil, INCRA, 2007). The dynamic variables (Fig. 3b) used were maps of highways, distance to the main highways, distance to secondary roads, distance to the "land-claiming area" (área fundiária), distance to settlement projects, distance to rivers, distance to deforested areas and distance to forest. These variables were characterized by their changing values during the model runs used for constructing the scenarios. Please see Fig. 3.

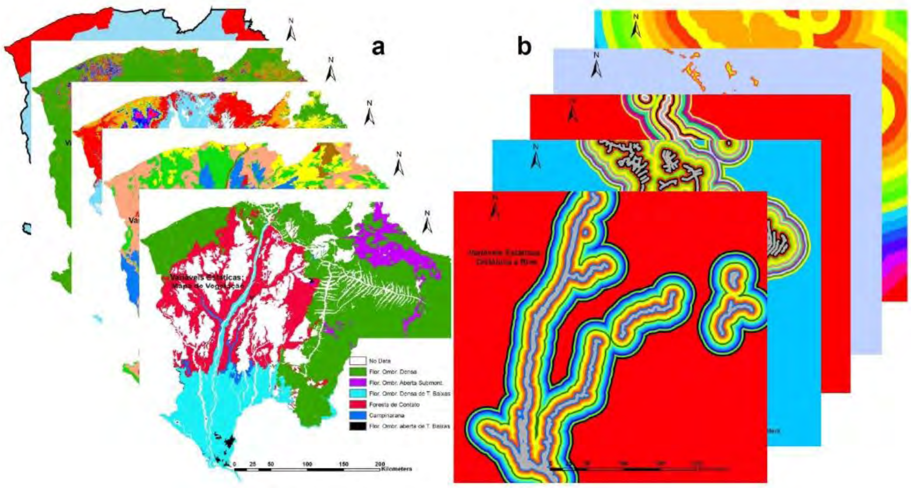

Figure 3. Maps of static variables (a) and dynamic variables (b)

Weights of evidence

Weights of evidence originated from the Bayesian method of conditional probability. In modeling the dynamics of land-use and land-cover change they are applied to calculate *a posteriori* probabilities, in this case the probability of deforestation, given that the locations with favorable conditions for deforestation are known *a priori*. In this step in the modeling, the maps of land use, static variables and dynamics were combined in a sub-model in DINAMICA-EGO for extraction of the weights of evidence (Please see Fig. 4). The influence of the weights of evidence on the variables can be positive (favoring deforestation) or negative (inhibiting deforestation). The weights of evidence are recalculated in each iteration considering the total area of forest that results from the roads that are created and added to the current road network. Highways can be programmed to be built at certain time steps or iterations of the simulation. Using this approach, planned highways follow the official calendar for construction at specified dates in the future (Fearnside, 2009). The probable impacts can be appraised, thereby aiding in prevention and mitigation measures.

