Linking Historical and Future Land-Use Change to the Economic Drivers and Biophysical Limitations of Agricultural Expansion in the Brazilian Cerrado

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The potential for expansion of intensive agriculture onto land currently occupied by degraded cattle pastures (i.e. land that is already altered but under utilized) is often presented as a means of avoiding further deforestation in the Cerrado and minimizing environmental degradation while increasing agricultural productivity. However, the capacity and suitability of land for this transition has not been evaluated or quantified on a regional basis. This proposal aims to quantify these degraded lands and their potential to mitigate future environmental impacts.

The specific objectives are:

1) Quantify the area of low productivity pastures using multiple resolution satellite sensors.
2) Assess the impacts of a range of scenarios for sugarcane expansion on future land use changes in the Cerrado.
3) Appraise inter-regional shifts in agricultural production within Brazil and the impact they have on deforestation pressure on the Cerrado.
4) Estimate historical and potential future changes in carbon stocks and emissions of N_2O and CH_4 from conversion to agricultural production.
5) Assess the hydrological impacts of historical and future scenarios of deforestation and conversion to intensive agriculture.

1) Quantify the area of low productivity pastures using multiple resolution satellite sensors.

There are two components to quantification of low productivity pasture, one radar based the other MODIS based.

RADAR. The first year of this study has largely been focused on data acquisition and processing to usable products. Wall-to-wall high-resolution (15 m) ALOS/PALSAR Fine-Beam Dual Polarization (FBD) data were acquired and mosaicked for 2007 (suppl. info. Figure 1), and partial coverage has been acquired for 2008 – 2010 in both FBD and Fine-Beam Single Polarization (FBS) (7.5 m resolution) modes. A single coverage contains 833 images. For data management and process tracking purposes, a PostgreSQL/PostGIS database was used to inventory and log all processing for each image. Raw images were processed with SARscape radar processing software on a high performance linux computeingcluster; images were multi-looked, filtered, and terrain-corrected to a normalized sigma-nought product expressed in both dB and power. In the coming year, the focus will shift from data acquisition and processing to analysis. A multi-sensor fusion of ALOS/PALSAR and Landsat-TM image data sets will be tested to determine if reference biomass estimates can be improved over TM alone. A tree-based regression approach will associate the high-resolution remote sensing data with field observations of biomass, resulting in an ALOS/TM-derived reference dataset that will then be scaled up to MODIS resolution (250 m). Additionally, the utility of ALOS/PALSAR and TM data alone (in the absence of MODIS) will be tested for its efficacy in producing high-resolution (30 -50 m) estimates of pasture biomass.

MODIS. During this first year of the project, the following activities were conducted by the LAPIG group at Universidade Federal de Goiâs: The Cerrado cultivated pasture area has been updated based on visual interpretation of 123 Landsat TM scenes. The results indicate an 8% increase in the Cerrado pasture area occurred between 2002 and 2008 (suppl. info. Figure 2 and Table 1). Acquisition and processing of monthly MODIS evapotranspiration and productivity data (MOD16 and MOD17 products, respectively) over the entire Cerrado cultivated pasture area for the period 2000 – 2010 has been completed (suppl. info. Figure 3). The preliminary analysis suggests that the moderate spatial resolution satellite imagery is appropriate for assessing pasture quality on a regional basis. The large biophysical variability depicted by these datasets agrees with the Cerrado pasture mosaic, which comprises a wide variety of physiognomic types (e.g. *Brachiaria decumbens, Brachiaria brizantha*, *Andropogon gayanus*, and *Panicum maximum*) and distinct management practices (e.g. rotation, fallow, undergrazing, and overgrazing), which results in different levels of degradation and biomass. Organization and preliminary analysis of the sugarcane area and distribution in the Cerrado biome has also been completed (data made available by the INPE Canasat project) (suppl. Info. Figure 4 and Table 2). By 2010, approximately 42,000 km^2 were occupied with sugarcane, an increase of about 136% since 2003. Interestingly, most of this expansion occurred over existent crops, followed by the replacement of cultivated pastures.

2) Assess the impacts of a range of scenarios for sugarcane expansion on future land use changes in the Cerrado.

The datasets necessary for calculating land use transitions in the Cerrado environment have been collected, including: annual sugarcane cropland area, infrastructure (suppl. info. Figure 5), forest carbon biomass (suppl. info. Figure 6), and land available for crop expansion. The cattle rent model (Bowman et al. in press) and sugarcane crop yield and rent model (Viana 2010) (suppl. info. Figures 7 & 8), which are used in calculating land use opportunity costs have been developed. The full SimBrasil land use, land use change, forestry, deforestation, and regrowth model has been developed and applied under various scenarios of agricultural land demand and deforestation policies using the wizard tutorial interface. The wizard interface enables the model to be easily customized by any end-user (suppl. info. Figure 9).

Manuscripts on historical land use change and the associated carbon emissions (Leite et al. in review) and modeling the drivers of deforestation in the Cerrado (Ferreira et al. in review) have been submitted. An abstract entitled " Reconciling agriculture expansion with forest conservation and restoration in Brazil" has been accepted for oral presentation at the conference “Planet under Pressure”, London, 2012.

3) Appraise inter-regional shifts in agricultural production within Brazil and the impact they have on deforestation pressure on the Cerrado.

The collection and processing of new agricultural data and the disaggregation of the animal sector production has been completed. This data is necessary to generate the disaggregated Social Accounting Matrix (SAM), which is used in the Computable General Equilibrium (CGE) model. Data are from several data sources:

- Agricultural Value of Production: Brazilian Agricultural Census 2006; value of production of milk, poultry and vegetal are used directly from the agricultural census.
- Animal value of production was obtained with the combination of herd size, slaughter rate, prices and others (suppl. info. Table 3). Table 3 also shows the share of each type of meat in every disaggregated region considered in the CGE model.

