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Greenhouse Gases Emissions in Roraima (2011-2050): The Impact of Uncontrolled Growth of Agriculture and Livestock on Different Forest Types

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Abstract - Estimates of greenhouse gases (GHG) emissions by country are necessary to control the effects of global warming. This information must be accurate and calculated at a scale that can be implemented effectively at the local and regional levels. Current approaches used to estimate emissions from land use/land cover change do not meet these requirements mainly due to the low spatial resolution used and the high uncertainties associated with the accuracy of forest biomass data. The aim of this study was to simulate two future deforestation scenarios (GOV - governance; and BAU - Business As Usual) associated with the GHG emissions (CO_2, CH_4 and N_2O) in Roraima between 2011 and 2050. We based our estimates on the primary data: socioeconomic variables for municipalities, deforestation dynamics and emissions from agriculture and cattle occurred in Roraima along 2000-2010. We used socioeconomic data from Brazilian Institute of Geography and Statistic (IBGE) and deforestation dataset (≥1 ha area) handle directly from Landsat TM/ETM+ images. A map of the original forest biomass for ecotone (a type of seasonal forest) and ombrophilous forest was obtained through geostatistical techniques. The BAU scenario, which simulated the uncontrolled expansion of agriculture and cattle in the state of Roraima, resulted in estimated emissions of 801.6 x 10^6 Mg of C-CO_2 (46.4% ecotone and 53.6 ombrophilous) and the GOV scenario released 462.7 x 10^6 Mg of C-CO_2 (47.3% ecotone and 52.7% ombrophilous). The current growth rates of agriculture and livestock in Roraima are unsustainable over a long time period and may result in large GHG emissions in the future.

Keywords: Global warming, Climate change, Annual emissions balance, Future scenarios, Simulated deforestation.

Introduction

Agriculture and livestock farming is responsible for nearly all deforestation in the Amazon Region (Greenpeace 2009). The formation of pastures and grazing areas requires the replacement of a high biomass layer with another type of biomass layer. This process, connected with the use of fire, reduces the biodiversity of the forest and other environmental services (Fearnside 2008) such as water cycles and the retention of carbon within the biomass, causing the annual release of millions of tonnes of greenhouse gases (GHG) into the atmosphere (Barni *et al.* 2015a; Nogueira *et al*. 2015).

The aggressive spread of deforestation in the Brazilian Amazon started during the military rule era in the 1970s, through the implementation of national integration projects. These projects were based, essentially, on the construction of roads for connecting the major commercial centers of Brazil (e.g. the cities of São Paulo and Rio de Janeiro), not located in the Amazon region, to the regional centers in the Amazon itself such as the cities of Manaus and Belém, cities associated with the distribution of land along highways, better known as Settlement Projects (SPs) (Barni *et al.* 2015b).

During this process, the rate of deforestation and quantity of greenhouse gases (GHG) in the Amazon was "driven" by periods of accelerated local economic growth which attracted large numbers of migrants to the most developed urban centers. This was followed by a collapse, which ensued further migration to newly formed border expansion fronts (Rodrigues *et al.* 2009). This process has been repeating cyclically due to consolidation of the oldest agriculture and livestock farming colonization frontiers, as well as through the creation of newer but more distant frontiers embedded in the heart of the forest, from which new opportunities are created through the opening of new access routes opened by loggers, both official and unofficial (endogenous) routes.

This process can be clearly observed in the state of Roraima, Brazil (Diniz and Santos 2005), where the agriculture and livestock farming industry has grown in a disorderly but steady manner (Barni *et al.* 2012), having mainly advanced through large areas of mature forest (Ombrophilous and Ecotone) which annually release millions of tonnes of GHG into the atmosphere (Fearnside *et al.* 2013; Barni *et al*. 2015a). A large part of the state of Roraima is located above the equatorial line. This expansive territorial distribution encompasses a geographic gradient consisting of two large phytoclimatic eco-regions (Barni *et al.* 2015c): (i) forest regions of lower humidity and with open canopies, occupied by contact zones and seasonal forests (ecotone group) located in a band of forest that borders the large savanna region located to the northeast of the State ; and (ii) more humid areas occupied by ombrophilous and 'campinarana' forests (ombrophilous group) located in the northwest / south-central / southeast and southwest regions of the state. Both forest groups have been affected by deforestation, forest fires and selective extraction of wood due to overlap with the Settlement Projects (SPs) located along the major highways in the municipalities of Roraima (Fig. 1). There are extensive emissions of GHG in both instances, with distinct behavioral evolution based on a number of historical and economic social factors.