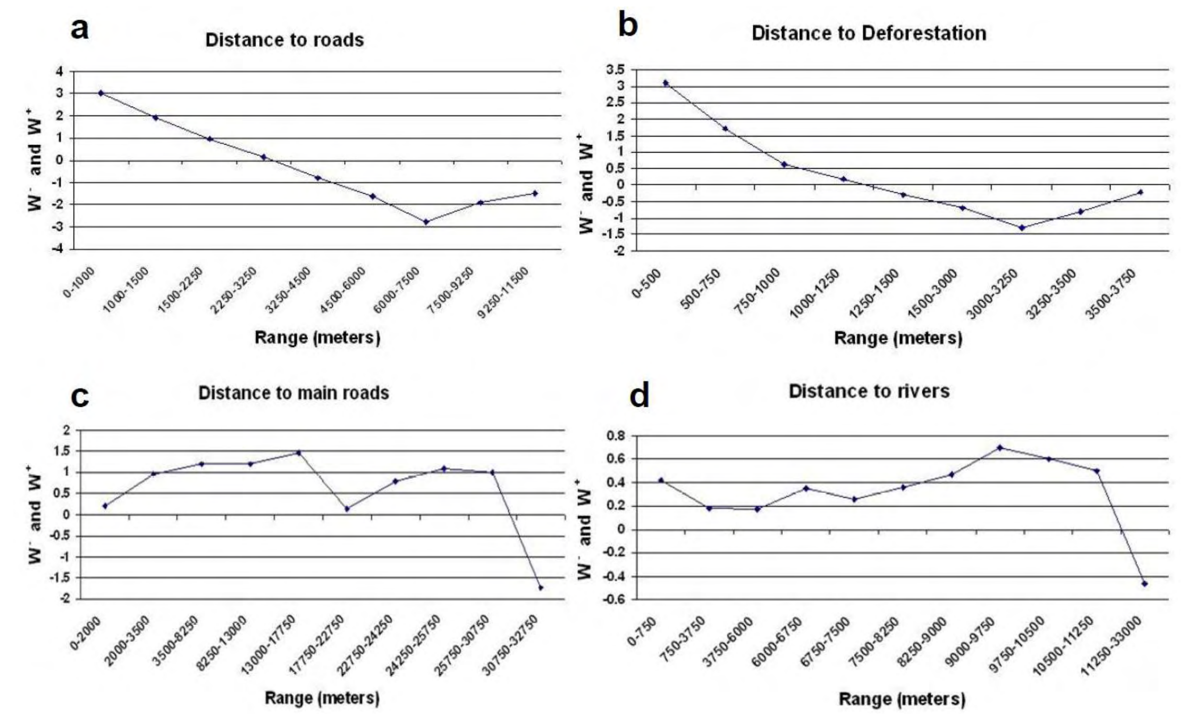

Figure 4. Examples of weights of evidence of some dynamic variables used in the model: distance to deforestation (a), distance to rivers (b), distance to secondary roads (c) and distance to main highways (d)

Patcher and expander functions

DINAMICA-EGO uses as a local rule for its cellular automata algorithm a transition mechanism composed of two complementary functions: "patcher" and "expander". The patcher function searches for cells in a chosen place for a combined transition to form new patches through a seeding mechanism. This is done by first choosing the central cell of a new patch and then selecting a specific number of cells adjacent to the central cell, in agreement with the transition probability P (i→j) calculated by the weights of evidence. The expander function is dedicated to the expansion or contraction of previous patches of any given class. In the expander function a new probability of spatial transition P (i→j) depends on the number of cells of type j in the neighborhood of a cell of type i. For construction of the scenarios the transitions used were: forest/deforestation (3→1), deforestation/regeneration (1→2) and regeneration/deforestation (2→1).

The AGROECO model and the road-building module

In generating the future scenarios for the southern portion of Roraima we used the AGROECO model developed by Fearnside *et al*. (2009) using the DINAMICA-EGO framework (Soares-Filho *et al*., 2006). The AGROECO model incorporates a series of innovations to the original conceptions of DINAMICA. The

AGROECO model creates, with each iteration, a surface of accessible forest. This area expands in response to building new roads in the road-building module. The area of accessible forest is adjusted to the roads in the model, expanding to include strips of pre-defined width on both sides of the new road. The AGROECO model, unlike demand-based models, is driven by creation of infrastructure such as highways planned for the future (Fearnside *et al*., 2009). In this study and for all of the scenarios, the modeled construction of major planned highways obeyed the government of Roraima's official schedule for paving highways. Secondary roads were mapped using the MCE (Multiple Criteria Evaluation) tool in the DINAMICA-EGO software. The probable dates of construction of the secondary roads were based on field interviews and on the literature.

Premises for the scenarios

The scenarios were built starting from a series of premises (Please see Fig. 5). These premises are impositions on the model in order to obtain answers and to help in interpretation of the scenarios generated later during the simulations.

Baseline Scenario

- Historical of Deforestation rates + Projected Construction of Roads

Conservation Scenario

Low effect of migration on deforestation due to policies of contention:

- Creation of Conservation Units
- No creation of New Settlement Projects
- No expansion of the existing Settlement Projects in the area
- High control and inspection of logging
- Enforcement of Ecological Economic Zoning

BAU (*Business As Usual*) Scenario

High effect of migration on deforestation due to the incentive and policies to attract migrants:

- Donation of Land
- Creation of New Settlement Projects and Expansion of old Settlement Projects
- Fiscal incentives to large Rural Producers
- Application of Agricultural Subsidies
- Lines of credit for Small and Medium Farmers
- Low control and inspection of logging
- No enforcement of Ecological Economic Zoning

Figure 5. Premises for the scenarios

Proposed conservation units

Proposed conservation units in the conservation scenario totaled approximately 695.000 ha (Fig. 6). The shape and location of the conservation units were planned to allow connectivity with other conservation units that had already been implanted in the area, forming an immense corridor from the south and southeast and reaching the northeastern part of southern Roraima (Ferreira & Venticinque, 2007). (See Fig. 6).