- Estimated regional agricultural technology coefficients (based on data from CONAB, suppl. info. Table 4)

Land use change modeling is based on a land conversion derived for the Amazon biome (Cattaneo, 2002). Specific features of Cerrado are included/modified to capture the pattern of land use conversion/transformation in the Cerrado. The following options will be included in the CGE model (suppl. info. Figure 10): (1) Cerrado is converted in pastures and after that in arable land for crops, such as soybeans; if arable land is not well treated it could become degraded land. As degraded land, it could be: (a) treated to be pasture again or reforested to become Cerrado. (2) Cerrado is converted to pasture and eventually (if no use of lime and fertilizers occurs) becomes degraded land; the degraded land can either become grassland again or Cerrado.

We are now in the process of estimating and balancing the regionalized Social Accounting Matrix (SAM) to be used in the model. We expect to complete this phase in 2012.

4) Estimate historical and potential future changes in carbon stocks and emissions of N_2O and CH_4 from conversion to agricultural production.

No deliverables were scheduled in year one for this portion of the product.

5) Assess the hydrological impacts of historical and future scenarios of deforestation and conversion to intensive agriculture.

We have begun validating a version of the Agro-IBIS dynamic agro-ecosystem model, which will be the basis of calculating the hydrologic balance of the Cerrado. Agro-IBIS has previously been updated to include a specific sugarcane module (Cuadras et al., 2011: GCB Bioenergy. doi: 10.1111/j.1757-1707.2011.01105.x) in addition to existing pasture and soybean modules. Fire is an important component of the environment, strongly affecting the structure and distribution of the Cerrado biome by influencing the competitive balance between grasses and trees. Agro-IBIS has a fire component that simulates fire burned area and plant mortality as a function of total litter and available water content in the upper soil layer. We have tested the Agro-IBIS fire module for the Amazonian/Cerrado climatic conditions and integrated annual land use maps to simulate potential past and future land use change and climate conditions on the biomass and hydrology of the Amazon/Cerrado transition zone (suppl. info. Figure 11). There is a strong effect of fire on the Cerrado and transitional forest areas: with fire the average biomass drops to values ranging less than 5 KgC/m^2 to as much as 10 KgC/m^2. The simulated fire frequency and greatest impact occur where dryness and biomass are favorable to ignition. The greatest impact occurs in the southeast Amazon and indicates that fire is an important determiner of the boundary between forest and Cerrado. Land use changes further degrade total above ground biomass to values less than 5 $Kg\text{-}C/m^2$ in much of the Cerrado.

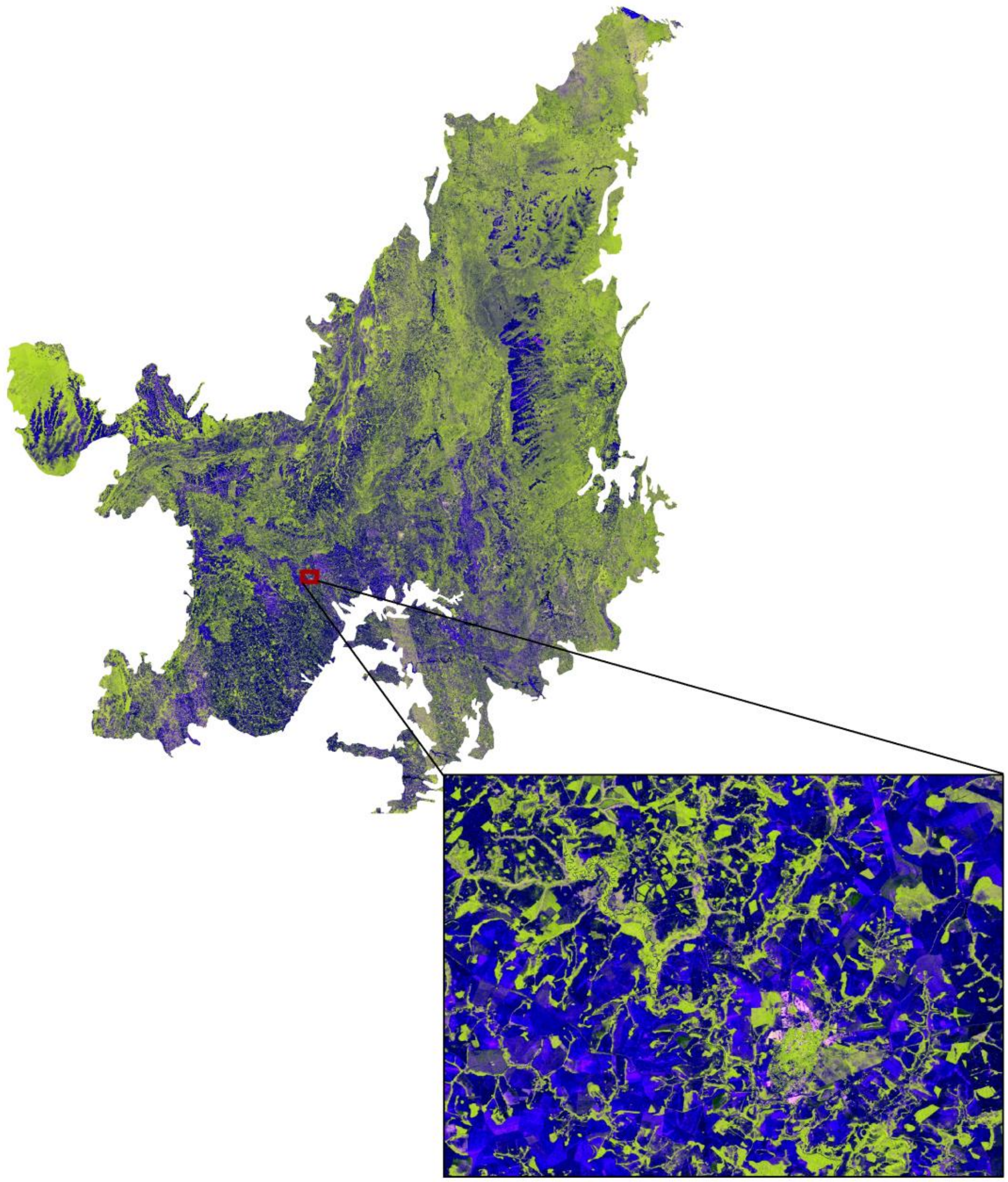

Figure 1. ALOS/PALSAR mosaic of study area. Inset illustrates detail provided by 15 m product.

