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Measuring the initial impacts on deforestation of Mato Grosso's program for environmental control

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Abstract

Although private forest use in Brazil has been regulated at least since the Forest Code of 1965, cumulative deforestation in the Brazilian Amazon reached 653,000 km² by 2003 (INPE 2004). Much of this deforestation is illegal. In 1999, the State Foundation of the Environment (FEMA) in Mato Grosso introduced an innovative licensing and enforcement system to increase compliance with land use regulations. If successful, the program would deter deforestation that contravenes those regulations, including deforestation of riverine and hillside forest (permanent preservation areas), and reduction of a property's forest cover below a specified limit (the legal forest reserve requirement).

This study seeks to assess whether introduction of the program affected landholder behavior in the desired direction. Simple before/after comparisons are not suitable for this purpose, because there is considerable year to year variation in deforestation due to climatic and economic conditions. Nor is it valid to assess program impacts by comparing licensed and unlicensed landholders, even though the program focused its enforcement efforts on the former. This is because, first, landholders with no intention of deforesting may choose to become licensed; and second, unlicensed landholders may be deterred from deforestation by the mere existence of a serious program that aims for universal licensing.

To meet these challenges, the study applies a difference-in-difference approach to geographically explicit data. It looks for, and confirms, post-program declines in deforestation in high-priority enforcement areas relative to other areas; in more easily observed areas relative to less easily observed areas; in areas of low remaining forest cover (where further deforestation is probably illegal) relative to high remaining forest cover. Thus, even against a backdrop of higher aggregate deforestation (driven in part by higher agricultural prices), there is evidence that the program in its early stages (before 2002) did shift landholder behavior in a direction consistent with reduced illegal deforestation. (The legality of deforestation was not however directly observed). We hypothesize that this behavioral change resulted from an initial perception of increased likelihood of the detection and prosecution of illegal deforestation, following announcement of the program. The study does not assess SLAPR impacts following the change of state administration in 2003.

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Acknowledgments

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Introduction

Brazilian federal policy emphasizes the importance of restraining illegal deforestation, as part of the overall goal of encouraging sustainable development in the Brazilian Amazon (Presidência da República 2004). Over the past 15 years, federal and state agencies have put in place a variety of legal and administrative instruments to regulate land and forest use in Amazônia. Yet deforestation of the tropical forest has continued, more or less unabated (see Figure 1), and an even greater proportion of the cerrado (savanna woodland) has been cleared. Much of this deforestation contravened two important requirements of the 1965 Forest Code. The Code requires each landowner to maintain *reserva legal* (RL: legal forest reserve) of 50% (later 80%) of each property under natural vegetation (in Amazônian forest areas), or 20% (later 35%) in Amazônian cerrado (savanna) areas. The Code also requires maintenance of *areas de preservação permanente* (APPs: permanent preservation areas) near rivers, on slopes and on hilltops. It places limits on the sum of APP and RL areas; in Amazônian cerrado, for instance, the sum cannot exceed 50% of the property.

The difficulty in enforcing regulations reflects several challenges. First, there is a strong economic incentive driving much deforestation (Margulis 2004). Second, there is a huge area to monitor. Third, while penalties for illegal deforestation were substantially increased in 1998, landholders may perceive a low probability that the long chain of detection, arraignment, prosecution, and judgment will result in an effective penalty (Akella and Cannon 2004; Hirakuri 2003). In other words, the perceived deterrent may be low.

For these reasons, there has been great interest in Mato Grosso's new system for environmental regulation (SLAPR), which deploys technological and institutional innovations to address these challenges.

On its introduction, the SLAPR was greeted enthusiastically and was credited with contributing to a reduction in Mato Grosso's state-wide deforestation rate. However, there has subsequently been a dramatic rise in the Mato Grosso deforestation rate, in absolute terms and relative to other Amazônian states. What do these aggregate deforestation rates tell us about the system's overall effectiveness?

This paper argues that simple before-program/after-program comparisons do not provide a measure of program effectiveness, because commodity prices, weather, and other factors strongly influence year-to-year variation in deforestation rates. Comparisons between deforestation inside vs. outside licensed properties are also problematic guides to effectiveness, because early volunteers for licensing may be systematically different in characteristics or motivation from their more reticent neighbors. Moreover, while we recognize that the program prioritized its enforcement efforts on licensed properties, we hypothesize that it may also have affected behavior in the unlicensed areas. This is because credible operation of the program within the licensed properties might increase the perceived probability of eventual detection and punishment of unlicensed activities.

The paper therefore reviews the methodological challenges in assessing program impact. It then proposes a solution, based on an innovative application of the difference-in-difference approach to geographically explicit data. We hypothesize that the program, if successful, will have a *differentially large* impact on three types of areas:

- those explicitly targeted for higher enforcement effort
- areas that are more easily observed, e.g. on very large properties
- areas where most deforestation is likely to be unauthorizable, e.g. in contravention of the forest reserve requirement.

Using multivariate analysis that holds constant a variety of factors, we find that deforestation in each of these areas declined, *relative to other areas*, after the program was instituted. The period of analysis however extends only through 2002, and cannot be generalized to the subsequent period. Starting in 2003 there was a change in state administration, with the governorship passing from an environmental advocate to one of the world's largest soybean farmers.

The plan of the paper is as follows. The next section describes the Environmental Control System and reviews the broad deforestation trends since its introduction. Section 3 discusses methodological difficulties in assessing program impact and proposes a conceptual framework and econometric test for addressing these issues, looking at post program changes in deforestation differentials across the landscape. The following section describes the data. The 'difference-in-difference' predictions are then examined via simple crosstabulations in section 5 and subjected to formal multivariate statistical tests in section 6. Section 7, a digression, looks at spatial variation in land values as an important factor in understanding the pressures for deforestation. The paper concludes with a brief summary.

1 FEMA's Environmental Control system

In 2000, FEMA (the Mato Grosso state environmental agency) implemented an improved rural environmental control system (State of Mato Grosso 2001), sometimes called SLAPR (an acronym for Rural Property Environmental Licensing System). Licensing, although prominent, is only one component in an integrated system.

The goal of the system is to "enforce current environmental legislation as simply and as inexpensively as possible" with particular focus on enforcing RL and APP requirements, enforcing rules on forest and field burning, and ensuring that all land use activities are appropriately licensed.[3] Cost-effectiveness results from the use of remote sensing (satellite imagery) to monitor large areas for deforestation and illegal forest burning; the use of GIS (geographic information systems) to manage data on licensed properties; and a focus on properties of greater than 1000 hectares, since these are relatively few in number but control most privately owned land and are presumed responsible for the bulk of deforestation.

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[3] The following description of the system is based largely on State of Mato Grosso (2001), from which the quote was taken.

FEMA has a multipronged approach to encouraging compliance with land use regulations: deterrence of deforestation on nonlicensed properties; encouragement of landowners to license their properties; and enforcement of regulations on licensed properties. In the first prong, satellite and field inspections of high deforestation areas identifies landowners who are out of compliance with regulations. Many of these, especially in the early phases of implementation, will have unlicensed properties. These violators are subject to severe civil and criminal penalties. However, FEMA's preferred approach is offer a reduction of up to 90% in fines if they repair the damage done to RL or APP areas. This is done through the licensing process. Landowners may also voluntarily opt to license their properties, motivated in some cases by lenders' requirements to show compliance with regulations.

In either case, recruitment of a property into licensed status facilitates enforcement of regulations. A first step in the licensing process involves detailed mapping of the property, and determination of compliance with RL and APP requirements. Landowners who are out of compliance are given an opportunity to redeem themselves by reestablishing native vegetation, by purchasing a compensating area of RL from another private property, or by purchasing for the state a private property within an already-gazetted conservation unit. Landowners who are already in compliance may apply for an authorization for legally compliant deforestation. Because the maps of licensed properties are stored in a GIS, subsequent violation of license terms can in principle be easily and unambiguously detected. Moreover, the owners of licensed properties are legally bound to observe the licensing terms, so that violation of these terms exposes them in principle to swift and severe penalties.

Initial studies of the environmental control program suggested that it was contributing to an observed reduction in aggregate deforestation. FEMA credited the control system with the decrease in deforestation rates (per total area) from 2% in the biennium 1998-99[4] to 1.35% in the biennium 2000-01 (FEMA 2002, 19). Fearnside's municipal-level study of FEMA's data for

[4] That is, the two year period ending in April 1999.

1998-99 and 2000-01 found a larger decrease in deforestation for municipalities with high enforcement activities (Fearnside 2002, 2003).

Subsequently, however, the deforestation rate in Mato Grosso increased. INPE estimates for Mato Grosso (which, unlike FEMA, cover only the forest biome, excluding the cerrado)[5] depict an 8.5% decrease in 1999-2000, a 20.9% increase in 2000-01, a 1.6% decrease in 2001-02 and a 27.2% increase in 2002/03. Figure 1 shows that the recent uptick in Mato Grosso deforestation contrasted with a downward trend elsewhere in the Amazon.

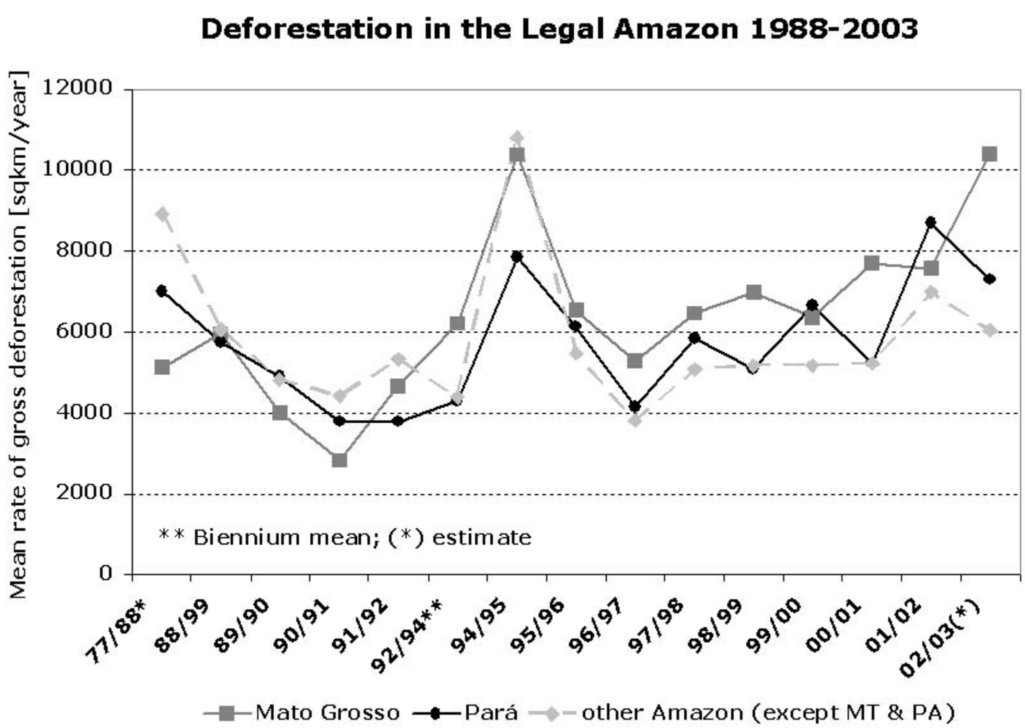

Figure 1: Deforestation in the Legal Amazon 1989-2003 (Source: INPE-Prodes 2004)

Does this mean that the environmental control program was initially effective and then lost its effectiveness? Not necessarily. Deforestation rates are driven by climatic and economic forces that vary sharply across space and time. For instance, deforestation is more likely when soil moisture is low, because this decreases the cost of clearing and increases the likelihood of

[5] See Fearnside and Barbosa (2004).

accidental (escaped) forest fires (Nepstad *et al.* 1999). Hence there is a strong relation between the El Niño cycle and deforestation. There is also a strong presumption that deforestation responds to the prices of agricultural commodities associated with forest and savanna conversion, especially beef and soybeans. The nominal price of beef approximately doubled between 1998 and 2003 due largely to an abrupt decline in the exchange rate; at the same time, Mato Grosso was declared free of aftosa (food and mouth disease) opening up export options (Kaimowitz *et al.* 2003). This combination of factors could well account for the sharp rise in Mato Grosso deforestation.