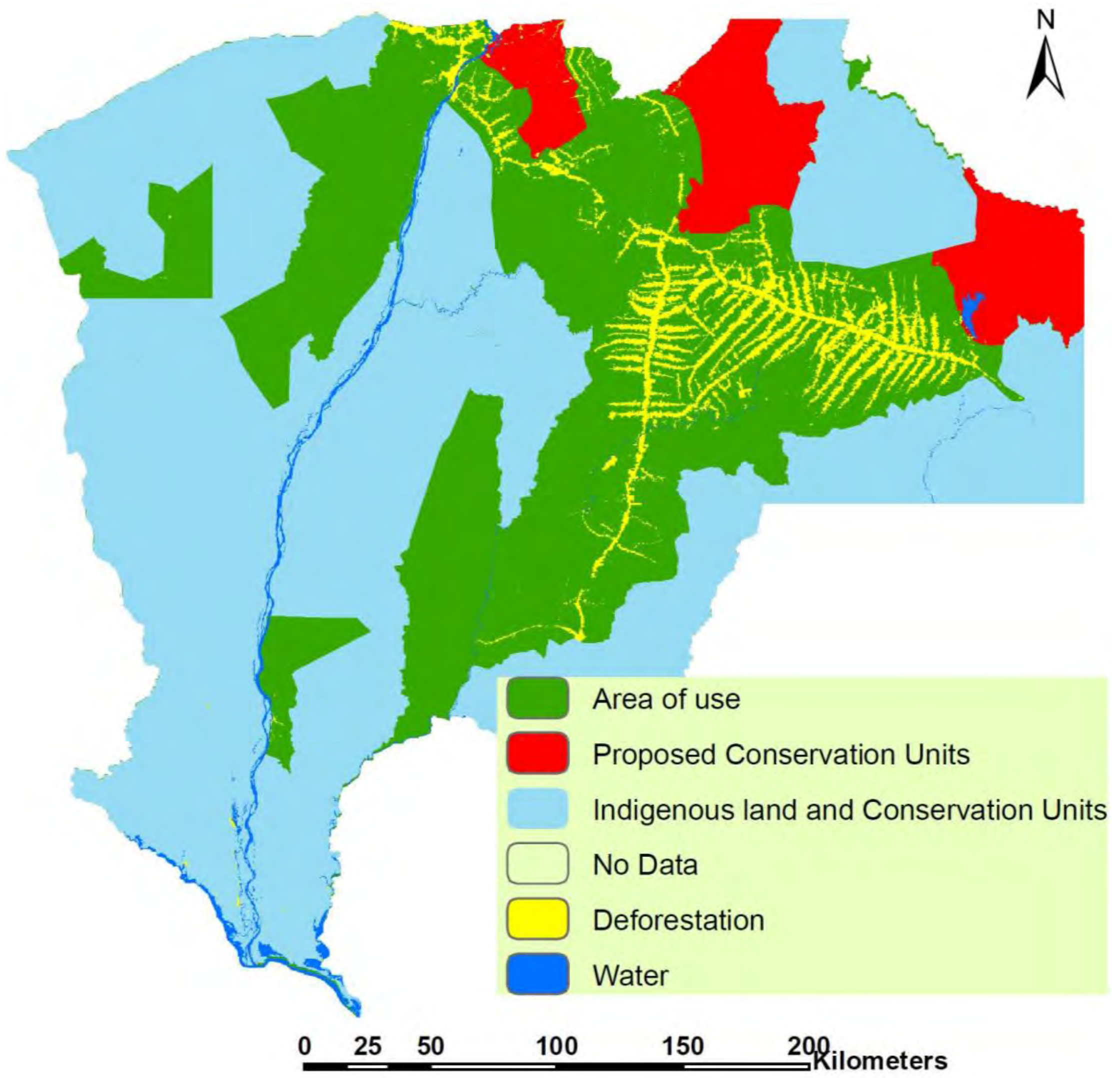

Figure 6. Conservation units proposed in the conservation scenario (in red)

Calibration and validation of the AGROECO model for generating scenarios

The AGROECO model was calibrated starting from the calculation of the forest/deforestation transition rates derived from land-use maps of the study area for 2004 and 2007 obtained from the PRODES project (Brazil, INPE, 2008), for the baseline scenario (CLB). This followed the trend of historical deforestation rates for southern Roraima (Barbosa *et al*., 2008) and it was also used for validation of the model (Fig. 7)