The objective of this study is to estimate the amount of GHG that is, and will be, released into the atmosphere (CO_2, CH_4 and N_2O: IPCC 2006) in Roraima from 2011 to 2050, through utilization of two future deforestation simulation scenarios: the Business As Usual (BAU) scenario, and the Governance (GOV) scenario, as part of a land-use model implemented through Dynamica-EGO software (Soares-Filho 2013). Besides the use of environmental and geographical models (maps), socio-economic models obtained at municipal level (Brazil, IBGE, 2013a) were also used during the construction of the deforestation model, with these models being evenly spaced over a 4 x 4 km cell grid, and implemented into the model using an econometric sub-model (mathematic). Thus, the regional effect of deforestation affecting the ecotone and ombrophilous forest groups in the study area has been evaluated by comparing GHG emissions with the BAU and GOV scenarios. The latter technique takes into account agriculture and livestock growth rates that are 50% lower than the BAU scenario.

Methodology

Study Area

The study area corresponds to a band of forest located in a north/south direction in relation to Roraima, with the exclusion of Protected Areas (PA = Indigenous Lands and Conservation Units), the Savanna in the northeastern region of the state, and the forests (campinas = oligotrophic systems) in the Rio Branco trough, in the south-central region of the state. This area covers the majority of the Settlement Projects located along the major highways (BR-174 and BR-210), totaling 92.1 $x10^3$ km^2 or ~41% of the total area of Roraima. The areas belonging to the ombrophilous forests (average annual rainfall of 2000 to 2300 mm) and ecotone forests (1700 to 2000 mm), represent 83.5% of the originally forested region of the study area, suffering from ~96% accumulated deforestation (9.32 x 10^3 km^2) by the year 2010 (Brazil, INPE 2013).