In sum, simple before versus after assessments of deforestation do not provide insight into program effectiveness – a common difficulty in the evaluation of any public policy that affects behavior over a large region. The next section considers this problem and suggests a solution.

2 Assessing program impacts on deforestation: methodological issues

2.1 A typology of deforestation

How might the Environmental Control System affect landholder behavior and deforestation? To think about this, it is helpful to distinguish, conceptually, three types of deforestation:

1. <u>non-authorized, non-authorizable (NN) deforestation</u>. This comprises actions, such as deforestation of APPs, or reduction of RL below the legal limit, which would ordinarily not be licensed.

2. <u>non-authorized, authorizable deforestation (NA)</u>. This class of deforestation includes all deforestation which meets the criteria for a deforestation authorization, but was illegal because the landowner did not in fact apply for or receive a license.

3. authorized, authorizable deforestation (AA). This includes all deforestation for which an official authorization was granted. (We assume that all authorized deforestation is also authorizable, ie that authorities correctly interpret and apply existing regulations.)

If successful, the SLAPR would be expected to reduce NN-type deforestation, in absolute terms. It would not necessarily reduce the total amount of authorizable deforestation (the sum NA+AA) – it might even increase it, as NN-deforesters shifted to AA. However, the program would be expected to shift NA-type to AA-type. Hence we predict that a successful program would reduce the ratio NN/(NA+AA) and the ratio NA/(NA+AA).

How might the program accomplish this? There are two avenues. First, the agency might directly target some landowners for recruitment into the system, i.e. licensing. Once licensed, these landowners will in principle face large, immediate penalties for noncompliant (NN) deforestation, but no penalties for AA deforestation. Second, program implementation may also affect the behavior of unlicensed landholders. These landholders must weigh the costs and benefits of undertaking unlicensed deforestation. Even though the program is less able to detect and punish illegal behavior outside licensed properties, unlicensed landholders may decide that NN-type deforestation has become riskier now that the program is in operation. They may respond either by entering the system; shifting to NA-type deforestation; or trying to conceal NN deforestation by undertaking it in less detectable locations.

2.2 Defining and detecting program impact on deforestation

This typology suggests that the program could be evaluated for its impact on three different measures of deforestation: total deforestation (NN+NA+AA), illegal deforestation (NN+NA), or unauthorizable deforestation (NN). While all are of potential interest, in this paper we focus on NN. In our view, this is the most policy-relevant measure of environmental impact, since NN-type deforestation is by definition the least desirable. The NA-to-AA shift, in contrast, is essentially a relabeling of deforestation. If successful, the relabeling would reflect a successful extension of the rule of law with important long-run impacts (in reducing future NN-type deforestation) but would not have any immediate environmental implications.

A second and more profound problem is controlling for other factors, besides the introduction of the program, which may affect deforestation. The problem here is lack of a good control area against which to compare the outcome of the state-wide experiment. As noted above, it is uninformative to compare pre-program and post-program deforestation rates, because of confounding factors. It is tempting to propose a comparison between the deforestation rate on licensed vs. unlicensed properties. But this comparison falls far short of the ideal of comparing a treatment vs. a control group. The problem is that licensed properties may differ from unlicensed properties in many ways – some unobservable. In particular, it is possible that the earliest volunteers for licensing were those with no plans for deforestation. This includes properties with no pressure or plans for forest conversion. It also includes properties where most forest was long ago converted, and whose prosperous owners now seek rapidly to achieve compliance status through compensation.[6] So, to take some extreme but illustrative scenarios:

- Suppose licensed properties consist only of those who had no plans for deforestation. In this case, the measured rate of deforestation rate on the licensed properties would be much lower than that of nonlicensed properties – but licensing (by assumption) had no behavioral effect.

- Suppose that all landowners who planned NA (non-authorized but authorizable) deforestation obtain licenses and carry out AA deforestation instead; meanwhile surveillance discourages most NN deforestation outside licensed properties. In this case, the program in fact successfully discouraged illegal deforestation, but measured rate of deforestation on licensed properties is much higher than on unlicensed properties.

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[6] The state offered these property owners incentives to exercise the compensation option as soon as possible. The ratio of required compensation area to past RL loss was scheduled to rise from 1 in 2001 to 5 in 2005.

These problems are, in theory, surmountable. The econometric solution requires:

1. data on the licensing status and deforestation behavior of individual landholders

2. data on variables that influence the landholder's decision on whether or not to license, but arguably have *no effect* on the decision whether or not to deforest. This would allow us to analyze natural experiments in the effect of licensing on deforestation. In other words, it would allow us to match 'treatment' and 'control' cases.[7]

In general, it is difficult to find variables that meet criterion 2. Even without them, however, we could look at the pre-program determinants of deforestation, and the post-program determinants of licensing, and thus determine whether licensees are mostly those with low or high deforestation risk.

2.3 A difference-in-difference approach

Unfortunately, property level data on licensing is not available to us, and indeed we do not even have maps of property boundaries. So we propose a different approach to detecting overall program impacts on deforestation behavior. Let us distinguish between 'high cover' and 'low-cover' areas. High-cover areas are lands (outside protected areas) in which local forest cover (computed as a moving average) exceeds the applicable RL limit, and low-cover areas constitute the remainder on non-protected lands. Deforestation rates may systematically differ between high-cover and low-cover plots of land, even after controlling for observable determinants of deforestation risk, such as road proximity and slope. There are a variety of reasons for this differential, which could work in either direction. Low cover areas may be more attractive for deforestation -- that is why they have already lost their cover. On the other hand, it may be

[7] For instance, suppose we thought that there was no difference between landholders with pre-program loans from banks that enforce the Protocolo Verde, vs. landholders with pre-program loans from other banks. But maybe those with loans from Protocolo Verde banks have a greater incentive to get licensed. So we could match treatment-control pairs of landholders between PV and non PV banks. We would hypothesize no difference in deforestation before SLAPR, but a large difference afterwards. Similarly, we may compare adjacent properties on different sides of the Mato Gross/Pará state border, hypothesizing that they are identical save for the state laws they face.

that in low cover areas, the only remaining forest patches occupy poor soils unattractive to farmers or ranchers (Chomitz *et al*, 2005).

How will this differential between high and low cover areas change with the advent of the Environmental Control System? The low cover areas are much more likely to be in violation of the RL requirement. (This is a statistical assertion, since we do not observe the actual compliance status of any point.) If the program is effective in deterring type NN deforestation, then we would expect a decline in the deforestation of low cover areas *relative* to high cover. In other words, we expect the differential to change after the program is introduced. This is a variant of the difference-in-difference approach widely used in program analysis. However, this is the first application of which we are aware for geographically explicit data.

Formally, let

y_{it}= deforestation rate, plot i, time t

X_{it}= characteristics of plot i at time t

$LOWCOVER_{it}$ = 1 if plot is low cover at time t, =0 else

$POSTPROGRAM_t$=1 if program is operational at time 1, =0 else

μ_t be a year-specific effect

We can model the deforestation rate as:

(1) $y_{it}= X_{it}\beta + \gamma\, LOWCOVER_{it}+\delta(POSTPROGRAM_t * LOWCOVER_{it}) + \mu_t$

This equation is consistent with a standard spatial model of deforestation (see e.g. Chomitz and Gray 1996). Then the hypothesis that the program reduces NN deforestation of legal reserve implies that:

$\delta<0$

given the assumed high correlation between LOWCOVER and noncompliance with RL.

We use this general framework to test several hypotheses about program impacts. For instance, we can examine the relative impact of the program in areas targeted for more intensive enforcement, using an ENFORCEMENT dummy variable in place of the LOWCOVER:

(2) $y_{it} = X_{it}\beta + \gamma\ \mathrm{ENFORCEMENT}_{it} + \delta(\mathrm{POSTPROGRAM}_t * \mathrm{ENFORCEMENT}_{it}) + \mu_t$

Here we predict $\gamma > 0$ (because priority enforcement areas were chosen on the basis of high observed deforestation rates, but again expect $\delta < 0$.

We assert that, if successful, the program will be observed to reduce deforestation in:

- low-cover areas relative to high-cover areas
- areas prioritized for enforcement relative to others
- APP areas relative to non APP areas
- areas close to roads (these being more observable and targeted for greater levels of enforcement) relative to far from roads.

We stress again that these comparisons are not simple differences, but rather, *differences in differences*.

We also hypothesize that the program will have differentially greater impact on large-patch deforestation relative to small-patch deforestation, for two reasons. First, large patches are more easily detectable by remote sensing and might be supposed to attract greater attention from the authorities. Second, large-patch deforestation characterizes large properties, which were the explicit focus of the Environmental Control System. Next we describe our study area, our approach to analyze program effectiveness, the available data sets and our data sampling technique.

3 Methodology

3.4 Study area and time period

With about 906,000 square kilometers, Mato Grosso is the third largest federal state of the Legal Amazon and Brazil. It is located in the center-west region of the country and has parts of three major ecoregions: Amazon moist forests (52%), "*Cerrado"* savanna woodlands (41%) and "*Pantanal"* wetlands (7%) (FEMA 2002, 6). All of them are considered to be globally outstanding and of high conservation priority. Yet they are threatened by agricultural expansion, road construction, water projects and pollution (Dinerstein *et al.* 1995).

Colonization of Mato Grosso started already in the 1950s and 1960s when extensive tracts of land were sold for large-scale cattle-ranching projects to entrepreneurs from southern Brazil. Induced by the growth-oriented policies of the 1970s and the export-oriented policies of the 1980s, soybean production expanded rapidly throughout the cerrado of Mato Grosso, making the state Brazilian's largest soybean producer in the 1990s. In 1995, 24.9% of Mato Grosso was used for agricultural purposes, primarily for large-scale pasture (57.7%) and large-scale annual crop cultivation (18.8%). Less than a quarter of the agricultural land was used for subsistence agriculture (13.9%) in 1995 (SEPLAN 2002). In contrast to some other parts of the Amazon, the colonization process of the Mato Grosso was dominated by private large-scale entrepreneurs who are perceived to be the greatest contributors to deforestation in Mato Grosso. In 1996/97, 62.4% of the total deforestation patches monitored by FEMA were greater than 200 hectares (FEMA 2002).

Although the program was announced in 1999, licensing activities began in 2000, accelerating in 2001 and especially 2002. We expect therefore increased program credibility and deterrent effect after 1999. Hence we compare FEMA deforestation rates from periods prior to program implementation (1996-97; 1998-99) with post-program FEMA data (2000-01; 2002). Since FEMA enforcement targets private rural properties, our analysis extent was limited primarily to non-protected areas of Mato Grosso. Because the program prioritized enforcement on large landholders (FEMA 2001:21), we compare the change of large-scale deforestation (deforestation clearings greater 200 hectares) versus small-scale deforestation (clearing below 200 hectares)[8].