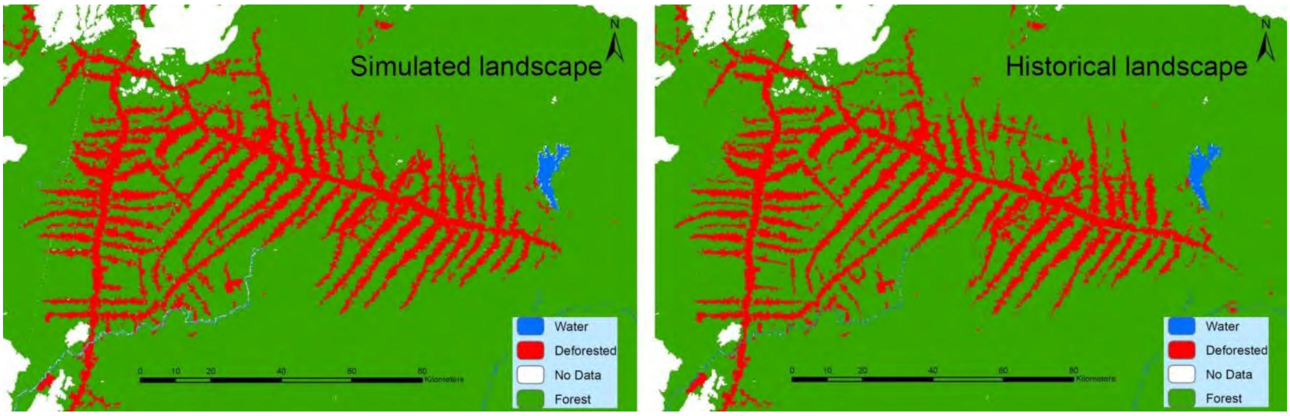

Figure 7. Enlarged detail of the comparison between the map of simulated deforestation between 2004 and 2007 and the map of deforestation observed in southern Roraima in 2007 from PRODES satellite imagery (Brazil, INPE, 2008) for the validation of the model

Validation of the model consisted of comparing the map of simulated deforestation from 2004 to 2007 in a baseline scenario and the map of deforestation observed in 2007. We used the modified fuzzy method (Hagen, 2003), which considers a similarity of 50% to be sufficient for validation. A similarity index value of 51.2% was obtained for the baseline scenario model, which assumes no reconstruction and paving of the BR-319 in 2011. The baseline scenario served as a reference for the other scenarios. The transition rate was calculated as:

$$TBA = ((DEFORESTATION_{(2007)} - DEFORESTATION_{(2004)}) / FOREST_{(2004)})) / 3 \quad (1)$$

Where TBA is the "annual base rate" derived from the land-use maps for 2004 and 2007.

In the iterations where the construction of highways was programmed, TBA was multiplied by a "planned highway rate" (TEP). The calculation of TEP is given by the ratio:

$$TEP = (AFDE_t / AFD_{(t-1)}) + 1 \quad (2)$$

Where: AFDEt is "Area of forest made available by the road at time t" and AFD it is the "area of available forest at time t-1".

TEP represented an increase in the probability of there being deforestation in the area made available by the roads in the subsequent iterations. This is due to the assumption of an increase in the human pressure on the accessible area, which is made possible by building the roads.

In the model built to run the conservation scenario (CC), which assumes that the BR-319 will be reconstructed and paved in 2011, the same rates were used as in the baseline scenario. In the conservation scenario built to simulate policies for containing deforestation three conservation units were created (Fig. 6) and the planned roads to destinations in the newly created conservation units were removed from the model.

For the business-as-usual (BAU) scenario, which also assumes that the BR-319 will be reconstructed and paved in 2011 and that the deforestation rates described for the previous scenarios apply, a "migration factor" (FM) was used. This factor simulated the increase of deforestation as a function of the expected migratory flow to the area after the reconstruction and paving of the BR-319 in 2011:

$$FM = TDPA_{(95/97)} / TBA \quad (3)$$

Where: $TDPA_{(95/97)}$ is the rate of deforestation observed in the settlement projects created between 1995 and 1997 in southern Roraima. This rate is derived from information on the period between 1996 and 2001. In this period a large migratory flow to the area occurred that was stimulated by the local government through donation of land and creation of settlement projects (Mourão, 2003). The FM was applied starting from the year 2012. It was assumed in this study that the new roads served as access infrastructure in the settlement projects and therefore were causes of the increased rates of deforestation (Brandão Jr. & Souza Jr., 2006).

The calculations of the rates presented above were done in the non-spatial numerical model in Vensim® (Ventana Systems, 2008). The rates are calculated in Vensim and passed to the spatial model (AGROECO) via a connecting link between DINAMICA-EGO and Vensim (Fearnside *et al*., 2009) to obtain rates that vary with each iteration. (See the Fig. 7).

Estimate of forest biomass

To estimate forest biomass above- and belowground (excluding soil carbon) we used the map of average biomass density in Amazonia developed by Nogueira *et al*. (2008). For savanna ecosystems, which are not included in the RADAMBRASIL inventories (Brazil, Projeto RADAMBRASIL, 1975), studies by Barbosa & Ferreira (2004) and Barbosa & Fearnside (2005) were used. For estimates of the biomass of the roots of these ecosystems the root/shoot ratio of 2.81 was used based on cerrado studied by Abdala *et al*. (1998) and Castro and Kauffman (1998). The calculations were done using map algebra operations in the ArcGis 9.1 software, using the map of classes of average biomass density for Amazonia and the map of land use in 2007. To obtain the areas occupied by each forest type a multiplication was done of the binary map of forest class (1) and the map of biomass classes. The total of these areas was obtained by summing the number of pixels in each class and multiplying by the area of each pixel (6.25 ha). The total value of the average remaining biomass in the southern part of Roraima in 2007 was obtained from the total area (ha) occupied by each forest type multiplied by its respective average biomass (t ha^{-1}). This average total biomass (above and belowground, including the necromass) was calculated for southern Roraima to 2007. After conversion it represented the stock of carbon in the remaining forests in the area up to 2007 (Table 1).