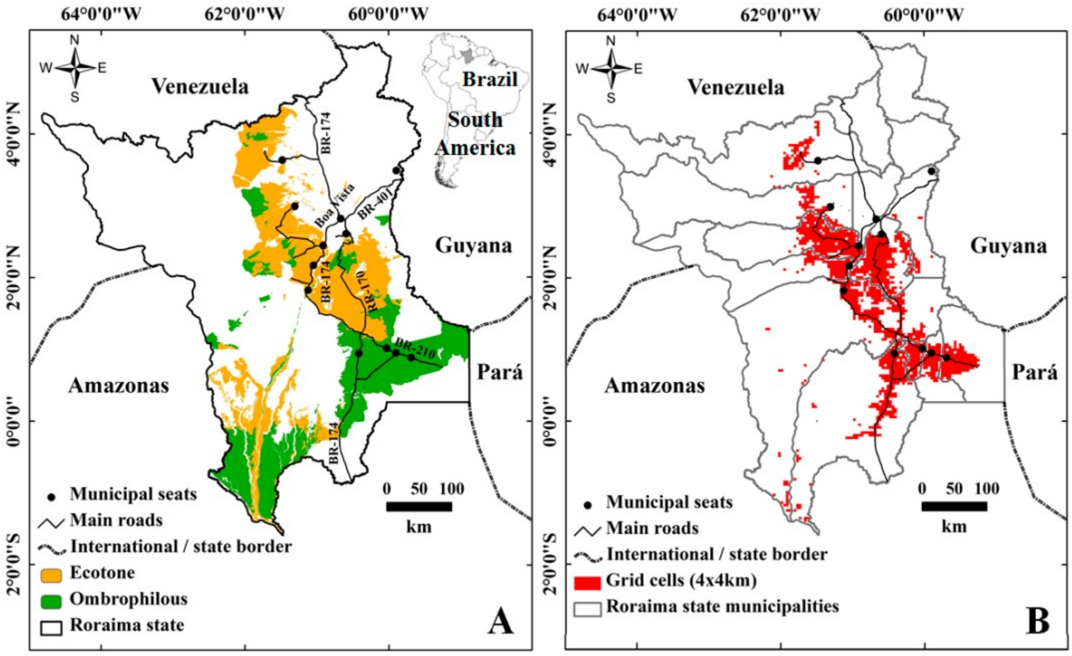

Fig. 1: Study area represented by the groups of ecotone and ombrophilous forest phytophysiognomies (A) and by the 4 x 4 km cell grids intersecting the municipalities of the state of Roraima (B).

Execution flowchart of the simulation

The fundamental details of each simulated scenario (GOV and BAU) are calculated on the basis of assumed levels of deforestation advancement, based on continued levels of non-governance and the continued growth rates of agriculture and livestock farming in Roraima from 2011 and 2050. The rates were calculated on a yearly basis using an econometric model, then passed through a spatial model for implementing the changes onto the maps at municipal level, done so using Dinamica-EGO software, in accordance with the findings of Barni (2014). The Carbon-Bookkeeping model of the Dinamica-EGO software was used to estimate GHG emissions (Soares-Filho 2013) (Fig. 2).

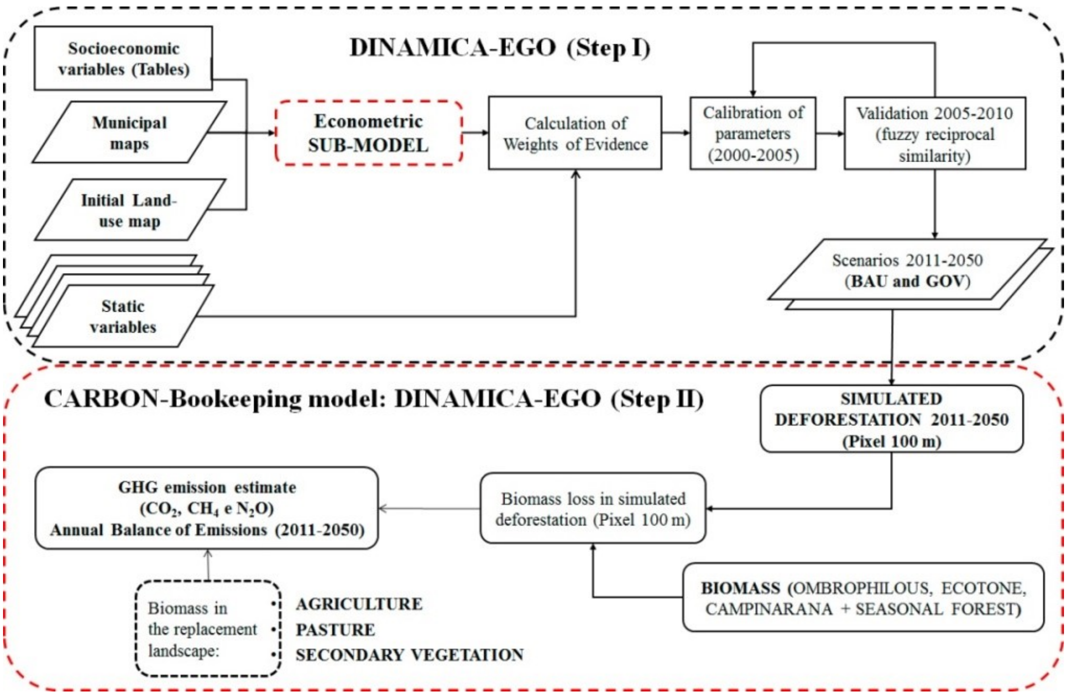

Fig. 2: Execution flowchart of the deforestation model, utilizing an econometric sub-model within the DINAMICA-EGO software framework (Step I), and application of the Carbon-Bookkeeping Model package for estimating the emissions of GHG, utilizing the Annual Balance (Step II).

