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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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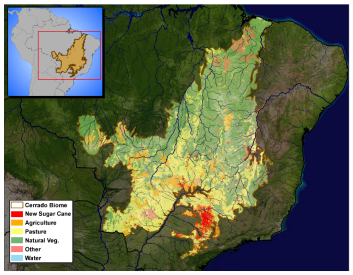
1. Introduction

The savanna ecosystem is the second largest biome of tropical South America (Figure 1). Although deforestation of the Amazon rainforest has received much public attention, most of the Brazilian deforestation has taken place, and continues to take place, in the savanna environments outside of the Amazon basin (locally called Cerrado). Of the original 2,000,000 km^2 of Cerrado that existed in Brazil before about 1940, about 50% has been converted and fragmented by deforestation and expansion of the agriculture frontier. The Cerrado is considered a hot spot for biodiversity and is the headwater region of major rivers of eastern South America. It is also currently the focus of agricultural expansion in response to domestic and international markets for soy, beef and biofuels.

The potential for expansion of intensive agriculture onto land currently occupied by degraded cattle pastures (i.e. land that is already altered but underutilized) 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 project 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.

In the first year of the project we have concentrated on objectives 1, 2, and 5, which are discussed in section 2 below.

Figure 1. The Cerrado region of Brazil with agricultural lands (orange), pasture (yellow), native vegetation (green), and sugarcane (red).

2. Results and Analyses - year 1

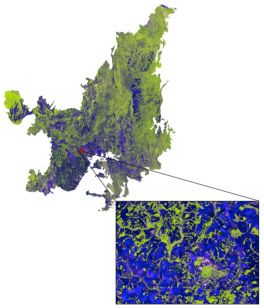


Figure 2: ALOS/PALSAR mosaic of Cerrado area. Inset illustrates detail provided by 15 m product.

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

There are two components to quantification of 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 (Figure 2), and partial coverage has been acquired for 2008 – 2010. A single coverage contains 833 images. 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. The Cerrado cultivated pasture area map, which is the official Brazilian land cover map was created in 2002. It has been updated based on visual interpretation of a combination of 123 Landsat TM scenes for the year 2008, MODIS, and ALOS/PALSAR imagery and related ground-based validation measurements (Figure 3). The results indicate an 8% increase of pasture area in the Cerrado region occurred between 2002 and 2008.

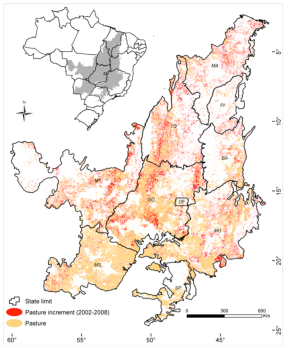


Figure 3. Cerrado pasture before 2002 (orange) and additional pasture increment to 2008 (red).

A recent MODIS-based analysis quantifies annual deforestation rates, which the LandSat-MODIS product shown in Figure 3 cannot provide. This analysis shows that although deforestation rates declined significantly after 2005 there was a large increase in the rate in the 2010-11 season. (Figure 4). This recent increase may be in anticipation of the changes to the Brazilian forest code that are expected in 2012. The total area deforested in this period was about 48,000 km^2 (Rocha et al, 2011).

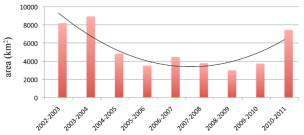


Figure 4. Total annual deforested area summed for the Cerrado environment (km^2). This product is provided as part of the Cerrado Deforestation Warning System (SIAD) created and available at LAPIG http://www.lapig.iesa.ufg.br:8080/imaps/composer/.

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

The second objective will be addressed by expanding and refining a deforestation simulation framework. The amount of land allocated to sugarcane will be simulated based on national and global market demands for biofuels and conversion from degraded pastures and other land use categories to sugarcane. Conversion will occur in a stochastic fashion using rents as transition probabilities, considering existing and projected infrastructure, climate, and land suitability.

The datasets necessary for calculating land use transitions in the Cerrado environment have been collected, including: annual sugarcane cropland area, infrastructure, forest carbon biomass, and land available for crop expansion. The cattle rent model and sugarcane crop yield and rent model, which are used in calculating land use opportunity costs have been developed.

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). By 2010, approximately 42,000 km^2 were occupied with sugarcane, an increase of about 136% since 2003 (Figure 5). Interestingly, most of this expansion occurred over existing crops, followed by the replacement of remnant Cerrado (Figure 6).

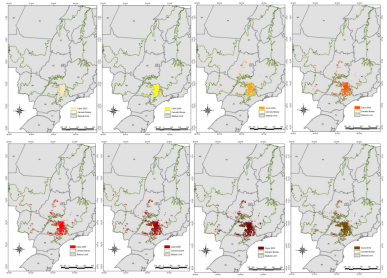


Figure 5. Annual maps of sugarcane area from 2003 (upper left) to 2010 (lower right).