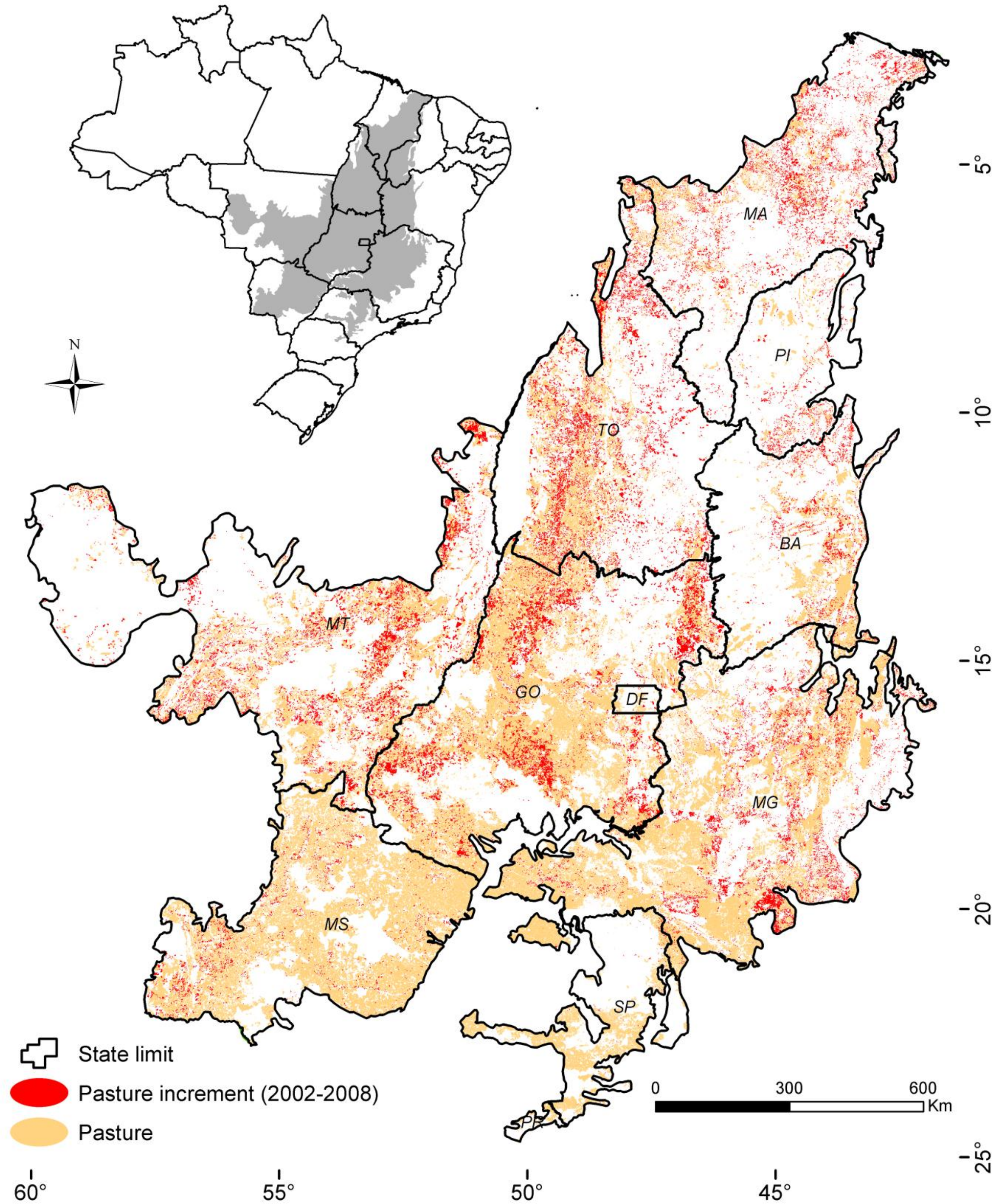

Figure 2. Cerrado pasture before 2002 (orange) and additional pasture increment to 2008 (red) derived from visual inspection of 123 LandSat scenes.

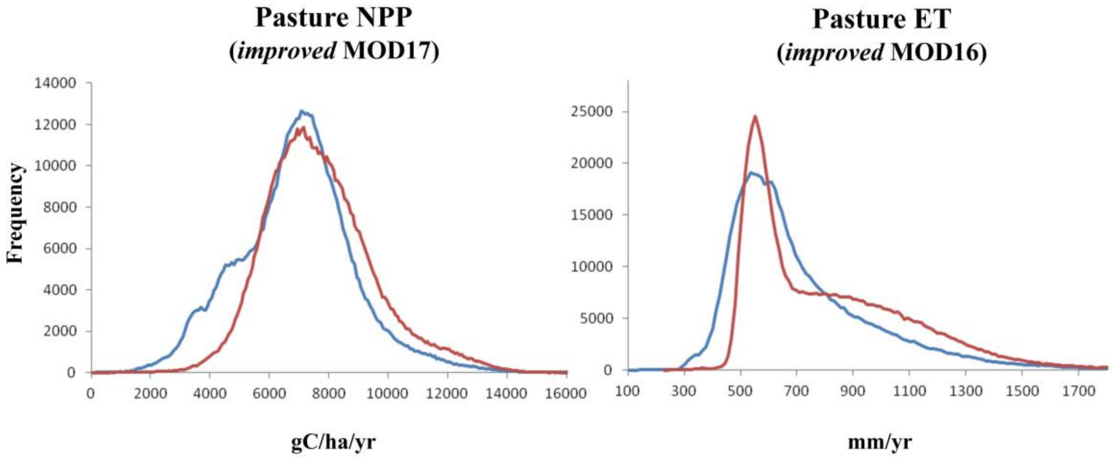

Figure 3. MODIS 17 pasture productivity (left) and MODIS 16 evapotranspiration frequency diagrams for current (red) and previous (blue) analyses.