Table 1. Biomass present in the forests of southern Roraima in 2007. Calculations of average biomass below and aboveground done by Nogueira et al. (2008)

*Code	Forest type	VALUE	**Pixels by forest type	ABOVE and BELOW	Inventories	Biomass	Carbon Stock
		n	n	Ton/ha^{-1}	n	Ton/Forest type	Ton/Forest type
LO	Contact zone: rainforest & vegetation on white sand	**15**	149864	384.6310	274	360264645.5146	174728353.0746
Fs	Seasonal semideciduous forest, submontane	**10**	187	315.6799	33	368950.8934	178941.1833
Ab	Open-canopy rainforest on non-flooding lowlands	**6**	36318	363.4307	265	82494236.1540	40009704.5347
As	Open-canopy rainforest, submontane	**7**	87053	336.0238	618	182824258.4537	88669765.3500
Da	Dense-canopy rainforest on river floodplain	**14**	38542	360.8265	144	86918603.7334	42155522.8107
Db	Dense-canopy rainforest on non-flooding lowlands	**13**	229923	384.5027	517	552537610.4613	267980741.0737
Dm	Dense-canopy rainforest, montane	**11**	20845	361.3022	27	47070899.0478	22829386.0382
Ds	Dense-canopy rainforest, submontane	**12**	415241	385.3348	533	1000042511.1369	485020617.9014
La	Open Woody Oligotrophic Vegetation of swampy & Sandy areas	**8**	26939	60.6171	[a]	10206025.3556	4949922.2975
Ld	Dense Woody Oligotrophic Vegetation of swampy & Sandy areas	**4**	100589	365.0000	[d]	229468656.2500	111292298.2813
Lg	Grassy-woody Oligotrophic Vegetation of Swampy & Sandy areas	**3**	7727	46.0000	[c]	2221512.5000	1077433.5625
Sa	Open Woodland Savanna	**2**	13506	44.6951	[b]	3772825.1288	1829820.1874
Sg	Grassland Savanna	**1**	524	12.573	[b]	41176.5750	19970.6389
	Total	-	**1127258**	-	-	**2558231911.20**	**1240742476.93**

*** Brazil, IBGE, (1992).**
**** Pixel resolution: 250 meters (6.25 ha).**
[a] Barbosa & Ferreira, (2004) and 2.81 (root/shoot) for root fraction (Barbosa, Personal comm.).
[b] Barbosa & Fearnside, (2005) and 2.81 (root/shoot) for root fraction (Barbosa, Personal comm.).
[c] Estimates from Kauffman et al., (1988) and Klinge et al., (1975).
[d] Estimates from Project RadamBrasil (1973-1983).

forests) used for the scenarios were 22% and 14% for regrowth (de Barros Ferraz *et al*., 2005; Soares-Filho *et al*., 2006).

Estimate of carbon emissions to the atmosphere

The biomasses of forest and of the secondary forest were converted to carbon using the conversion factor of 0.485 (Silva, 2007; Nogueira, 2008). Biomass was calculated as:

$$\text{tons } C_{(forest)} = \text{tons forest biomass} * 0.485 \qquad (4)$$

Where tons $C_{(forest)}$ it is the estimate of carbon contained in the biomass, in tons; tons forest biomass is the total biomass found in the forest and in the secondary forest (*capoeira*).

The estimates of emissions for each scenario generated up to 2030 were calculated from the loss of carbon stock in the remaining forests in 2007 until the date of the simulated deforestation. This is calculated as follows (Houghton *et al*., 1997; Fearnside *et al*., 2009):

$$\Delta C_{(Scenario)} = A * (C_{2030} - C_{2007}) \quad (5)$$

Where: $\Delta C_{(Scenario)}$ is the net emission of carbon (tons C) from deforestation between 2007 and 2030 for each scenario, discounting the average stock of carbon in the equilibrium landscape that replaces the forest (Fearnside, 1996); A is the area (ha) deforested in the period; C_{2030} and C_{2007} represent the stocks of carbon (tons C ha^{-1}) in the landscape before and after deforestation.