3.5 Data

The original and derived data sets (digitally coded maps) that are used in the analysis are summarized in Table 1. All data is projected to Universal Transversal Mercator (UTM), Zone 21 South, South American Datum 1969.

An important variable in our study distinguishes high/low natural vegetation cover. Ideally, we would like to distinguish between deforestation potentially consistent with the RL requirement versus deforestation on properties that are already out of compliance with the requirement. Lacking a map of property boundaries, we constructed a proxy. Using the SEPLAN land cover map, the proportion of natural vegetation cover within a radius of about 1,250 meters – an area of 625 hectares that corresponds to the mean property size in Mato Grosso (IBGE 1998) – was computed for each 100 meter pixel. Based on the biome specific legal reserve requirement, the mean natural vegetation cover in non-protected areas in Mato Grosso was classified into areas of "high" (in concordance with the RL-definition) and "low" (below the RL-requirement) proportion of natural vegetation cover. We defined high versus low cover based on the legal reserve requirement of the revised Forest Code 1965, i.e. 35% in the Cerrado, 80% in Amazon

[8] Our criterion based on size of *incremental* clearing corresponds to the criterion of 200 ha *incremental deforestation size* which distinguishes FEMA oversight (large-scale deforestation) from IBAMA oversight (Mato Grosso – Ordem Serviçio No. 26/00). However, it differs from the criterion of 300 ha *property size* which distinguishes FEMA oversight (larger properties) from IBAMA oversight (MMA/FEMA Pacto Federativo 2003-2004).

(Provisional Measure 2001) and 50% in the Transition biome (Mato Grosso Complementary State Law No. 38/1995).[9]

Data inconsistencies between FEMA and SEPLAN datasets present a challenge to accurate deforestation assessment in Mato Grosso. The deforestation data available to us identified areas on which forest cover was lost, but did not identify pre-existing forest cover. The SEPLAN land use/ land cover map is based primarily on 1995 satellite imagery with some additional images from 1996 and fieldwork conducted in 1997 with updates from 1999 (SEPLAN 2004). As the SEPLAN land use/land cover map integrates information from different years, there are inconsistencies between the SEPLAN map and FEMA deforestation data. The proportion of

9 The legal reserve requirement was revised since 1996 (Provisional Presidential Decree No. 1.511/96). Prior to 1996, RL requirement was 50% in forest areas and 20% in the Cerrado (Forest Code 1965).

Name	Date of map content	Date of publication	Scale	Source	Description of the map content	Map
Municipalities with increased FEMA enforcement	2000-01	2001	1:250,000	Mato Grosso State Foundation of the Environmental (FEMA)	Municipalities with targeted increased enforcement activity upon the implementation of the FEMA environmental control system in 1999. The municipalities were identified from FEMA documents, notably FEMA (2002).	Map 1
Incremental deforestation in Mato Grosso	1996-97, 1998-99, 2000-01, 2002	2004	1: 250,000	Mato Grosso State Foundation of the Environmental (FEMA)	Human induced loss of any natural vegetation in Mato Grosso (unlike INPE, FEMA also considers deforestation in the Cerrado biome). Until 2001, deforestation was measured bi-annually (two years). Since 2002, deforestation is measured annually.	Map 2
Ecoregions of Mato Groso	1977-1981	2001	1: 1,000,000	Derived from the vegetation map of the RadamBrasil Project by FEMA	Vegetation map with three biomes (i.e. Amazon, Transition, Cerrado) as classified by FEMA (Instrução Normativata No. 2/2001) identify the required legal reserve proportion for a given property in Mato Grosso.	Map 3
Permanent preservation areas (APP) of Mato Grosso	unknown	2003	1: 250,000	Mato Grosso State Foundation of the Environmental (FEMA)	APP around waterbodies (rivers and lakes). The width of the waterbody defines the width of the APP buffer (Forest Code 1965).	Map 4
Protected areas of Mato Grosso		2003	1: 250,000	Mato Grosso State Foundation of the Environmental (FEMA)	Indigenous territories and conservation units	Map 5
Land use/land cover of Mato Grosso	1995	2002	1: 250,000	State Secretary of Planing and Coordination (SEPLAN)	Actual land use and land cover bases on satellite imagery primarily of 1995 and some of 1996, and fieldwork conducted in 1997 and some updates in 1999. The map was elaborated as part of the socio-economic ecological zoning exercise (ZSEE) in Mato Grosso.	Map 6
Natural vegetation cover of Mato Grosso	1995	-	1: 250,000	Derived from land use/ land cover map (own calculation)	Natural vegetation cover corresponds to the land cover (without any human activity as of 1995) of the SEPLAN land use/land cover map.	Map 7
High/low natural vegetation cover in Mato Grosso	1995	-	1: 250,000	Derived from natural vegetation cover map (own calculation)	Mean natural vegetation cover on a 25x25 pixel neighborhood (corresponding to a mean property size in Mato Grosso of 625 hectareas) was calculated for each pixel on the 100 meter rasterized natural vegetation cover 1995. The resulting mean values were ove	Map 8
Elevation of Mato Grosso	2002-2003	2003	90 meter	US Geological Survey (USGS)	Digital elevation model for Mato Grosso from the Shuttle Radar Topography Mission (SRTM)	-
Slope of Mato Grosso	2002-2003	-	90 meter	Derived from elevation grid (own calculation)	Slope was calculated from elevation grid.	Map 9
Roads of Mato Grosso	unknown	2003	1: 250,000	Mato Grosso State Foundation of the Environmental (FEMA)	Primary (paved) and secondary (unpaved) roads in Mato Grosso	-
Distance to roads in Mato Grosso	unknown	-	1: 250,000	Derived from road map (own calculation)	Bird distance to the nearest road calculated for each pixel of the 100 meter rasterized road map.	Map 10
Agricultural suitability of Mato Grosso	1995	2002	1: 250,000	State Secretary of Planing and Coordination (SEPLAN)	Agricultural suitability was defined by SEPLAN as part of the socio-economic ecological zoning exercise (ZSEE) in Mato Grosso.	Map 11
Land value of Mato Grosso	2003	2003	1: 250,000	derived from INCRA 2003	Geo-referenciation of land values to municipal boundaries of Mato Grosso	-

Table 1: Catalog of original and derived data for the analysis

FEMA deforestation taking place on areas identified as agricultural in 1995-7 by SEPLAN, is 25.5% in 1996-97, 19.4% in 1998-99, 13.2% in 2000-01 and 9.5% in 2002. To overcome the inconsistencies, we decided to limit the econometric analysis extent to the SEPLAN natural vegetation cover, presumably of 1995.[10] For describing aggregate deforestation rates, however, we use two approaches:

Relative rate (or forest cover change): FEMA deforestation in period t divided by the imputed forest cover (i.e. SEPLAN forest cover in 1995 minus cumulative FEMA deforestation since 1995).

Absolute rate: FEMA reported deforestation in period t divided by invariant land area (i.e. regardless of forest cover and therefore constant over time).

Some further inconsistencies were found in the FEMA deforestation data. For some areas, the same area was deforested several times. E.g., although an area was deforested in 1996-97, it was deforested again in 1998-99 or 2000-01. Table 2 tabulates areas reporting deforestation in two different time periods. To correct for this data problem, we only considered the deforestation at a given point in the first period it was reported.

Duplicate deforestation [sqkm]	1998-99	2000-01	2002
1996-97	60	381	148
1998-99	-	347	134
2000-01	-	-	4

Table 2: Duplicate deforestation in the FEMA deforestation data [sqkm]

3.6 Data sampling

The analysis was done using data on a sample of land points. The information was derived from digital maps using geographic information system (GIS) techniques. Sampling was performed by overlaying a 1-kilometer rectangular grid over the state of Mato Grosso, yielding

[10] Note that subsequently, we refer to the SEPLAN land use/land cover map as depicting the status of 1995.

905,995 sample points. The resulting sample point layer was overlaid on each of the assembled digital maps (Table 1) to extract location-specific characteristics for each point (e.g. deforested or non-deforested in year x) surrendering categorical variable information. After assessing deforestation in protected areas, they were excluded from the subsequent analysis. Water and urban points were also excluded, leaving 745,718 sample points for analysis. To reduce spatial autocorrelation in the econometric analysis, we created sub-samples from the original set of sample points by selecting sets of every ninth point (ie. every third x-coordinate and every third y-coordinate). Several combinations of ninth-point samples were extracted using the modulo-function on the xy-coordinates of the original samples points.

4 Deforestation trends

4.7 Deforestation in protected areas

Before turning to deforestation in private lands, the focus of this study, we briefly assess deforestation in protected areas. For each of the study periods under question we found a deforestation rate (with forest cover as the denominator) of less than 0.08% per year within protected areas – an order of magnitude lower than the deforestation rate outside protected areas. There was no clear time trend in this already-low rate. Although we did not examine the role of remoteness and soil conditions in explaining the extremely low deforestation rate in protected areas, it seems reasonable to suppose that protected area demarcation serves as a reasonably effective deterrent to deforestation.

4.8 Deforestation trends by biome

We turn now to deforestation rates in non-protected areas. *Relative* annual deforestation rates refer to the geometric average yearly forest cover change with adjusted SEPLAN natural vegetation cover as denominator (Figure 2). *Absolute* annual deforestation refers to the average yearly deforestation rate with total biome land area as denominator (Figure 3).

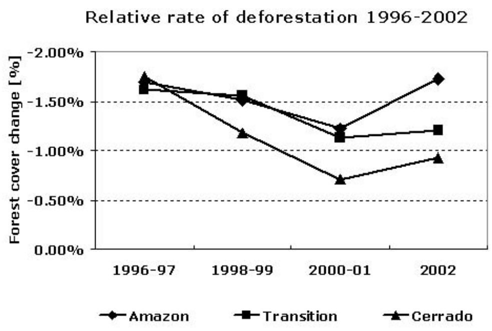

Figure 2: Relative annual deforestation rates 1996-2002 in Mato Grosso (FEMA 2004)

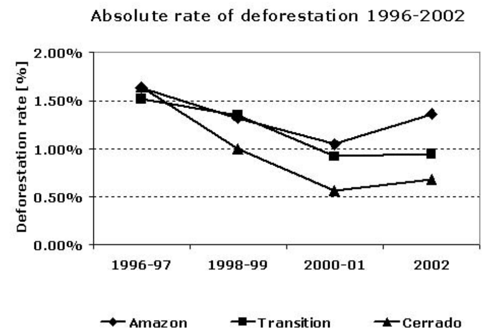

Figure 3: Absolute annual deforestation rates 1996-2002 in Mato Grosso (FEMA 2004)

The gross trends do not show any clear relationship with program implementation. Already prior to the FEMA enforcement program, in biennia 1996-97 and 1998-99, absolute and relative deforestation rates decline across all biomes. Deforestation rates continue to decrease after program implementation in 2000-01, but then start increasing again in 2002 (when FEMA began to report single-year observations), especially in the Amazon.

4.9 Trends inside and outside APPs

To test for the compliance of the APP requirement, we assessed whether deforestation dropped in APPs relative to non-APP areas. Specifically, we compared deforestation change within APPs, just outside them, i.e. within a 300 meter buffer extending outwards from the APPs, and completely outside of the APPs and their 300 meter buffer before and after initialization of the FEMA enforcement program. The comparison was done separately for each biome, i.e. for the non-protected biome area, and is depicted in Figure 4-6.