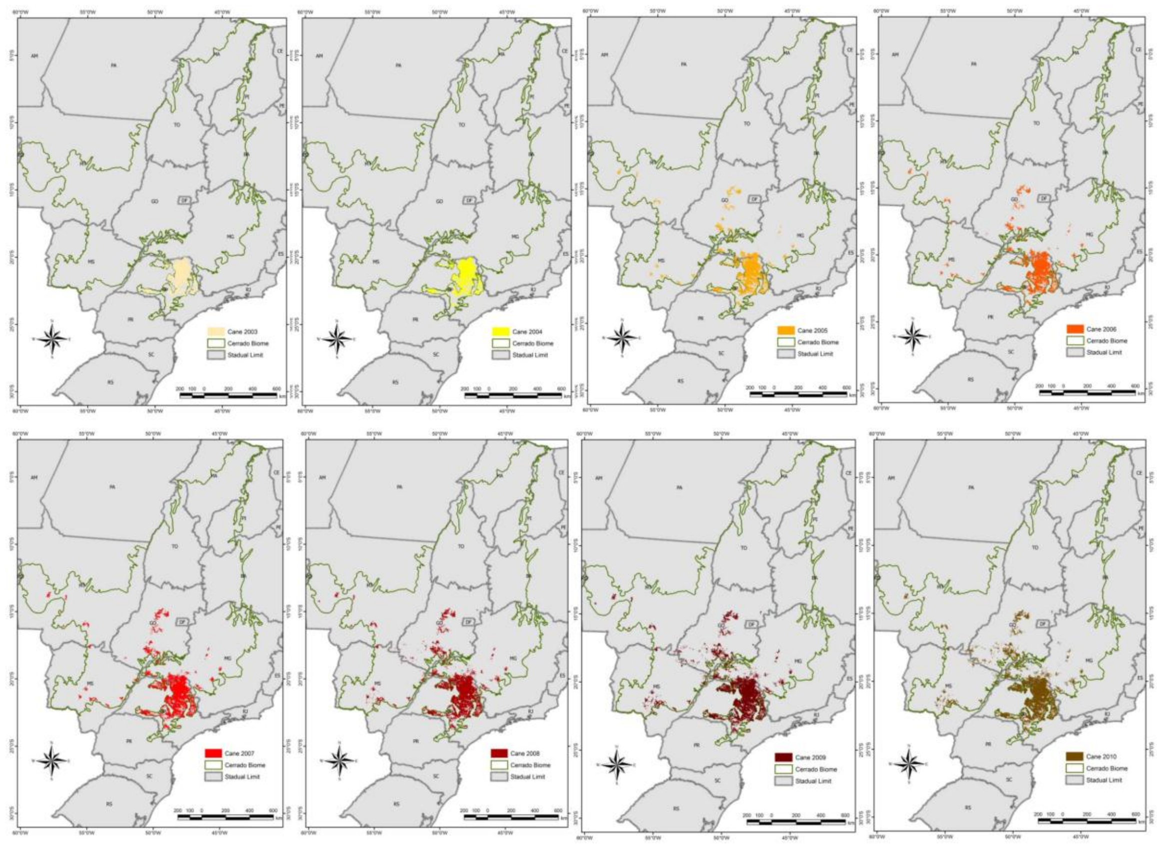

Figure 4. Annual maps of sugarcane area from 2003 (upper left) to 2010 (lower right).