Spatial data for the model

The Dinamica-EGO software requires a set of cartographic data to be used as entry data for commencement of the simulation. These maps cover the entire study area, and were put together using sub-models from the Dinamica-EGO software. The utilized spatial resolution was 100 m (1 ha), with the cartographic projection being UTM (*Universal Transverse Mercator)*, Zone 20 North – WGS 1984. The following entry data was used for simulation of the scenarios: (1) Land-use classification maps from 2000, 2005 and 2010: forest class (value 2) and deforestation (value 1). Land-use maps based on deforestation data from 2000 to 2010 were obtained through visual interpretation of the TM Landsat images (deforested areas ≥ 1 ha: Barni *et al*. 2015c) and combined with accumulated deforestation maps from PRODES (Brazil, INPE, 2013) in order to produce the deforestation maps of the periods (i) before 2000, (ii) up to 2005, and (iii) for the period up to 2010. (2) Static variable maps: a) Altitude (SRTM: Brazil, Embrapa 2013); b) Slope (derived from SRTM data); c) Soils (Brazil, IBGE 2013b); d) Vegetation (Brazil, IBGE 2013b); e) Indigenous Lands and Conservation Units (Brazil, IBGE 2013b); f) Distance from rivers (Brazil, IBGE 2013b); g) Distance to secondary roads (derived from road network data from 1998 (Brazil, IBGE 2013b) and updated by the author for 2010 utilizing TM Landsat images); h) Distance to main roads (Brazil, IBGE 2013b); i) Distance to the Settlement Projects (Brazil, INCRA 2007); j) Distance from the savanna.

Econometric sub-model

The deforestation model was designed to be linked together with an econometric sub-model (mathematical model of multiple spatial regression), utilizing various socioeconomic variables at municipality level of the study area (Soares-Filho 2013). The deforestation model is split into three interconnected parts: (i) entry data - receipt of the entry variables: maps (e.g. land-use maps, municipality maps, etc.) and tables; (ii) pre-calculus (econometric sub-model) - for calculating rates of change; (iii) the simulation model that, in association with the probability map calculated by the Weights of Evidence (WE), transforms the received rates into effective deforestation information on the maps.

For the implementation of the model in the study area, an econometric model (mathematic model) with spatial dependence was adapted (Anselin 2004) from the case study using 11 municipalities in the state of Roraima (Figure 1). The study took place through the initial exploration of 30 explanatory variables, applied to the econometric model in order to predict (Y) the deforestation between 2000 and 2005, applied at local level, utilizing a regular grid of cells measuring 4 x 4 km (16 km^2) covering all of the municipalities involved (Barni 2014).

Calculation of Weights of Evidence (WE)

The WE calculation is based on the conditional probability statistical method (Bayesian), in addition to being used by the Dinamica-Ego software in order to determine the probability of a cell switching from one state 'i' (e.g. forest) to the other state 'j' (e.g. deforestation), on the basis of specific class-based evidence of the land-use and land-cover maps. The WE coefficients were thus calculated by cross-referencing the statistical variable maps with the land-use maps, while also taking into consideration discrete distance intervals in the maps of continuous variables (e.g., distances from roads and rivers) and the classes in the maps of categoric variables (e.g. soils, vegetation).

Validation of the simulation model

After the calibration period (2000-2005), the model was validated by testing the adjustments obtained during this phase for the 2005 to 2010 period (Soares-Filho 2013). This was followed by comparison of the simulated map for 2010, with the map observed in 2010 by PRODES. The evaluation took place by applying the *fuzzy reciprocal similarity* test (Soares-Filho 2013) over the observed and simulated map. The model reached a minimum similarity index of 50% inside a window, with spatial resolution of 1300 meters (Soares-Filho 2013).

Emission (clearing) / absorption (regrowth) by the secondary vegetation

The initial secondary vegetation area was calculated based on 42% of the area of each land-use map being deforested. In the simulation, transition values of 9% and 8% per year, in terms of the growth and cutting of the secondary vegetation areas, respectively, were taken into account. The annual rate of 8.4 Mg ha^{-1} year^{-1} was used for the growth of the secondary vegetation biomass in the two scenarios (Yanai *et al*. 2012) and an annual rate of 43.0 Mg ha^{-1} year^{-1} for the cutting of biomass (Fearnside *et al.* 2007).