The most notable feature is the lower deforestation rate within vs outside APPs, at all periods. In theory, the comparison between just inside and just outside the APPs should provide some insight into the effectiveness of enforcement, both before and after the new system went into place. Since most APP area in Mato Grosso arises from stream proximity rather than hillslopes, one would imagine that in the absence of enforcement there would be a higher rate of deforestation inside rather than outside APPs[11]. So, the observed lower rate may reflect the deterrent effect of regulations and enforcement. The precision of this comparison is however, blurred by the possibility of registration errors in overlaying the maps. Note that there is at most a slight indication of a post-program change in the differential deforestation rate inside versus outside APPs.

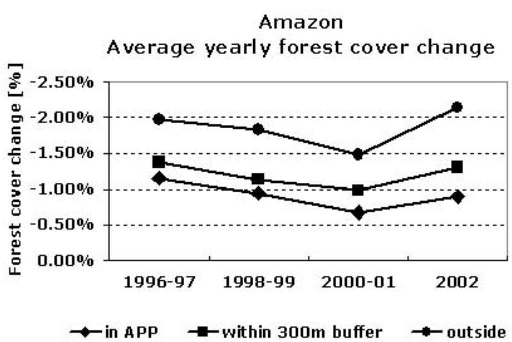

Figure 4: Forest cover change inside/outside APPs in the Amazon biome (FEMA 2003)

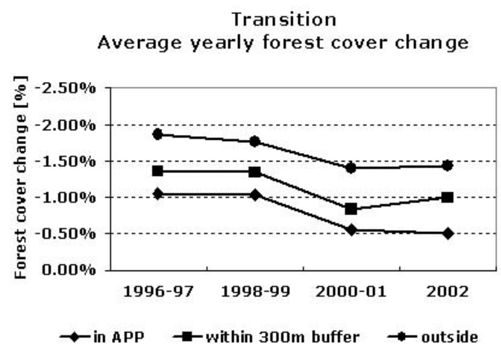

Figure 5: Forest cover change inside/outside APPs in the Transition biome (FEMA 2003)

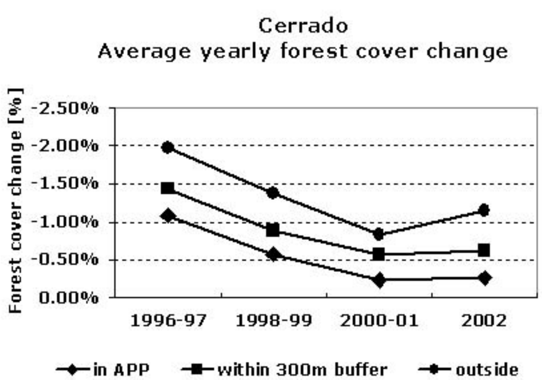

Figure 6: Forest cover change inside/outside APPs in the Cerrado biome (FEMA 2003)

Figure 7 depicts forest cover changes (relative denominator) in large- versus small-scale deforestation inside versus outside APPs across biomes. (Large scale deforestation is that occurring in deforestation patches of greater than 200 ha in extent.) In and around cerrado APPs, large-scale deforestation closely tracks small scale. But elsewhere, large scale

[11] On the other hand, areas suitable for soybean may be situated on flat areas further away from streams.

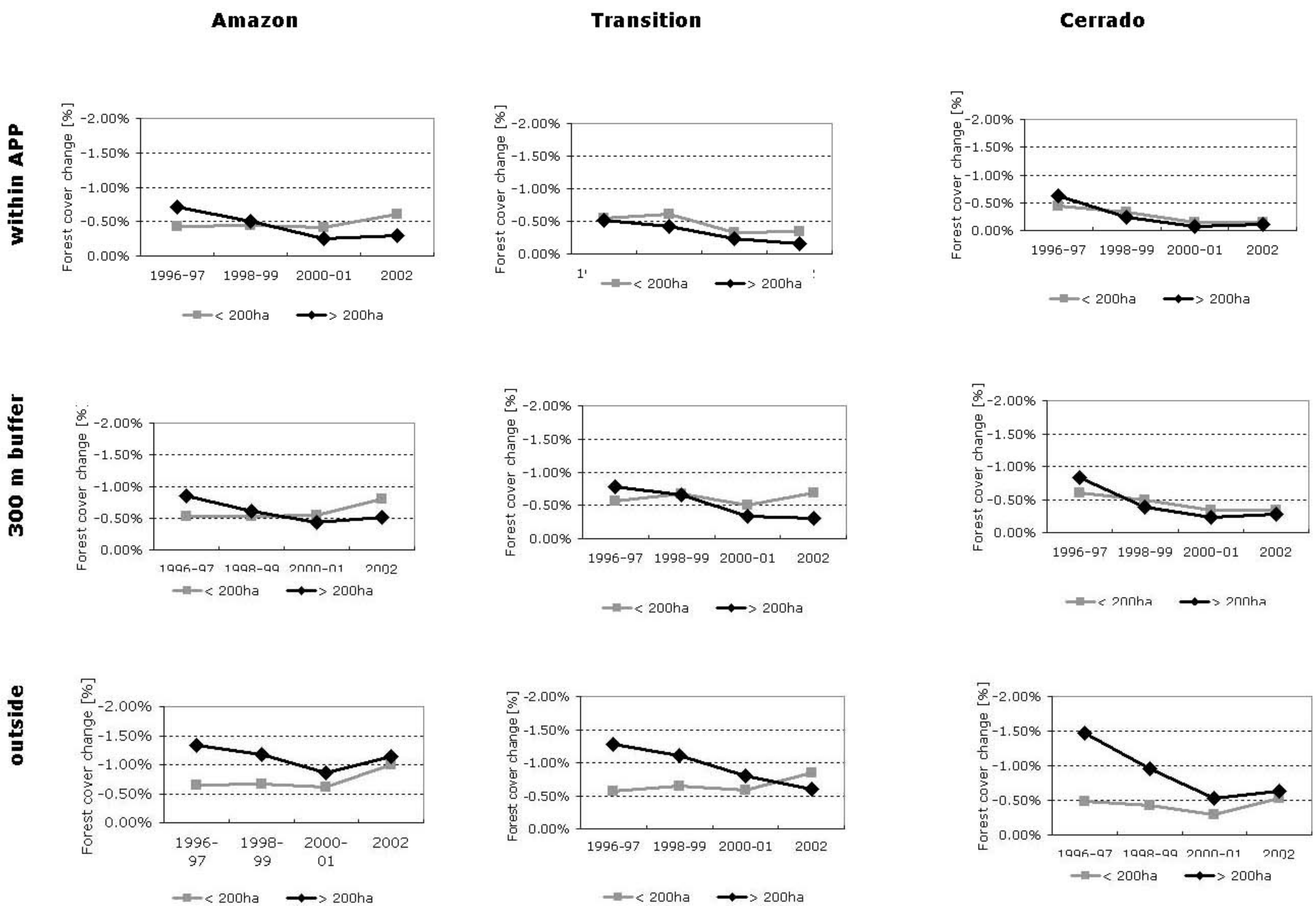

Figure 7: Forest cover change 1996-2002 in deforestation patches smaller/greater 200 hectares inside/outside APP across biomes (Source: FEMA 2003)

deforestation appears trend downwards relative to small scale, though not always in absolute terms. The absolute decline in large-scale cerrado deforestation, outside APPs, is noteworthy.

4.10 Spatial effects related to the RL requirement

Recall that we use a spatial moving average of high vs. low cover (relative to the biome-specific RL requirement[12]) as a proxy for (unobserved) landholder compliance. Table 3 depicts the absolute and relative distribution of high/low natural vegetation cover per total and per forested area across biomes. The proportion of biome with high/low natural vegetation cover is depicted in second row (row percentage). The share of high/low natural vegetation cover by biome is captured in the third row (column percentage).

		High natural vegetation cover		Low natural vegetation cover		Total	
Biome	Unit	Land area	Forest area	Land area	Forest area	Land Area	Forest area
Amazon	[km²]	231,006	230,533	117,103	43,415	348,109	273,948
	[%]	66.4	84.2	33.6	15.8	100.0	100.0
	[%]	45.6	48.2	49.5	84.5	46.8	51.7
Transition	[km²]	87,472	82,938	31,627	4,569	119,099	87,507
	[%]	73.4	94.8	26.6	5.2	100.0	100.0
	[%]	17.3	17.3	13.4	8.9	16.0	16.5
Cerrado	[km²]	188,187	164,927	87,871	3,369	276,058	168,296
	[%]	68.2	98.0	31.8	2.0	100.0	100.0
	[%]	37.1	34.5	37.1	6.6	37.1	31.8
Total	[km²]	506,665	478,398	236,601	51,353	743,266	529,751
	[%]	68.2	90.3	31.8	9.7	100.0	100.0
	[%]	100.0	100.0	100.0	100.0	100.0	100.0

Table 3: Spatial distribution of high/low natural vegetation cover across biomes (own calculations using SEPLAN Landcover Map 1995 and RadamBrasil (1972-1980) Vegetation Map)

Figures 8,9, and 10 depict, by biome, the average yearly deforestation rates in high versus low cover areas for the periods 1996-97, 1998-99, 2000-01 and 2002.

[12] According to the Medida Provisoria (2001), a legal reserve in the Amazon forest must cover 80% of the property area and in the Cerrado biome 35%. According to the Complementary State Law in Mato Grosso (1995), a 50% legal reserve requirement is defined for properties in the Transition biome. See the methodology section for the computation of the moving average

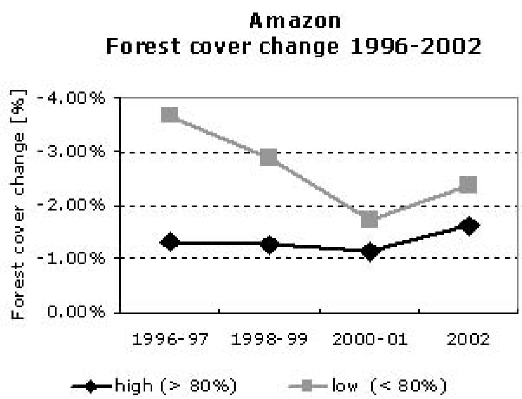

Figure 8: Deforestation rate in high/low cover areas of he Amazon (FEMA 2003)

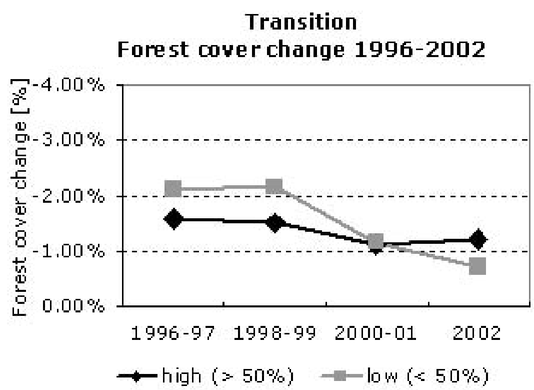

Figure 9: Deforestation rate in high/low cover areas of the Transition (FEMA 2003)

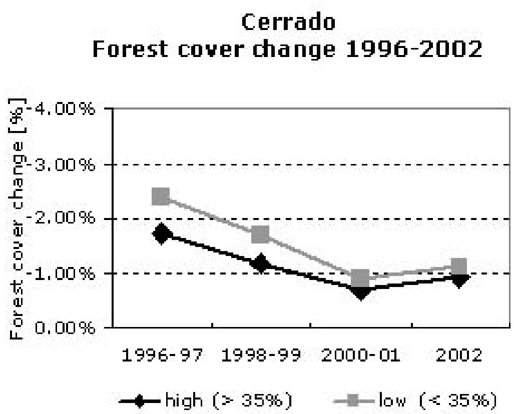

Figure 10: Deforestation rate in high/low cover areas of the Cerrado (FEMA 2003)

In the Amazon and cerrado, high cover deforestation rebounds (after a three period decline), while deforestation in low-cover areas is approximately static. This may be a possible signal of program impact. Figure 11 points to a relative decline in large-scale vs. small-scale deforestation in low cover areas, but an relative increase in high cover Amazonian areas. This may possibly represent a displacement effect: with greater enforcement in low-cover areas and greater scrutiny of large operators, some deforestation activities may have been shifted to high-cover areas. Note however, that large-scale deforestation would be expected to decline over time in low cover areas, simply because it becomes more and more difficult to find a single 200+ hectare forest patch.