Results and Discussion

Deforestation scenarios, biomass estimates and carbon emissions

It was a challenge to model the scenarios of deforestation for southern Roraima. Due to the lack of models providing examples of highway construction in one location causing deforestation in another location. Construction of highways in Amazonia always leads to more deforestation (Fearnside, 1989; Nepstad *et al*., 2001; Escada & Alves 2001; Geist & Lambin, 2002; Soares-Filho *et al*., 2004, 2006). However, it is not evident that the reconstruction and paving of a highway like the BR-319 will make the rates of deforestation increase in the southern part of the state of Roraima. However, some indications point to the likelihood of such an increase in deforestation: (1) the recent development of most of states in Amazonia was only possible because of highways and migration (Fearnside & Graça, 2005, 2006); (2) there is a shortage of available land in the arc of deforestation due to the expansion of the extensive cattle ranching and of agribusiness; (3) construction of major infrastructure projects is expected in the area with great potential for attraction of migrants; (4) Roraima has low population density; (5) in the recent past the government of Roraima created attraction policies to stimulate migration by donating land to new arrivals. Between 1995 and 1997 Roraima opened lines of agricultural credit and created 23 settlement projects (Brazil, INCRA, 2007), of which 16 were in southern Roraima (Barbosa, 1993; Mourão, 2003). More than 50 thousand migrants were attracted to the state between 1996 and 2000 (Brazil, IBGE, 2008).

Baseline scenario

The baseline scenario, which is represented by the second curve in Figure 8a, followed historical rates of deforestation in southern Roraima (Fig. 10a). During the simulations the rates of deforestation increased due to the opening of endogenous roads that are generated automatically by the model and by planned highways in the region. Due to these conditions the baseline scenario deforested 347,760 ha up to 2030 (3478 km²). This area corresponded to an increase of 93.4% as compared to the area deforested in the initial scenario, which was 372,250 ha to the year 2007. Under this scenario 59.1×10^6 tC were emitted (Fig. 9), after discounting the carbon contained in the biomass of the secondary forest in the equilibrium landscape.

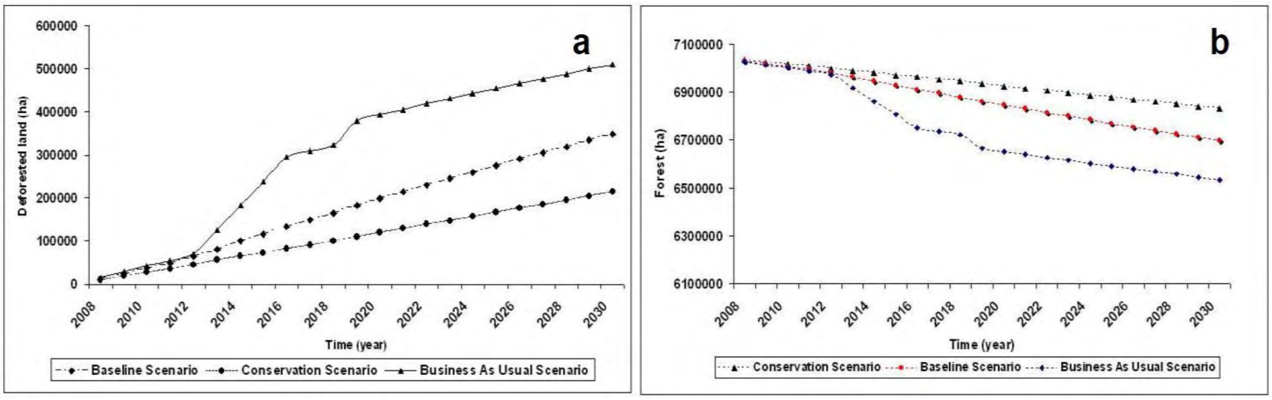

Figure 8. Cumulative deforestation (a) and decline of forest area (b) under the three simulated scenarios from 2007 to 2030, in hectares

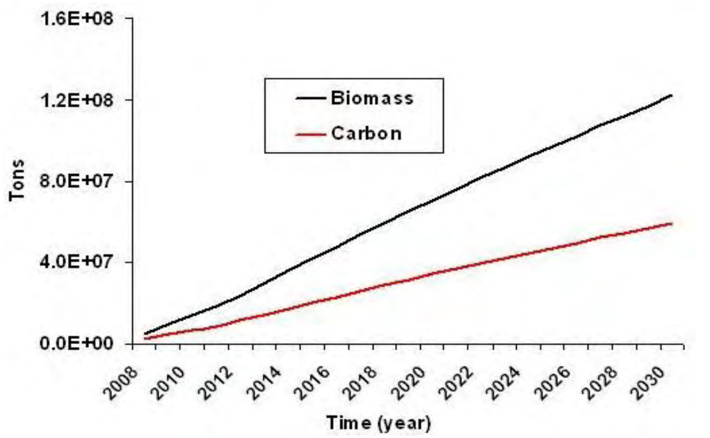

Figure 9. Biomass loss and cumulative emissions of carbon under the baseline scenario