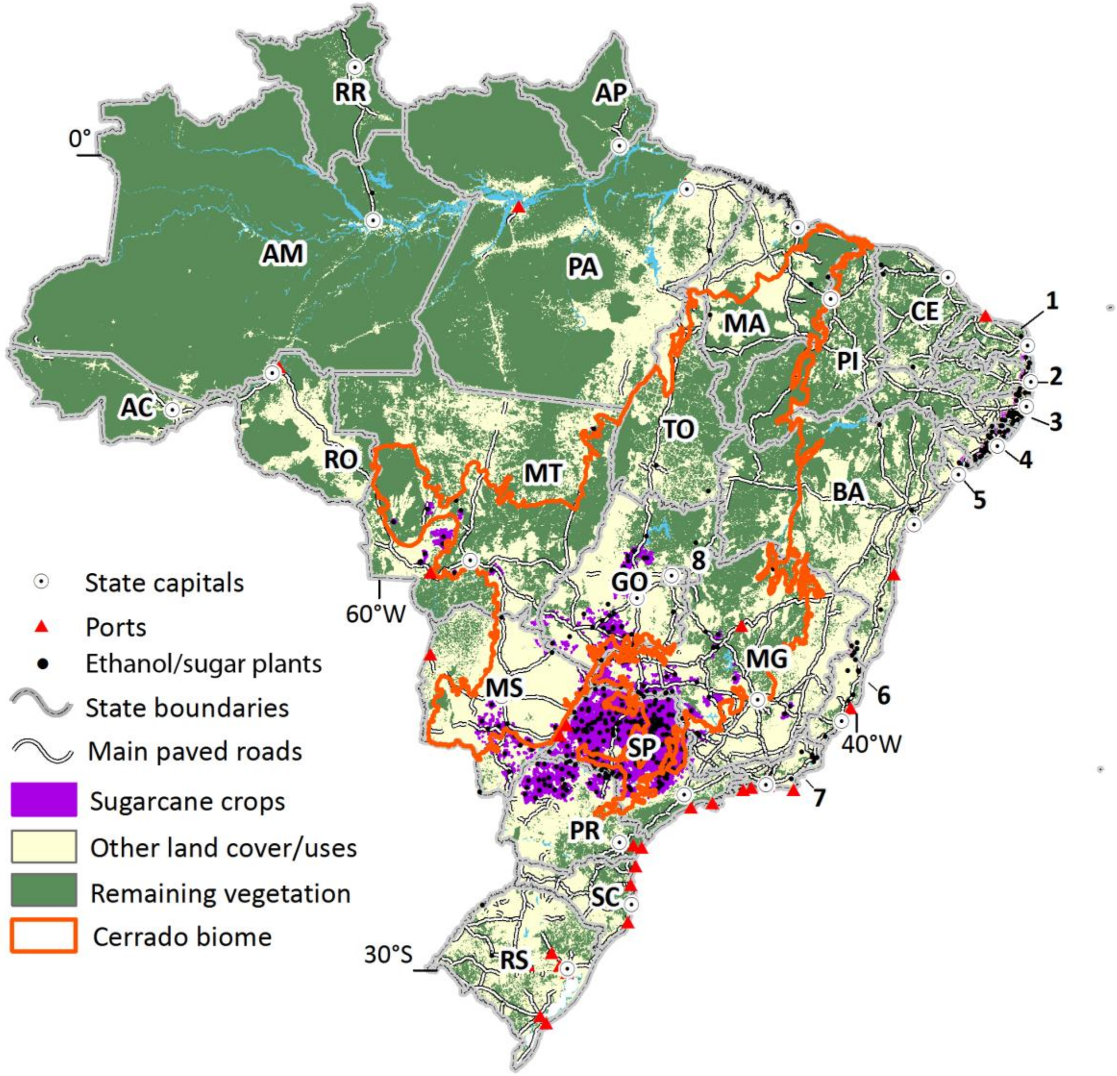

Figure 5. Sugarcane crops in Cerrado Biome and surroundings in Brazil. List of Brazilian states, 1 - Rio Grande do Norte, 2 - Paraíba, 3 - Pernambuco, 4 - Alagoas, 5 - Sergipe, 6 - Espírito Santo, 7 - Rio de Janeiro, 8 - Distrito Federal, AC - Acre, AM - Amazonas, AP - Amapá, BA - Bahia, CE - Ceará, GO - Goiás, MA - Maranhão, MG - Minas Gerais, MS - Mato Grosso do Sul, MT - Mato Grosso, PA - Pará, PI - Piauí, PR - Paraná, RO - Rondônia, RR - Roraima, RS - Rio Grande do Sul, SP - São Paulo, SC - Santa Catarina, TO - Tocantins.

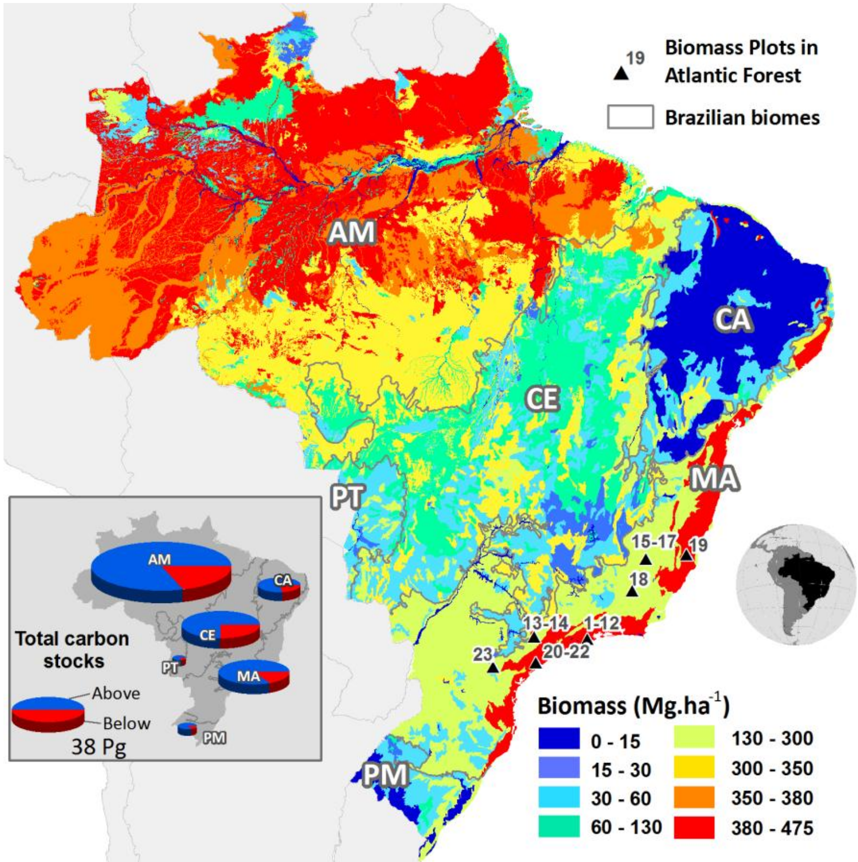

Figure 6. Forest carbon biomass distribution in Brazil Original vegetation biomass distribution (MgC/ha) in Brazil.