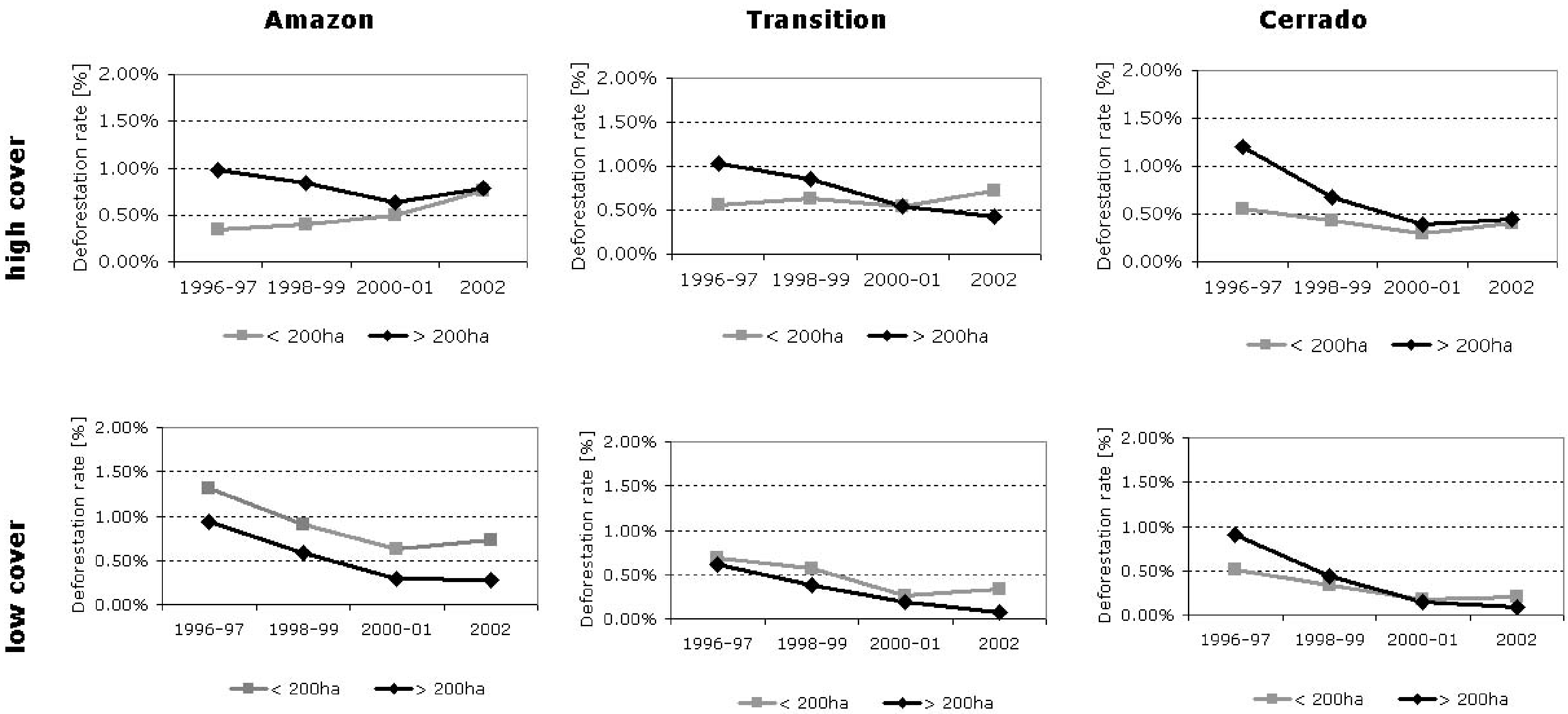

Figure 11: Deforestation rates in high versus low cover areas by biome (FEMA 2003)

4.11 Trends in deforestation relative to road proximity

Enforcement activities are likely to be more vigorous near roads; or landholders may believe that road proximity is associated with greater surveillance. Indeed, the Environmental Control System's first year of operations targeted a 60 km corridor around the states' main roads for special attention (FEMA 2001). Hence the program may be associated with a reduction in deforestation close to roads relative to deforestation far from roads. To examine this hypothesis, forest cover change, separated by size class, was tabulated across road distance classes.

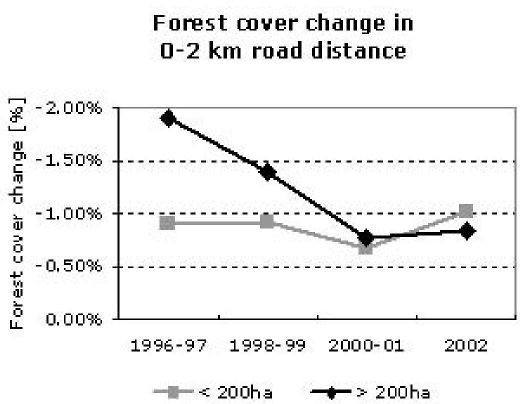

Figure 12: Forest cover change in 0-2 km distance from closest roads (FEMA 2003)

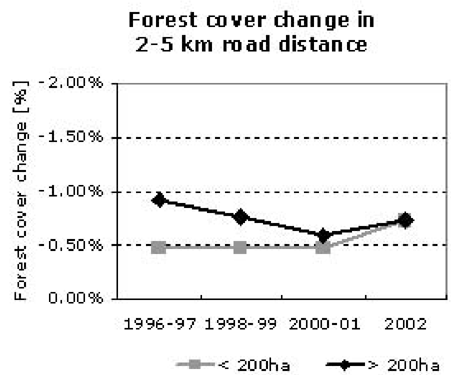

Figure 13: Forest cover change in 2-5 km distance from closest roads (FEMA 2003)

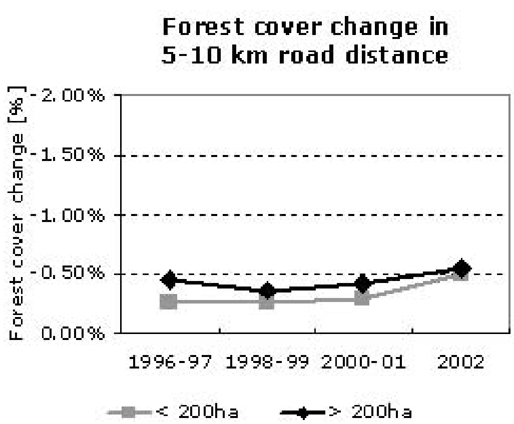

Figure 14: Forest cover change in 5-10 km distance from closest roads (FEMA 2003)

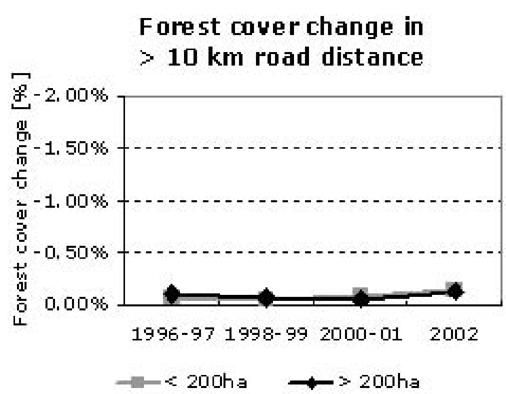

Figure 15: Forest cover change in greater 10 km distance from closest roads (FEMA 2003)

There is some suggestion of program impacts on large-scale deforestation. Based on the graphs, large-scale deforestation declines more rapidly, especially in 0-2 kilometer road distance, than small-scale deforestation. This pattern disappears when moving further than 5 kilometers from roads. Again, fragmentation of the forest within 2 km of roads will eventually result in a decline of large-patch deforestation relative to small. However, overall near-road deforestation appears to decrease relative to deforestation distant from roads.

4.12 Effects on size of deforestation patches

The Environmental Control Program explicitly focused on large landholdings. The argument was that large-holders contribute relatively more to deforestation in Mato Grosso than small-holders. Thus we would expect the program to depress large-scale deforestation (i.e. related to large individual clearings) relative to small-scale deforestation. Indeed, the proportion of large-scale deforestation, especially above 1000 hectares, decreased drastically in 2000-01 according to FEMA's statewide figures (Figure 16).[13] There was an increase in the proportion of deforestation occurring in smaller patches (50-200 has). This suggests an effect on large-scale deforestation which might be connected to the advent of the control system. But arguably it could be connected with changes in the nature or motivation of forest conversion.

[13] In Figure 16, the value on each bar expresses the per-cent proportion of deforestation per class of clearing size for a given year.

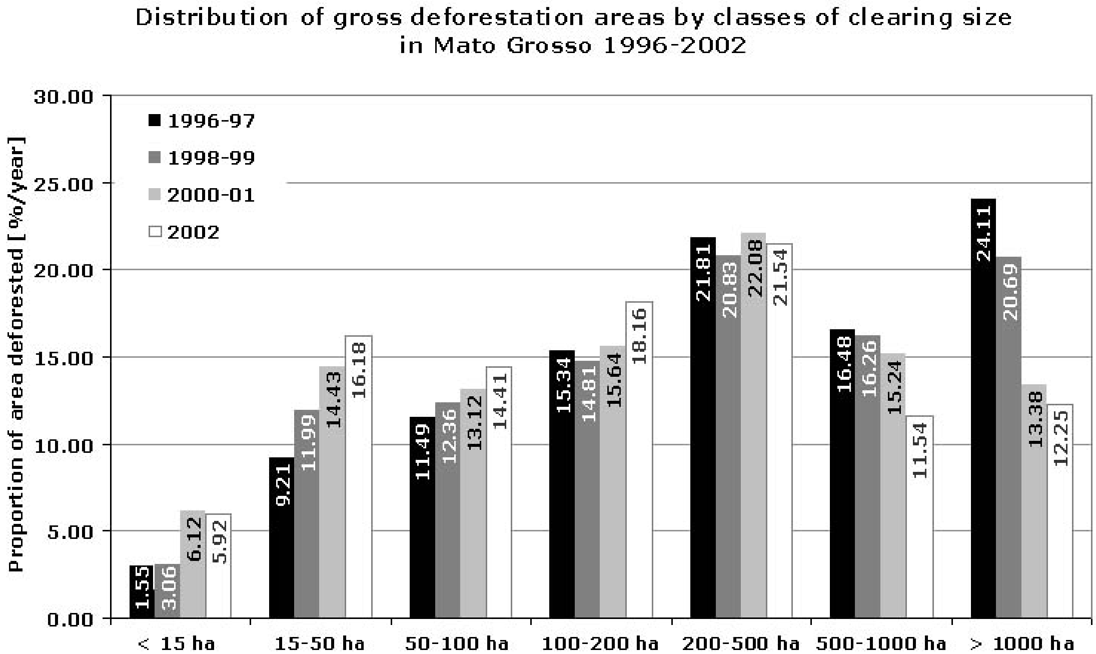

Figure 16: Distribution of mean rate of gross deforestation [%/year] in Mato Grosso by classes of size increment from 1996-2002 (FEMA 2004)

4.13 Summary

In summary, an overview of deforestation patterns suggests that, both before and after the implementation of the new control system, deforestation rates were relatively lower in APPs and especially in protected areas, as compared to other types of land. This is an encouraging finding, which suggests that even before the introduction of Mato Grosso's innovative system there was some compliance with the most critical aspects of land use regulations. There is striking evidence of a relative decrease in large-scale deforestation after the control system is implemented. There are somewhat ambiguous suggestions of the relative impacts on deforestation of legal reserves, and in APPs. The next section returns to these tests with a more powerful statistical apparatus.