Calculating GHG emissions through the simulated scenarios

In this phase of the study, the same parameters employed for the modeling of GHG emissions (Mg ha^{-1}) between 2000 and 2010 were used, by calculating losses in biomass (Barni 2014) and carbon through deforestation (burning + decomposition in 10 years), in addition to the post-deforestation covering landscape from which each type of gas originates (CO_2, CH_4 and N_2O: IPCC 2006). This step was carried out in a semi-automated format using the Carbon-Bookkeeping module (Soares-Filho 2013) adapted to provide the deforested GHG emissions (Mg ha^{-1}), simulated in the equivalent Carbon (C) to CO_2 (C-CO_2) scenarios, while also applying the global warming potential (GWP_{100}) for each type of greenhouse gas (IPCC 2006).

Results

The total GHG emissions through deforestation (burning + decomposition) for the 2011 to 2050 period, using the BAU scenario, were estimated as being 480.3 x 10^6 Mg C-CO_2 (including coal: ~0.42% on average in the two scenarios). Emissions relative to the ecotone forest group (222.7 x 10^6 Mg C-CO_2) were ~13.5% less than the estimated emissions from the ombrophilous forest group (257.6 x 10^6 Mg C-CO_2), even though the ecotone deforested group is 17.7% larger than the ombrophilous group (Table 1: Fig. 3).

Table 1: Deforested area (km^2), emissions per scenario, per type of GHG (x 10^6 Mg C-CO_2) and per forest group, over a period of 100 years (*GWP*; IPCC 2006). Upper letters on the line are indicative of a significant difference (Test *t* for different variances: p<0.0000; α=0.05).

	Ecotone					Ombrophilous					
Scenario	Area (km^2)	CO_2	CH_4	N_2O	Total C-CO_2	Area (km^2)	CO_2	CH_4	N_2O	Total C-CO_2	Total general C-CO_2
GOV	1,508.6	83.0	3.2	1.4	**88.0^A**	1,187.3	92.1	3.6	1.6	**97.7^B**	**185.7**
BAU	3,826.8	210.1	8.2	3.6	**222.7^A**	3,149.9	242.9	9.5	4,1	**257.6^B**	**480.3**

Taking into account the sum of all sources of GHG emissions in the BAU scenario, minus regeneration, the balance was 449.4 x 10^6 Mg C-CO_2 in 2050. This value was 60.1% greater than the final balance registered for the GOV scenario of 179.3 x 10^6 Mg C-CO_2 (Table 2).

Table 2: Estimation of GHG emissions in the state of Roraima (x 10^6 Mg C-CO_2) from 2011 to 2050 (including Campinarana and Seasonal emissions).

Source	GOV	BAU
Burn + Decomposition	194,4	501,3
Replacement landscape	128,8	149,8
Clearing	139,5	150,5
Emission Total	462,7	801,6
Regrowth	-283,4	-352,1
Final balance	**179,3**	**449,4**