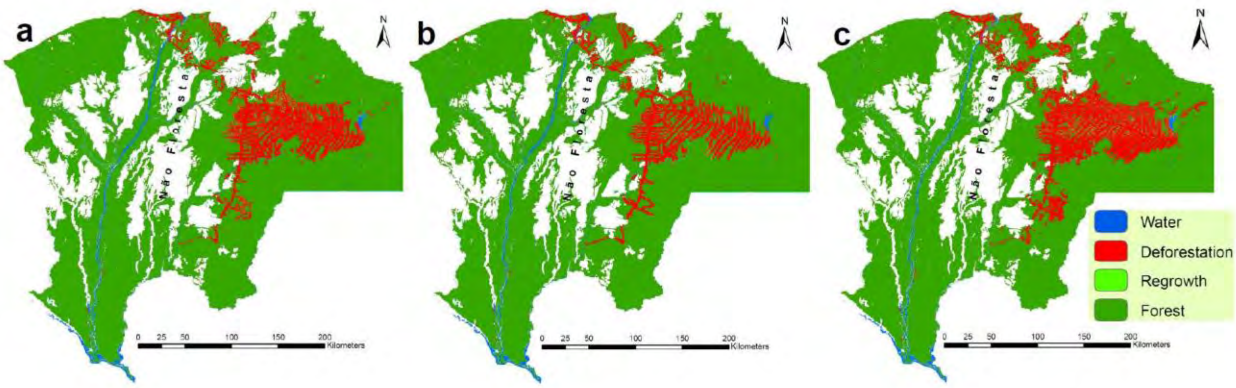

Figure 10. Baseline scenario (a), Conservation scenario (b) and business-as-usual scenario (c) as a result of the simulations in 2030

The biomass contained in the remaining forest in 2030 (Fig. 8b) was 2.4 × 10^6 tons, also including the biomass of the secondary forest in the landscape. In this scenario the regeneration or abandonment of the land, represented by the secondary forests, reached 15.4% of the deforested area. This percentage is similar to that found by Soares-Filho *et al*. (2006) observing rates of abandonment in the southern part of the state of Pará and in the area along the Transamazon Highway (Pará).

Conservation scenario

The conservation scenario (Fig. 10b) it is the one that shows the landscape as being less fragmented by deforestation. Conservation units created as measures to contain deforestation resulted in a compact landscape in 2030, forming corridors of forest when the conservation units are considered together with the indigenous areas (Fig. 6). Under this scenario deforestation increased by 213,440 ha (2134 km²) in comparison with the deforested area in 2007. That area deforested in the 2007-2030 period corresponded to 57.3% with respect to the initial (2007) scenario. Emissions to the atmosphere were of the order of 35.3 × 10^6 tC (Fig. 12). The remaining biomass of the forest (Fig. 8b), including the biomass of the secondary vegetation in the equilibrium landscape, was estimated at 2.5 × 10^6 tons. This scenario avoided the loss of 49,.0 × 10^6 tons of biomass to deforestation and avoided emission of 23.8 × 10^6 tC as compared to the baseline scenario, the area of forest saved being estimated at 134,320 ha (1343 km²) (Fig. 11).

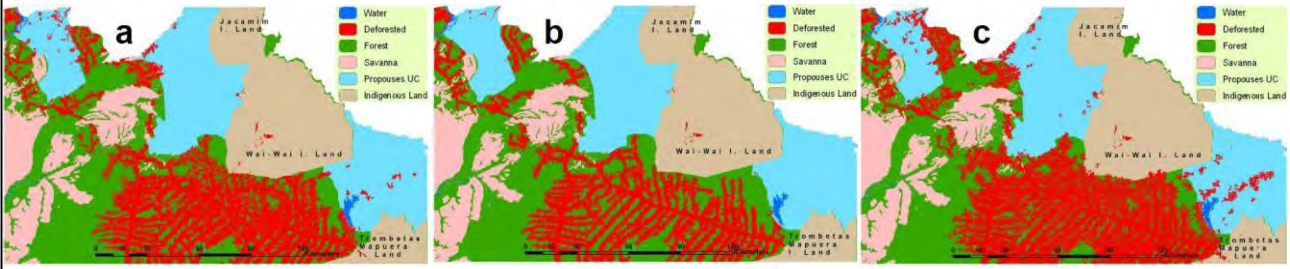

Figure 11. Effectiveness of proposed conservation units comparing each scenario in 2030: baseline (A), conservation (B) and business as usual (C)