5 Statistical analysis of program effectiveness in Mato Grosso

We now apply multivariate methods to the 'difference in difference' tests suggested in section 3. Multivariate analysis allows us simultaneously to test the predicted impacts. It also allows us to correct for the change in sample characteristics over time, as forest areas more amenable to deforestation are converted.

We modify equation (1) in two ways. First, since our data is based on forested points rather than areas, we treat y as a latent variable, where we observe deforestation if $y>0$, and continued forest if $y\leq 0$. This permits the equation to be estimated as a logit or probit. Second, we need to account for the fact that our final period of observation is a single year, while the other periods are each two years in length. This complicates the interpretation of the coefficient δ, which we would like to interpret as a change in the annual deforestation rate. We adopt two approaches. First, we estimate a separate deforestation model for each observation period, eg:

$$y^*_{it} = X_{it}\beta_t + \delta_t LOWCOVER_{it} + u_{it}$$

observe deforestation if $y^*_{it}>0$

Here our prediction is that δ_t, expressed on an annual basis, should decrease in the post-program years.

Second, we estimate a multiperiod logit model of the form

$$y^*_{it} = X_{it}\beta_t + D_t\gamma_t + LOWCOVER_{it}(\delta_0 + D_t\delta_t) + u_{it}$$

[where a category is omitted from each set of dummy variables]

This implies that:

ln [(prob deforestation/(1-prob deforestation)]=

$$y^*_{it} = X_{it}\beta_t + D_t\gamma_t + LOWCOVER_{it}(\delta_0 + D_t\delta_t) + u_{it}$$

In this formulation, the coefficients γ_t adjust for the difference in the ln odds of deforestation between two-year and one year observation periods. The coefficients δ_t measure the differential impact of LOWCOVER (or other variable of interest) in preprogram vs. post program years.

The sample consists only of points having forest cover at the beginning of the observation period t, where t is in the set (1996-97, 1998-99, 2000-01, 2002). To reduce spatial and temporal autocorrelation, we chose a different subsample of the 1 km gridded points for each time period, and merged them into a single multiperiod data set. The sample for each time period consists of one out of nine of the original sample points, chosen as points on a 3 km by 3 km grid.

Table 8 contains the summary statistics of the regressors used in the single-period regressions, where deforestation was estimated separately for each observation period; the regressions themselves are in Tables 9-12. Instead of coefficients, the tables show $\Delta F/\Delta X$, the effect of each categorical variable X on the probability F of deforestation rate, holding other variables at sample means. For instance, in Table 9, location in high cover areas is associated with a 2.76 percentage point lower probability of deforestation, other things constant, as compared to low cover areas.

To facilitate a comparison of the single-period estimations, the effects and their statistical significance are summarized in Table 13. (All deforestation rates are true rates, e.g. expressed as proportions of the standing forest.) Specifically, the single-period estimations find:

(i) Compared to areas outside the initial enforcement target zones, the probability of deforestation within the initial (2000-2001) enforcement target zones was strongly significantly higher by 1.04% in 1996-97, significantly higher by 0.40% in 1998-99, insignificantly higher by 0.25%, and insignificantly lower by 0.1% in 2002. In other words, areas with high deforestation rates in 1996-99 were designated as priority enforcement zones for 2000-01. After that designation, observed deforestation rates inside the enforcement zone dropped to the same level as outside the zone (other things constant. This strongly declining *differential* in deforestation rates is consistent with a post-program response to increased (real or perceived) enforcement in the initial target zone.

(ii) Compared to low cover areas, the probability of deforestation in high cover areas is highly significantly lower by 2.76% and 1.87% in 1996-97 and 1998-99, significantly lower by 0.98% in 2000-01, yet insignificantly lower by 0.29% in 2002. The declining differential of deforestation rates in high and low cover areas is consistent with a post-program response to increased enforcement of the RL-requirement. (We stress that "response to increased enforcement" is here a shorthand for "a deterrent effect due to increased actual or perceived or feared enforcement".)

(iii) For all periods, there is a very strong and highly significant relationship between deforestation road distance. Deforestation rates decrease as distance to roads increases, for example areas in more than 10 km from roads have a lower deforestation rate between 3.01% in 1996-97 and 1.11% in 2002 compared areas less than 2 km from roads. However, the effect of distance decreases over time. In 1996-97, the deforestation rate is 1.5% lower in the 2-5 km distance bracket, compared to locations < 2 km from the road, and this effect is significant at the .00001 level. By 2002 the differential is just 0.2%, and the significance level is 0.2. The declining differential in deforestation rates in areas close vs far from roads is consistent with a post-program response to a perceived increase in enforcement near roads.

(iv) The interaction effect between low cover and road proximity is not however, fully consistent with the hypothesis. If there was a strong deterrent effect associated with the combination of low cover and road proximity, we would expect this interaction variable to become more negative after program implementation. Instead, it is approximately constant over the period 1996-97, 1998-99 and 2000-01, but increases (from a well-determined -0.01 to a poorly determined -0.003) in 2002.

(v) Compared to areas outside permanent preservation areas (APP), the probability of deforestation for both within APPs and just outside them (within a 300 meter buffer) is strongly significantly lower across all periods. However, this differential narrows over time, contrary to our hypothesis of relatively increased enforcement or deterrent in or near APPs.

(vi) For all periods, a very strong and highly significant relationship between deforestation and soil quality. Areas with soil quality rated "no agricultural value" have deforestation rates of about 2.1% lower than areas rated "good for annuals and perennials" in 1996-97. This differential narrows to about 1.0% in 2002, suggesting some possible displacement from more favorable to less favorable areas – possibly consistent with a shift by landowners from more observable to less observable deforestation.

We turn now to the multi-period logit regressions; Table 14 contains summary statistics of the regressors used in the estimation of the multi-period logit model and the regression results are reported in Table 15. (Table 16 reports the antilog of the coefficients: the impact of each variable on the odds in favor of deforestation.)

The period dummies in this regression control for the difference in the length of the observation periods. Relative to 1996-97, the odds of deforestation were 14% lower in 1998-99, 6% lower in 2000-01, but 34% lower in the single year period 2002. Controlling for this, we see the hypothesized effect of road proximity and of low cover. In both cases, these variables are not significantly related to a reduction in deforestation in 1998-99 compared to 1996-97. But in both cases, these variables are associated with large and significant post-program (2000-1 and 2002) reductions in the odds of deforestation– 40% to 45% reductions in the case of road proximity, 25% to 33% in the case of low cover. The effects of high enforcement are less clearly in accord with the hypothesis. Before allowing for year-specific interactions, deforestation rates are 46% higher in the areas chosen for high enforcement in 2000-01. Compared to 1996-97, however, the odds of deforestation in these priority enforcement areas dropped by 17% in 1998-99, 20% in 2000-01, and 39% in 2002.

In general, the multiperiod regression reproduces the main findings of the individual period regressions. Deforestation odds are substantially lower on poor soils, far from roads, on high slopes, and in APPs.

6 Land value and deforestation in Mato Grosso

Since enforcement against deforestation in Mato Grosso (and elsewhere) appears to have had limited success, the question arises whether this is due to the strength of economic pressure for deforestation, and whether policies could focus more successfully on deterring deforestation that yields only low economic returns. Hence, the objective is to assess the magnitude of economic pressure for deforestation in Mato Grosso by looking at regional differences in environmental costs (loss of biodiversity and carbon sequestration functionality) versus net economic gain (value of land less cost of conversion) from deforestation. This results in two hypotheses:

(i) land value is closely related to road access, soil quality and rainfall (biome);

(ii) deforestation rates are closely related to land values.

6.14 Statistical analysis of land values and deforestation in Mato Grosso

To obtain first insight into the hypotheses, mean municipal-level land values for 2003, resulting from subjective estimation by INCRA technicians were assembled to be tabulated across road distance, soil quality and biome (INCRA 2004). However, municipios exhibit considerable internal variation in soil characteristics and road access. INCRA only considers land value variation for some municipalities, notably Cáceres, Campo Verde, Pedra Preta and Primavera do Leste, where land in agricultural use is far more valuable than pasture land. In these cases, INCRA assigns two values. To adjust for further intra-municipal variation in land value, we regressed mean municipal land values on agricultural suitability category, biome and road-distance category. With the objective to assess the role of land value in private deforestation decisions, only sample points of nonprotected areas of Mato Grosso were used (i.e. where deforestation can be authorized). Based on the SEPLAN land use information, municipalities with two land values became separate observations.[14] We then used the parameters of the municipal level regression to impute land values for each sample point.

In order to spatially impute land values, we assume that plot-level land value is a linear function of land characteristics. Then, by linear aggregation, the INCRA mean municipal land value is a linear function of the proportion of municipio land with each relevant characteristic. We estimated this function by linear regression. Six observations with mean land value above 1700 Reais/hectare presented outliers in our dataset. These were the agricultural land areas in the municipalities of Alto Garças, Alto Taquari, Campo Verde, Itiquira, Pedra Preta and Primavera do Leste, all situated in the old agricultural frontier, mainly in south-east Mato Grosso. The outliers were extracted and the sample used for estimation was limited to observations with mean land value below R$1700/hectare. Table 17 depicts the summary statistics and Table 18 the outcome of the robust regression model. A simple exploratory functional form (chosen for ease of imputation) found that land values reflect locational rents from road proximity and soil quality, confirming the first hypothesis. For subsequent imputation purposes, the omitted observations with INCRA land values greater than R$1700 hectares were left with their original land value; we do not believe that these values are in error but rather reflect characteristics we are unable to measure.

[14] In fact, the municipio-level data set was derived from aggregating point level information. Hence, additional municipio observations were created by assigning all points of municipio x in agricultural land (pasture land) the INCRA land value for agricultural land (pasture land).

6.15 Spatial characteristics of land values in Mato Grosso

Mean municipal-level land values for 2003, were tabulated across road distance, soil quality and biome (INCRA 2004). INCRA land values are based on average land price of regional land markets. Thus INCRA values only reflect legal reserve restrictions, if they are also reflected in official land prices. We undertook two variants of this tabulation. The unadjusted tabulation applies the mean municipal level value to every point within the municipio. Our preferred, adjusted tabulation uses the regression coefficients of Table 18 to impute values to each sample point within the municipio. This allows for within-municipio variation in land values due to differences in soils and road proximity. This is our preferred measure of land values.

To test for the hypotheses, the following tabulations of unadjusted (INCRA) and imputed land values across road distance, soil quality (agricultural suitability) and biome is limited to the nonprotected areas with natural vegetation cover[15] as of 1995 (i.e. according to the SEPLAN land use/land cover map 1995, see section 4.5).