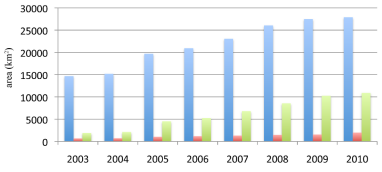


Figure 6. Total area occupied by sugarcane each year (km^2) in the Cerrado biome (sum of blue, red and green bars) and the landcover types prior to conversion to sugarcane (blue = cropland, green = native Cerrado, and red is pasture).

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 (Ferreira et al., in press). The simulations to the year 2050 using current socio-economic drivers of change show the potential for significant increases in total deforested area (Figures 7 and 8).

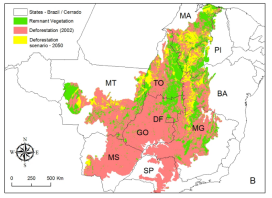


Figure 7. Deforested area observed in 2002 (pink) and simulated for the year 2050 (yellow) for the Cerrado biome. Remnant native Cerrado is shown in green.

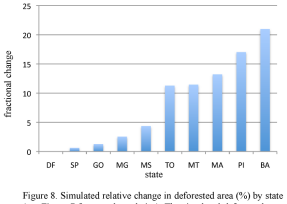


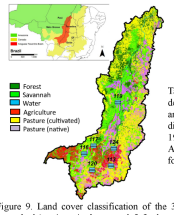
Figure 8. Simulated relative change in deforested area (%) by state (see Figure 7 for state boundaries). The simulated deforested area is equivalant to a rate of about 40,000 km^2/decade and is similar to the rate of deforestation observed from 2002-2011 (Figure 4).

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

The fifth objective uses data and numerical models to quantify the effects of deforestation and conversion to sugarcane and other agricultural lands on the discharge and climate of the Cerrado. Deforestation generally results in increased discharge because annual crops and perennial pastures have reduced root density and depth, plant leaf area index, and growing season length, hence, lower evapotranspiration compared to the more diverse natural vegetation systems that they have replaced.

A recent study in the Araguaia basin documented an approximate 25% increase in mean discharge of an 82,000 km^2 sub-watershed (See station number 113 Figure 9 and Table 1) since the 1970s. Numerical modeling suggests that about 2/3 of the increase is attributable to land cover changes and the rest from an increase in precipitation (Coe et al., 2009).

An ongoing analysis of these hydrological changes shows that discharge increases are widespread throughout the region of greatest landcover disturbance (Figure 9, Table 1). Discharge has increased by 10-27% throughout a 120,000 km^2 region upstream of station 119 (Figure 9) despite no significant change in precipitation.



Gauge	Deforested (%)	Discharge (%)
113	71%	27%
116	11%	15%
117	12%	16%
119	9%	15%
120	62%	11%
124	60%	18%

Table 1. Total observed deforested fraction as of 1996 and fractional change in discharge from the 1970s to the 1990s for six gauges in the Araguaia basin (see Figure 9 for location of stations).

Figure 9. Land cover classification of the 370,000km^2 Araguaia watershed (see inset in the upper left for location of basin) derived from LandSat and MODIS imagery. Stream gauges (6 in total) are numbered (e.g. 113, 124).

3. Publications

Coe, M.T., E.M. Latrubesse, M.E Ferreira, and M.L. Amsler, 2011: The effects of deforestation and climate variability on the streamflow of the Araguaia River, Brazil. Biogeochemistry, 105, 119-131, DOI: 10.1007/s10533-011-9582-2.

Ferreira, L.G., G.P. Asner, D.E. Knapp, E.A. Davidson, M.T. Coe, M.M.C. Bustamante, and E.L. de Oliveira, 2011: Equivalent water thickness in savanna ecosystems: MODIS estimates based on ground and EO-1 Hyperion data. IJRS, DOI: 10.1080/01431161.2010.523731.

Ferreira, M.E., L.G. Ferreira Jr., F. Miziara, and B.S. Soares-Filho, Modeling landscape dynamics in the central Brazilian savanna biome: Future scenarios and perspectives for conservation, J. Land Use Sci, in press.

Ferreira, L.G., L. Fernandez, E.E. Sano, A.A. Ellias, S.B. Sousa, and F.M. Araujo. Biophysical Properties of Cultivated Pastures in the Brazilian Savanna Biome: An Analysis in the Spatial-Temporal Domains Based on Ground and Satellite Data. Remote Sensing (in prep).

Rocha, G.F., L.G. Ferreira Jr., N.C. Ferreira, and M.E. Ferreira, 2011: Detecção de desmatamentos no bioma Cerrado entre 2002 e 2009: padrões, tendências e impactos. RBC. Revista Brasileira de Cartografia (Online), v. 63, p. 341-349.

Rocha, G.F.; Ferreira, L.G.; Ferreira, M.E.; Ferreira, N.C. Patterns and trends of land conversion in the Brazilian savanna as observed by the MODIS vegetation indices. J. Land Use Sci., (in prep).