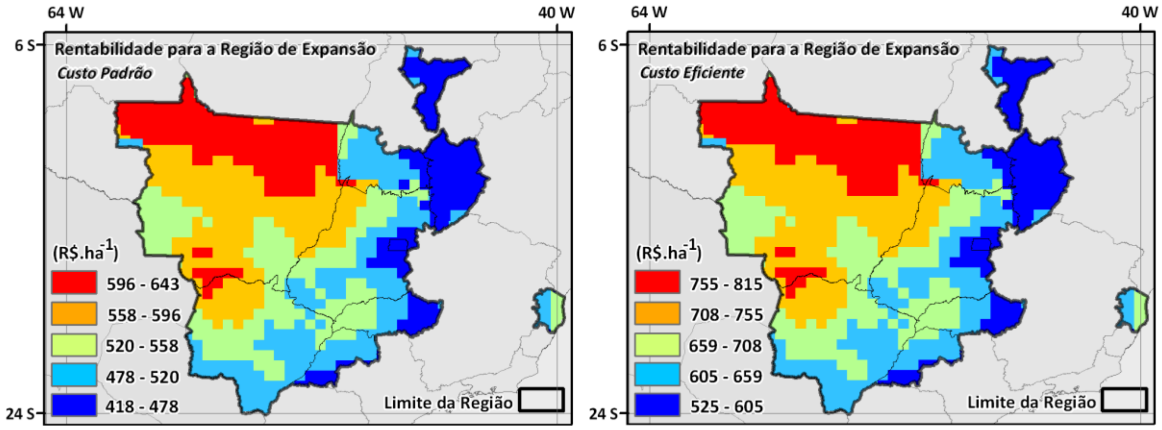

Figure 7. Sugarcane rents in Brazilian Reais for the central Cerrado. For standard system (left) and improved system (right).

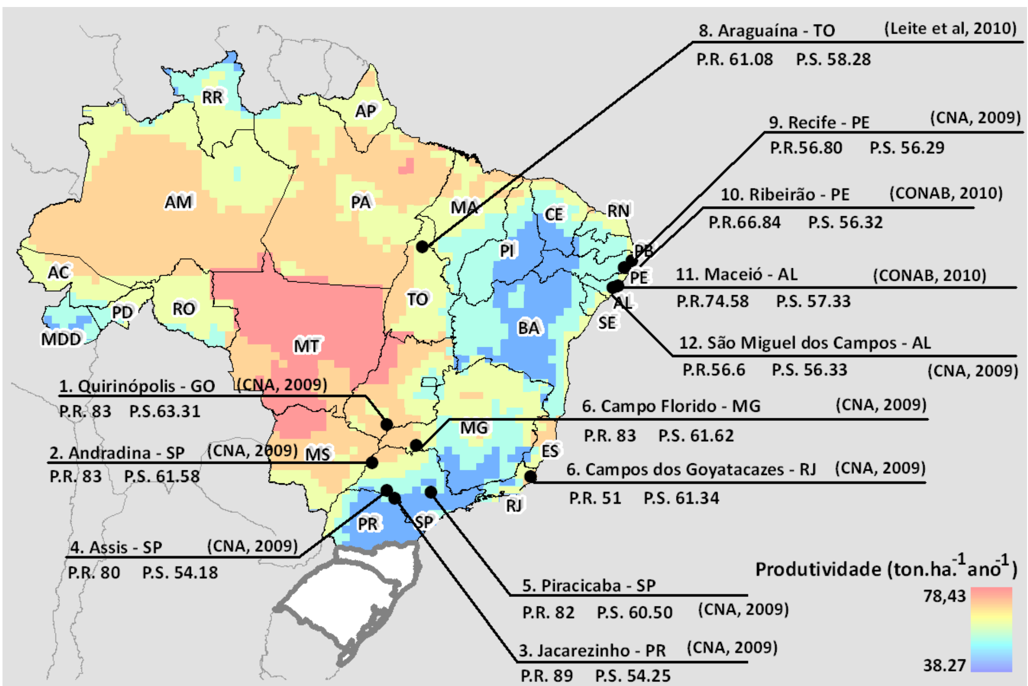

Figure 8. Comparison of results from our rent model with values from CNA (2009) and CONAB (2010).

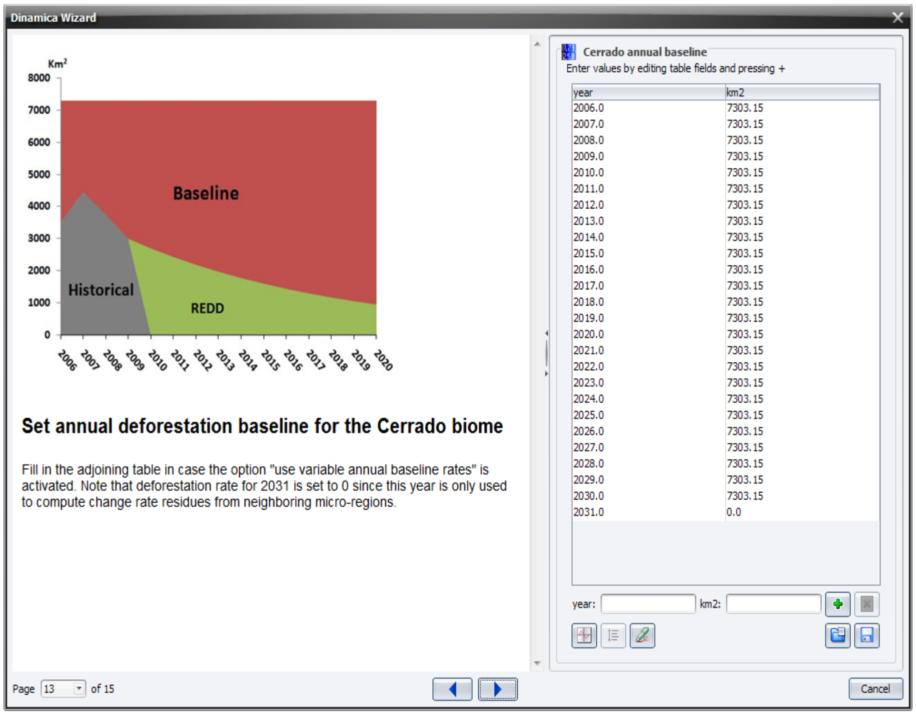

Figure 9. Wizard interface of Simbrasil.