Pattern of land value and road accessibility

Table 4 contains mean land values per road distance categories for areas with natural vegetation cover in 1995. Imputed land values decline with increasing distance from roads.

Road distance	unadjusted mean land value [R$/sqkm]	adjusted mean land value [R$/sqkm]
0-2 km	46,378	66,176
2-5km	44,527	13,638
5-10km	38,552	11,252
> 10 km	25,411	9,249

Table 4: Table: INCRA mean land value per road distance category (INCRA 2003)

[15] Recall that "natural vegetation cover" includes, besides forest formations, also Cerrado vegetation formations.

Pattern of land value and soil accessibility

Table 5 depicts the mean land value per soil quality (i.e. agricultural suitability) classes in Mato Grosso. Notably, mean land value varies with soil quality, i.e. the more favorable soils are for agriculture or pasture, the higher their land value.

Agricultural suitability	unadjusted mean land value [R$/sqkm]	adjusted mean land value [R$/sqkm]
good, annual & perennial	40,833	52,489
regular, annual & perennial	37,974	26,714
restricted, annual & perennial	35,838	10,848
possible for planted pasture	53,091	49,594
possible for natural pasture	36,794	9,216
no agricultural value	41,774	5,819

Table 5: Table: INCRA mean land value per agricultural suitability classes (INCRA 2003; SEPLAN 1995)

Pattern of land value and rainfall (biome)

Table 6 contains the mean land value per rainfall zone (proxied by biome) in Mato Grosso. Notably, land values as estimated by INCRA are about one-third lower in the Amazon than in the Cerrado; values in the Transition biome are intermediate.

Biome	unadjusted mean land value [R$/sqkm]	adjusted mean land value [R$/sqkm]
Amazon	35,829	30,104
Transition	44,112	32,606
Cerrado	50,784	40,001

Table 6: INCRA mean land value per biome (INCRA 2003; RadamBrasil 1972-1980)

6.16 Pattern of land values and deforestation in Mato Grosso

To obtain further insight into the hypotheses, INCRA land values were tabulated across deforested areas in 1996-97, 1998-99, 2000-01 and 2002 (FEMA 2003) and geographic characteristics. The tabulation was restricted to non-protected sample points within the

SEPLAN natural vegetation cover was used. These tabulations implicitly assume that there is no compliance with the RL requirement.

Table 7 contains the mean and total land value per road distance categories and deforested areas in 1996-2002 in Mato Grosso. This tabulation finds:

(i) Most remaining forest and most deforestation is located in "high cover" areas (and would presumably be legal if properly permitted). However, deforestation rates are higher in "low-cover" areas (presumed illegal) areas although low cover deforestation rates decrease, especially in 2000-01. Contrary to expectation, the value of deforested land is not much higher in low cover areas (perhaps because remaining forest in these heavily exploited areas is on poorer soils), although the difference increases after 2000.

(ii) In absolute terms, most deforestation occurs within 2 kilometers of the existing road network. Deforestation rates are far higher here than in more remote locations. And land values are much higher. The causal connections here could be debated – does road access confer value, or does high-quality land attract roads? However, there is a clear association between high-value land, road access, and deforestation.

(iii) There is a strong association between land quality, land value, and deforestation rates. Deforestation rates and land values are highest in the land rated as being best for annuals and perennials. Deforestation rates and land values are the lowest in land rated as unsuitable or suitable only for natural pasture. Land rated as 'restricted' for crops has low imputed value but rather high deforestation rates. In 2002, only about 8.6% of deforestation took place on these three classes of low-suitability soils, but this represented a total of 608 km^2.

(iv) In 2002, Amazonian forest had lower land values and a higher deforestation than the Cerrado. (However, effective land values would be higher in the Amazon if RL requirements were enforced.)

		Deforested in 1996-1997 (2 years)				Deforested in 1998-1999 (2 years)				Deforested in 2000-01 (2 year)				Deforested in 2002 (1 year)			
Geographic variables	Natural vegetation cover 1995, SEPLAN [sqkm]	Area deforested [sqkm]	Proportion of nat.-veg cover [%]	unadjusted mean value [R$/sqkm]	adjusted mean value [R$/sqkm]	Area deforested [sqkm]	Proportion of nat.-veg cover [%]	unadjusted mean value [R$/sqkm]	adjusted mean value [R$/sqkm]	Area deforested [sqkm]	Proportion of nat.-veg cover [%]	unadjusted mean value [R$/sqkm]	adjusted mean value [R$/sqkm]	Area deforested [sqkm]	Proportion of nat.-veg cover [%]	unadjusted mean value [R$/sqkm]	adjusted mean value [R$/sqkm]
Land value of deforested areas in high/low natural vegetation cover areas (own calculation: 625ha properties)																	
high cover	480,294	14,454	3.01%	47,838	52,629	11,865	2.55%	46,995	49,438	9,364	2.06%	43,249	43,544	6,029	1.36%	42,098	41,879
low cover	57,277	3,745	6.54%	43,797	50,114	2,747	5.13%	43,453	49,543	1,688	3.32%	42,031	46,323	1,041	2.12%	41,622	48,624
Land value of deforested areas in road distance categories (own calculation based on road data by FEMA 2003)																	
0-2 km	214,076	11,956	5.58%	47,325	69,476	9,300	4.60%	46,587	67,856	6,012	3.12%	44,048	67,369	3,600	1.93%	44,177	68,240
2-5km	172,930	4,799	2.78%	47,413	18,609	4,107	2.44%	46,375	17,633	3,601	2.20%	43,214	16,317	2,413	1.50%	41,477	16,778
5-10km	85,963	1,225	1.43%	43,928	20,292	1,051	1.24%	45,536	16,796	1,226	1.46%	39,955	15,209	872	1.06%	37,150	15,723
> 10 km	64,647	219	0.34%	37,587	15,305	154	0.24%	34,835	17,006	213	0.33%	30,277	12,844	185	0.29%	30,426	16,017
Land value of deforested areas in agricultural suitability areas (SEPLAN 1995)																	
good, annual & perennial	114,218	5,644	4.94%	50,000	68,459	4,913	4.53%	49,426	62,103	3,735	3.60%	42,157	55,076	2,688	2.69%	41,259	54,476
regular, annual & perennial	188,424	7,045	3.74%	41,701	42,270	5,538	3.05%	42,005	41,092	4,267	2.43%	39,558	35,647	2,728	1.59%	39,173	32,760
restricted, annual & perenn.	11,247	404	3.59%	33,276	26,966	343	3.16%	32,246	20,417	195	1.86%	37,554	21,364	165	1.60%	33,643	18,920
possible for planted pasture	122,061	3,719	3.05%	57,766	60,369	2,552	2.16%	56,297	60,480	2,040	1.76%	54,945	55,106	1,046	0.92%	55,810	54,675
possible for natural pasture	69,082	1,074	1.55%	34,299	23,452	1,021	1.50%	36,126	22,725	562	0.84%	36,653	14,390	345	0.52%	35,437	18,322
no agricultural value	32,247	309	0.96%	45,804	18,834	243	0.76%	40,256	22,797	251	0.79%	38,325	13,993	98	0.31%	32,960	7,093
Land value of deforested areas across biomes (RadamBrasil 1972-1980)																	
Amazon	274,369	9,221	3.36%	40,178	46,312	7,992	3.01%	41,278	45,766	6,598	2.57%	38,223	40,841	4,483	1.79%	37,687	39,329
Transition	88,464	2,812	3.18%	45,415	48,366	2,640	3.08%	44,069	45,981	1,963	2.36%	43,290	42,407	1,002	1.24%	40,981	39,855
Cerrado	174,738	6,166	3.53%	58,003	63,571	3,980	2.36%	57,984	59,903	2,491	1.51%	55,755	54,198	1,585	0.98%	55,018	55,684

Table 7: Area and imputed land value of deforested land in Mato Grosso (FEMA 2003, INCRA 2003)

7 Conclusions

Against a backdrop of rising aggregate deforestation rates, we have attempted to assess whether the SLAPR program altered deforestation behavior, relative to a hypothetical without-program baseline. Our results suggest that announcement and early implementation (to 2002) of SLAPR affected landholder behavior. Landholders appear to have reduced deforestation in more observable areas, areas prioritized for enforcement, and areas with low remaining forest cover, relative to other areas. Although our data do not distinguish legal from illegal deforestation, the results are consistent with a reduction in deforestation that contravenes the legal reserve regulations. The results do not necessarily indicate that the program reduced *aggregate* deforestation against the hypothetical baseline.

What accounted for the behavioral change? In part, it may reflect direct enforcement activities by FEMA. Once landowners are licensed, they face heightened scrutiny by FEMA, and swifter and more certain penalties for noncompliance with regulations. We suspect, however, that SLAPR's deterrent effect was the more powerful influence on landholder behavior. With the transition from a lax enforcement regime to a well-organized and well-publicized one, landholders may have perceived an increased likelihood of eventual detection and prosecution for illegal deforestation.

Prospects for future program impact depend on the balance between economic pressures for deforestation and political will in expanding the scope and effectiveness of SLAPR. Our cursory examination of the economics of deforestation suggests that there are powerful economic incentives driving deforestation. In 2002, deforestation created farmland with an imputed gross value on the order of R$300 million. (Net profitability of forest conversion could be lower if average clearing costs exceeded average revenues from sale of timber or charcoal. On the other hand, in a land-surplus market, land prices may be less than the expected present value of profits.) To put this in perspective, agricultural GDP for Mato Grosso was about R$3.3 billion in 2000.

In general, high deforestation rates, and high absolute amounts of deforestation, are associated with areas of high market value for land. This may limit the scope for using economic instruments to discourage deforestation of areas with high environmental value but low agricultural value. Nonetheless, some deforestation is taking place in areas with very low land values (below US$100/ha). Here, modest taxes or fees for deforestation might deter forest clearance, with significant environmental gains. Instituting a trade in legal reserve obligations (Chomitz 2004; Chomitz, Thomas and Brandão 2004) could have the effect of protecting areas far from roads, with current low deforestation rates and land values but at risk of future deforestation as the road network expands.

The continued effectiveness of SLAPR depends on its success in expanding coverage to include all large landholders, and its success in deterring deforestation on areas not yet enrolled in the system. We have hypothesized that the apparent post-program shift in deforestation patterns was due to landholder perceptions of increased probability of law enforcement. Those perceptions – and their effect on landholder behavior – are likely to change as landholders observe actual government behavior in detecting and prosecuting illegal deforestation. In this paper we have analyzed deforestation only up to the final year of a state administration widely viewed as putting a high priority on environmental issues. Future work should examine the post-2002 evolution of FEMA operations and landholder behavior under a different state administration. As a coda we note that in mid-2005, the director of FEMA was arrested and charged with contributing to illegal deforestation – a reminder of the difficulties involved in rationalizing land use on the forest frontier.