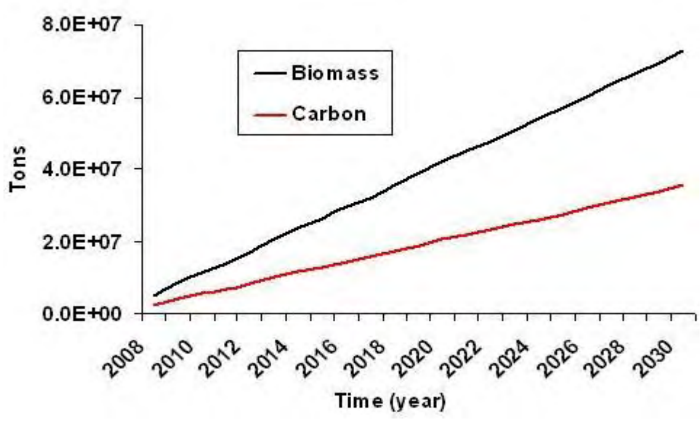

Figure 12. Biomass loss and emissions of carbon under the conservation scenario

In comparison with the BAU scenario, the conservation scenario avoided the loss of 105.6 × 10^6 tons of biomass from the remaining forest, which would have emitted 51.2 × 10^6 tC to the atmosphere. The area saved from deforestation was estimated at 2966 km² as compared to the BAU scenario (Fig. 11). The area covered by secondary forests in the conservation scenario was 13% of the area deforested by 2030. These results show that conservation units used in this scenario were efficient in inhibiting deforestation. It should be taken into consideration that this effect was also obtained because highways and settlement projects were not implemented, as this was established as an initial condition of the model.

The business-as-usual (BAU) scenario

The BAU scenario (Fig. 10c), considered to be the worst-case scenario, was the one that resulted in the greatest biomass loss and emissions of carbon to the atmosphere in the period (Fig. 13). A steep slope in the biomass curves and the emission of carbon observed in Figure 13 were due to the high rates of deforestation applied in the model from 2013 to 2019, due to the increase in human pressure (Soares-Filho *et al*., 2006). The emissions to the atmosphere between 2007 and 2030 were on the order of 86.5 × 10^6 tC. The area deforested under this scenario reached 510,000 ha (5100 km²) by 2030, an increase of 137% compared to the area deforested initially in 2007. The biomass of the remaining forest in 2030, under the BAU scenario, was 2.4 × 10^6 tons (Fig. 9b). Secondary vegetation covered 14.8% of the landscape generated in the scenario in 2030.

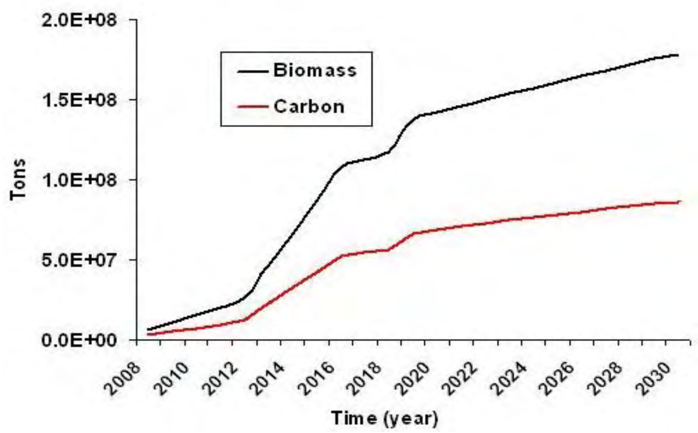

Figure 13. Cumulative loss of biomass and emissions of carbon under the business-as-usual scenario

The simulated settlements were created as part of policies for attracting migrants soon after the paving of the BR-319. Under this scenario there is widespread invasion of public lands, invasion of conservation units and of indigenous areas, the Ecological Economic Zoning (ZEE) is not respected and illegal logging takes place with strong impacts on the rate of deforestation (Fig. 11c).

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Conclusions

Under the baseline scenario (CLB), which assumes that the BR-319 Highway will not be reconstructed and paved and that historical rates of deforestation will continue, the deforested area would reach 720, 010 ha in 2030, of which 347,760 (93.4%) would be deforested between 2007 and 2030. In this scenario 59.1 × 10^6 tC would be released to the atmosphere in the period. Under the worst-case business-as-usual (BAU) scenario, which assumes that the BR-319 will be reconstructed and paved in 2011 and that a strong migratory flow to southern Roraima will occur, deforestation would reach 882,250 ha in 2030, of which 510,000 ha would be deforested between 2007 and 2030. According to these estimates, 86.5 $\times 10^6$ tC would be emitted to the atmosphere in the period, with great loss of environmental services.

The conservation scenario (CC) showed that if conservation measures are applied in southern Roraima, assuming that the BR-319 were reconstructed and paved in 2011, the release of 51.2 $\times$ 10^6 tC to the atmosphere could be avoided in comparison with the worst-case BAU scenario. The area saved from deforestation under this scenario would be 296,560 ha up to 2030.

Future improvements to the AGROECO model should incorporate tools that help estimate the forest degradation and vulnerability to the fire due to the edge effects caused by deforestation.

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