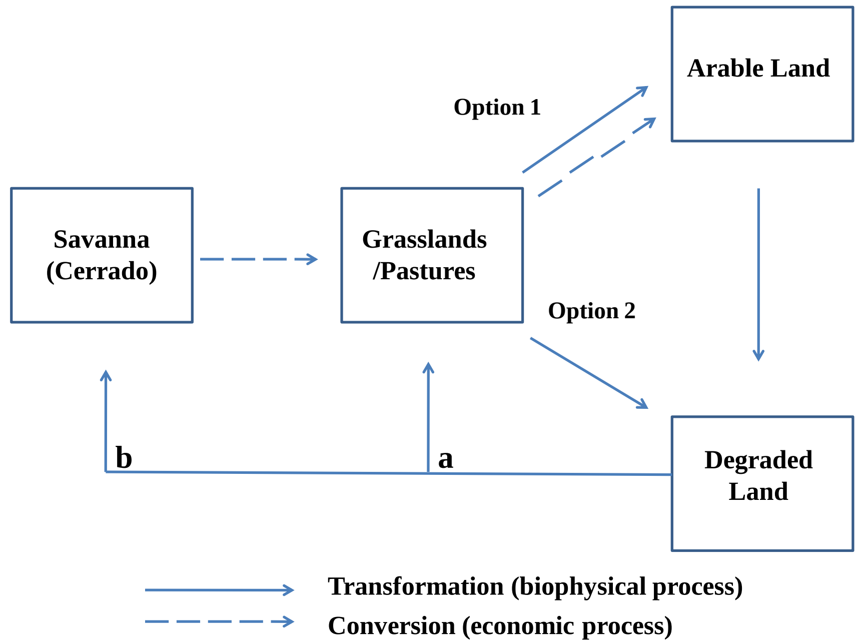

Figure 10. Schematic of land conversion options to be inserted in Computable General Equilibrium (CGE) model. Option 1: Cerrado is converted in pastures and after that in arable land for crops, such as soybeans; if arable land is not well treated it could become degraded land. As degraded land, it could be: (a) treated to be pasture again or reforested to become Cerrado. Option 2: Cerrado is converted to pasture and eventually (if no use of lime and fertilizers occurs) becomes degraded land; the degraded land can either become grassland again or Cerrado.

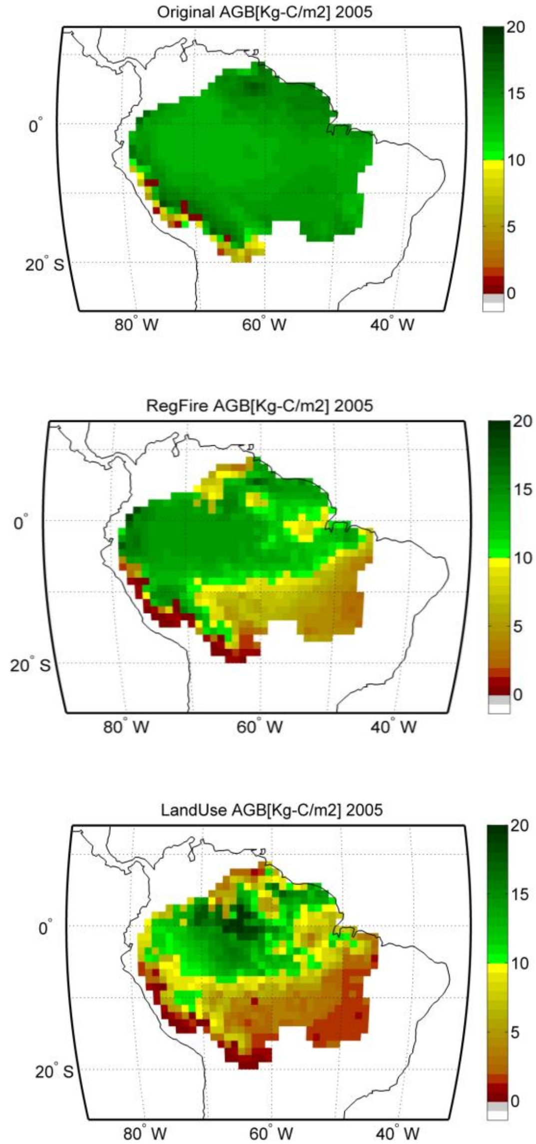

Figure 11: IBIS numerical model simulation of total above ground biomass for the Amazonian region including forest and Cerrado environments in year 2005. Simulated potential vegetation (top); potential vegetation with fire module on (middle); and potential vegetation with fire module and land use change (bottom).

Table 1. Pasture Increases in the Cerrado between 2002-2008

Pasture Increment in the Cerrado between 2002-2008 (ha)			
	Cultivated Pasture (ha)		
State	**PROBIO (2002)**	**Increment (2008)**	**%↑**
Bahia (BA)	2,247,962	172,332	7.7
Distrito Federal (DF)	119,314	4,494	3.8
Goiás (GO)	12,868,742	1,151,731	8.9
Maranhão (MA)	1,874,663	448,360	23.9
Mato Grosso (MT)	6,518,174	930,488	14.3
Mato Grosso do sul (MS)	11,500,684	171,429	1.5
Minas Gerais (MG)	11,884,100	600,485	5.1
Paraná (PR)	103,673	0	0.0
Piauí (PI)	515,919	86,292	16.7
São Paulo (SP)	2,615,369	6,426	0.2
Tocantins (TO)	4,369,326	805,247	18.4
Total	54,617,926	4,377,284	8

Table 1

Table 2. Total sugarcane area (km^2, column 1) and fraction derived from existing agriculture, pasture and natural vegetation (columns 2, 3 & 4, respectively).