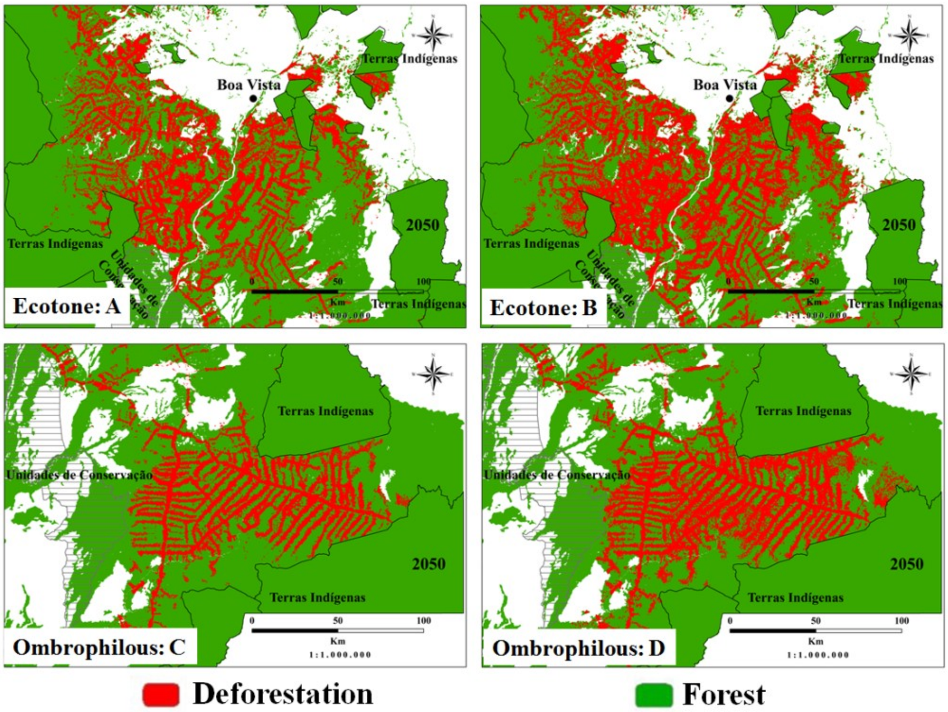

Fig. 3: GOV (A and C) and BAU (B and D) scenarios, simulated in 2050. In A and B, the accumulated deforested area is predominantly in the ecotone group; whereas in the C and D scenarios, the accumulated deforested area is predominantly in the ombrophilous group.

Discussion

The BAU scenario assumes a continuous level of agriculture and pasture growth advancing over the ecotone and ombrophilous forest areas in the state of Roraima. This is in accordance with the deforestation spatial spread pattern observed between 2000 and 2010, also due to the opening of new roads in the vicinity of the Settlement Projects and Protected Areas (Barni *et al.* 2015c), resulting in a no-control situation in the State by 2050. (Fig. 3). In order to control this process, local governments need to implement measures for the prevention of further deforestation, through reorganization of land-use and agriculture and livestock farming at municipal level. Land-use reorganization is imperative for the control of deforestation, as this results in significant abandonment of pastures and fields in the Settlement Areas, huge expansions in actual land-use, and the invasion of public lands in new deforestation fronts (Barni *et al.* 2015c), as verified in other Amazon studies (D'Antona *et al*. 2011; Carrero and Fearnside 2011). On the other hand, the GOV scenario exemplifies the application of preventive deforestation public policies in the state of Roraima, with low carbon agriculture and cattle farming being achieved by 2050 (Nepstad *et al*. 2011; Bowman *et al*. 2012).

The greater emission of GHG presented by the ombrophilous group in relation to the ecotone group in both scenarios, even with lesser areas of deforestation, is explained by the greater biomass content per area unit (Mg ha^{-1}) of this phytophysiognomic group (Barni 2014). In terms of carbon (C) derived from coal, the Brazilian government still classifies this repository as a form of carbon emission (Brazil, MCT 2010). We suggest that this repository should be classified as a long-term stock of carbon in these systems, since burning and forest fires produce large amounts of coal with high concentrations of carbon which is stored along the soil profile and which cannot, as such, be classed as being emitted at the time of the actual biomass burning.

Conclusions

GHG emissions in the state of Roraima are affected by the eco-regional context, based on the different historical, socioeconomic and phytophysiognomic contexts that govern distinctions in deforestation behavior, associated with the biomass content (Mg ha^{-1}) discrepancies between the ombrophilous and ecotone forest groups (Barni 2014). Eco-regional differences must be taken into account as part of future GHG emission estimations for the Amazon region, due to the various forest groups that comprise the entire region having different structures (vertical and horizontal) and species compositions, directly affecting the calculation of emissions.

The BAU scenario demonstrates that the current growth rate of agriculture and livestock farming in the state of Roraima is non-sustainable and may result in huge emissions of GHG in the future. Maintaining such a scenario over the long-term could be even more harmful to the environment than the re-opening of the BR-319 highway, followed by a state of controlled deforestation in the Brazilian state of Roraima (Barni *et al*. 2015ab).

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