Sugarcane Area (compared to PROBIO 2002 land cover classes)				
	Area km²	Sugarcane/ Agriculture*	Sugarcane/ Pasture*	Sugarcane/ Vegetation*
Cane 2010	41,468	20	8	3
Cane 2009	39,963	19	7	3
Cane 2008	36,731	18	7	3
Cane 2007	31,740	15	6	3
Cane 2006	27,891	13	5	2
Cane 2005	25,737	12	5	2
Cane 2004	18,363	9	3	1
Cane 2003	17,572	8	3	1
Agriculture	207,406			
Pasture	546,246	*% values		
Vegetation	1,232,984			

Table 3. Data sources to obtain animal value of production for Amazon, Cerrado, South/Southeast and Northeast (2006 prices)

ACTIVITY	SOURCE	AMAZON R$ 1000 (% Brazil)	CERRADO R$ 1000 (% Brazil)	SOUTH/SOUTHEAST R$ 1000 (% Brazil)	NORTHEAST R$ 1000 (% Brazil)
Beef cattle – Grassfed	Ag Census 2006 (herd), Anualpec FNP Consultoria (male and female slaugher rate), EMBRAPA-CNPGC[1], Agrolink (beef cattle prices)	4,747,507 (19.3)	10,722,750 (43.5)	7,003,857 (28.4)	2,182,992 (8.9)
Beef cattle - Grainfed		46,359 (5.0)	554,895 (59.8)	298,132 (32.1)	28,504 (3.1)
Swine (meat)	Ag Census 2006 (herd), EMBRAPA-CNPSA[2], CONAB[3]	216,369 (6.4)	681,741 (20.1)	2,199,566 (65.0)	288,689 (8.5)
Goat (meat)	Ag Census 2006 (herd), papers	1,382 (1.9)	8,106 (11.0)	3,680 (5.0)	60,186 (82.0)
Sheep (meat)	Ag Census 2006 (herd), papers	18,841 (4.3)	49,579 (11.3)	144,224 (32.9)	226,187 (51.5)
Buffalo (meat)	Ag Census 2006 (herd), papers	114,071 (67.4)	21,444 (12.7)	27,628 (16.3)	5,996 (3.5)
Poultry	Ag Census 2006 (directly)	362,033 (3.4)	2,760,246 (26.1)	5,708,697 (54.1)	1,717,356 (16.3)

[1] Empresa Brasileira de Pesquisa Agropecuária – Gado de Corte, Campo Grande - MS (Brazilian Agricultural Research Corporation – Beef Cattle, Campo Grande - MS)

[2] Empresa Brasileira de Pesquisa Agropecuária – Suínos e Aves, Concórdia - SC (Brazilian Agricultural Research Corporation – Swine and Poultry, Concórdia - SC)

[3] Companhia Nacional de Abastecimento – Ministério da Agricultura, Pecuária e Abastecimento (National Company of Agricultural Supply – Ministry of Agriculture, Livestock and Food Supply)

Table 4. Data sources

ACTIVITY	REGION (STATES, see Figure 5)	SOURCE
Soy (Conventional, GMO)	MT, BA, DF, PR, PR,	CONAB
Corn	MT, GO, PR,	
Sugarcane	AL, PE,	
Rice	MT,	
Beans	MG, BA, PR, SP,	
Sunflower	RS, MT	
Wheat	PR, DF, MG	
Castor oil plant (Mamona)	BA	
Milk	MG, SP, RS,	
Buriti	MA,	
Apples	RS, SC	
Grapes	RS	
Peaches	RS	
Garlic	RS, MG	
Rapeseed (Canola)	RS	
Chicken	RS, SC, PR, PE, CE, SP, MG, MS, GO	
Beef Cattle	RO, MS, GO, RS, PA,	EMBRAPA – CNPGC
Mango	PE	EMBRAPA – CPATSA[4]
Acai	PA	EMBRAPA – CPATU[5]
Passion Fruit	DF	EMBRAPA – CPAC[6]; EMBRAPA – CNPF[7]
Sheep	CE	EMBRAPA – CNPC[8]

[4] Empresa Brasileira de Pesquisa Agropecuária – Semiarido, Petrolina - PE (Brazilian Agricultural Research Corporation – Semiarido, Petrolina - PE).
[5] Empresa Brasileira de Pesquisa Agropecuária – Amazônia Oriental, Belém - PA (Brazilian Agricultural Research Corporation – Amazônia Oriental, Belém - PA).
[6] Empresa Brasileira de Pesquisa Agropecuária – Cerrados, Planaltina, DF (Brazilian Agricultural Research Corporation – Cerrados, Planaltina, DF).
[7] Empresa Brasileira de Pesquisa Agropecuária – Florestas, Colombo, PR (Brazilian Agricultural Research Corporation – Florestas, Colombo, PR).
[8] Empresa Brasileira de Pesquisa Agropecuária – Caprinos e Ovinos, Sobral - CE (Brazilian Agricultural Research Corporation – Caprinos e Ovinos, Sobral - CE).

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CONAB. Companhia Nacional de Abastecimento. Estimativas de custos de produção da cana-de-açúcar. available at http://www.google.com.br/url?sa=t&rct=j&q=produtividade%20cana-de-a%C3%A7%C3%BAcar%20ribeir%C3%A3o%20pernambuco%20conab&source=web&cd=1&ved=0CB0QFjAA&url=http%3A%2F%2Fwww.conab.gov.br%2FOlalaCMS%2Fuploads%2Farquivos%2F11_04_07_11_21_42_cana-de-acucar_2010..xls&ei=-03eTuOgN8rKgQeOt8nUBQ&usg=AFQjCNGkZ2AqBsmvl5ETF16uHN_BEsXJiA&cad=rja

CONAB**. Custos de Produção**. Disponível em: <http://www.conab.gov.br/conteudos.php?a=545&t=2>.

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