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Glossary

Areas of permanent preservation (APP)	Defined in the Brazilian Forest Code (1965), APPs are strictly protected areas along rivers, steep slopes and on hill tops.
FEMA deforestation	FEMA defines deforestation as the human induced loss of natural vegetation of the Amazon, Transition and Cerrado biome. Until 2001, FEMA monitored deforestation bi-annually. Since 2002, FEMA monitors deforestation annually. To track actual deforestation FEMA uses satellite imagery from the months with highest deforestation activity (April-May).
Legal reserve (RL)	Each private property must preserve a defined share under native vegetation cover (i.e. "legal reserve"). The proportion to be conserved depends on the biome, in which the property is located and requires 80% in the Amazon, 50% in the Transition and 35% in the Cerrado biome.
High/low natural vegetation cover	To be able to test for compliance of the legal reserve requirement, a proxi for "mean natural vegetation cover" was calculated. This was done using a 100 meter grid of the natural vegetation cover (without any human activity as of 1995) obtained from the SEPLAN land use/land cover map 1995 and calculating for each pixel, the average natural vegetation cover in a 25x25 pixel neighborhood, which corresponds to the average property size in Mato Grosso of 625 hectares. The resulting mean natural vegetation for an average property in Mato Grosso was then, biome specific, classified into "high" (exceeding the RL-requirement) and "low" (below the RL-requirement).
INPE deforestation	INPE defines deforestation as the human induced loss of primary forest in the Amazon and Transition forest. With the focus of primary forest, INPE does neither consider deforestation of mature secondary growth nor re-growth in their measurements (i.e. INPE measures only gross deforestation). INPE monitors deforestation annually, using satellite imagery from in cloud-free period (July-September) to monitor deforestation from August to August of the following year.
INPE forest cover	This refers to the spatial delineation of primary forest and is provided with the digital deforestation maps from INPE/Projeto PRODES.
SEPLAN natural vegetation cover	This refers to the natural vegetation cover (i.e. forest and savanna vegetation) as defined by SEPLAN in 1995.

Tables

Table 8: Summary statistics for variables used in probit regressions

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Deforestation					
Total deforestation	225210	0.0241996	0.15367	0	1
Deforestation greater 200 hectares	225210	0.0146841	0.12029	0	1
High/low natural vegetation cover (omitted "low")					
low cover	225210	0.0924915	0.28972	0	1
high cover	225183	0.9074975	0.28973	0	1
Inside/outside permanent preservation areas (omitted "outside")					
within permanent preservation areas (APP)	225210	0.073296	0.26062	0	1
within 300 m buffer around APP	225210	0.3477288	0.47625	0	1
Ecoregions (omitted "Amazon")					
Transition	225183	0.1651812	0.37134	0	1
Cerrado	225183	0.3186963	0.46597	0	1
Road distance classes (omitted "0-2 km distance from roads")					
2-5 km distance from roads	225210	0.3241597	0.46806	0	1
5-10 km distance from roads	225210	0.1643888	0.37063	0	1
> 10 km distance from roads	225210	0.1260646	0.33192	0	1
Slope categories (omitted "0-2 degree slope")					
2-5 degrees	225210	0.3043115	0.46012	0	1
5-10 degrees	225210	0.0691843	0.25377	0	1
> 10 degrees	225210	0.0295236	0.16927	0	1
Agricultural suitability class (omitted "good, annual & perennial")					
Regular, annual & perennial	225066	0.3513903	0.47741	0	1
Resticted, annual & perennial	225066	0.0210871	0.14368	0	1
Possible for planted pasture	225066	0.2262492	0.41840	0	1
Possible for natural pasture	225066	0.1297797	0.33606	0	1
No agricultural value	225066	0.062164	0.24145	0	1
Interaction variable low cover & road distance 0-2 km					
Low cover & road distance 0-2 km	225210	0.0573554	0.23252	0	1
Enforcement dummy (high enforcement in 2000-01)					
High enforcement in 2000-01	225210	0.146299	0.353407	0	1

Table 9: Probit regression on total deforestation in Mato Grosso 1996-97

Number of observation:	58883
Pseudo R-squared:	0.0678
Likelihood Ratio Chi-squared:	1170.42

Variable: total deforestation 1996-97	dF/dx	Std. Error	z	P|z|	x-bar	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")							
high cover	-0.02762	0.00485	-7.33	0.00000	0.90228	-0.03713	-0.01811
Inside/outside permanent preservation areas (omitted "outside")							
within permanent preservation areas (APP)	-0.00970	0.00184	-4.39	0.00000	0.07242	-0.01332	-0.00609
within 300 m buffer around APP	-0.00731	0.00124	-5.69	0.00000	0.34502	-0.00974	-0.00489
Ecoregions (omitted "Amazon")							
Transition	0.00264	0.00188	1.45	0.14700	0.16558	-0.00104	0.00633
Cerrado	0.00512	0.00161	3.29	0.00100	0.31814	0.00197	0.00827
Road distance classes (omitted "0-2 km distance from roads")							
2-5 km distance from roads	-0.01576	0.00121	-12.09	0.00000	0.32157	-0.01814	-0.01339
5-10 km distance from roads	-0.02240	0.00110	-14.68	0.00000	0.16034	-0.02457	-0.02024
> 10 km distance from roads	-0.03012	0.00095	-14.43	0.00000	0.12122	-0.03198	-0.02826
Slope categories (omitted "0-2 degree slope")							
2-5 degrees	-0.00069	0.00132	-0.52	0.60200	0.30255	-0.00328	0.00190
5-10 degrees	-0.00584	0.00229	-2.31	0.02100	0.06853	-0.01034	-0.00135
> 10 degrees	-0.00986	0.00351	-2.26	0.02400	0.02923	-0.01674	-0.00298
Agricultural suitability class (omitted "good, annual & perennial")							
Regular, annual & perennial	-0.00200	0.00145	-1.36	0.17300	0.35416	-0.00484	0.00085
Resticted, annual & perennial	0.00024	0.00401	0.06	0.95100	0.02106	-0.00762	0.00811
Possible for planted pasture	-0.00984	0.00144	-6.18	0.00000	0.22439	-0.01267	-0.00701
Possible for natural pasture	-0.01699	0.00141	-8.96	0.00000	0.12598	-0.01976	-0.01422
No agricultural value	-0.02122	0.00142	-7.78	0.00000	0.06015	-0.02401	-0.01844
Interaction variable low cover & road distance 0-2 km							
Low cover & road distance 0-2 km	-0.00793	0.00254	-2.69	0.00700	0.06107	-0.01290	-0.00295
Enforcement dummy (high enforcement in 2000-01)							
High enforcement in 2000-01	0.01038	0.00194	5.99	0.00000	0.14719	0.00659	0.01417
obs. P:	0.03346						
pred. P (at x-bar):	0.02402						

Table 10: Probit regression on total deforestation in Mato Grosso 1998-99

Number of observation:	56868
Pseudo R-squared:	0.0728
Likelihood Ratio Chi-squared:	1056.08

Variable: total deforestation 1998-99	dF/dx	Std. Error	z	P|z|	x-bar	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")							
high cover	-0.01871	0.00412	-5.76	0.00000	0.90584	-0.02677	-0.01064
Inside/outside permanent preservation areas (omitted "outside")							
within permanent preservation areas (APP)	-0.01027	0.00145	-5.41	0.00000	0.07313	-0.01312	-0.00742
within 300 m buffer around APP	-0.00737	0.00108	-6.53	0.00000	0.34810	-0.00949	-0.00524
Ecoregions (omitted "Amazon")							
Transition	0.00406	0.00169	2.54	0.01100	0.16501	0.00074	0.00737
Cerrado	-0.00106	0.00134	-0.78	0.43300	0.31635	-0.00369	0.00157
Road distance classes (omitted "0-2 km distance from roads")							
2-5 km distance from roads	-0.01393	0.00107	-12.33	0.00000	0.32403	-0.01603	-0.01184
5-10 km distance from roads	-0.01858	0.00098	-14.26	0.00000	0.16326	-0.02050	-0.01666
> 10 km distance from roads	-0.02597	0.00083	-13.28	0.00000	0.12476	-0.02760	-0.02434
Slope categories (omitted "0-2 degree slope")							
2-5 degrees	0.00216	0.00121	1.82	0.06900	0.30578	-0.00021	0.00454
5-10 degrees	0.00221	0.00245	0.94	0.34800	0.06858	-0.00260	0.00702
> 10 degrees	-0.01222	0.00247	-3.18	0.00100	0.02917	-0.01706	-0.00738
Agricultural suitability class (omitted "good, annual & perennial")							
Regular, annual & perennial	-0.00609	0.00119	-4.95	0.00000	0.35101	-0.00842	-0.00376
Resticted, annual & perennial	-0.00367	0.00285	-1.18	0.24000	0.02135	-0.00926	0.00192
Possible for planted pasture	-0.01297	0.00114	-9.8	0.00000	0.22667	-0.01521	-0.01072
Possible for natural pasture	-0.01329	0.00122	-8.3	0.00000	0.12923	-0.01567	-0.01090
No agricultural value	-0.01674	0.00120	-7.44	0.00000	0.06093	-0.01910	-0.01438
Interaction variable low cover & road distance 0-2 km							
Low cover & road distance 0-2 km	-0.00833	0.00199	-3.37	0.00100	0.05782	-0.01223	-0.00444
Enforcement dummy (high enforcement in 2000-01)							
High enforcement in 2000-01	0.00404	0.00160	2.69	0.00700	0.14643	0.00091	0.00717
obs. P:	0.02796						
pred. P (at x-bar):	0.01876						

Table 11: Probit regression on total deforestation in Mato Grosso 2000-01

Number of observation:	55270
Pseudo R-squared:	0.0475
Likelihood Ratio Chi-squared:	534.01

Variable: total deforestation 2000-01	dF/dx	Std. Error	z	P|z|	x-bar	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")							
high cover	-0.00975	0.00333	-3.46	0.00100	0.90995	-0.01628	-0.00322
Inside/outside permanent preservation areas (omitted "outside")							
within permanent preservation areas (APP)	-0.00888	0.00140	-4.80	0.00000	0.07389	-0.01162	-0.00614
within 300 m buffer around APP	-0.00501	0.00104	-4.62	0.00000	0.34717	-0.00706	-0.00296
Ecoregions (omitted "Amazon")							
Transition	-0.00089	0.00142	-0.62	0.53800	0.16524	-0.00367	0.00189
Cerrado	-0.00583	0.00121	-4.57	0.00000	0.31827	-0.00820	-0.00346
Road distance classes (omitted "0-2 km distance from roads")							
2-5 km distance from roads	-0.00581	0.00107	-5.17	0.00000	0.32481	-0.00791	-0.00372
5-10 km distance from roads	-0.01008	0.00105	-7.77	0.00000	0.16651	-0.01214	-0.00801
> 10 km distance from roads	-0.02000	0.00080	-11.66	0.00000	0.12828	-0.02157	-0.01843
Slope categories (omitted "0-2 degree slope")							
2-5 degrees	0.00226	0.00118	1.96	0.04900	0.30467	-0.00005	0.00457
5-10 degrees	0.00104	0.00228	0.47	0.64100	0.06998	-0.00344	0.00552
> 10 degrees	-0.00297	0.00338	-0.81	0.41900	0.02911	-0.00959	0.00365
Agricultural suitability class (omitted "good, annual & perennial")							
Regular, annual & perennial	-0.00479	0.00115	-4.03	0.00000	0.35095	-0.00705	-0.00254
Resticted, annual & perennial	-0.00405	0.00268	-1.34	0.18100	0.02090	-0.00931	0.00120
Possible for planted pasture	-0.00922	0.00115	-7.01	0.00000	0.22634	-0.01146	-0.00697
Possible for natural pasture	-0.01294	0.00113	-8.03	0.00000	0.13114	-0.01516	-0.01073
No agricultural value	-0.01185	0.00134	-5.57	0.00000	0.06316	-0.01448	-0.00921
Interaction variable low cover & road distance 0-2 km							
Low cover & road distance 0-2 km	-0.00996	0.00159	-4.41	0.00000	0.05622	-0.01308	-0.00684
Enforcement dummy (high enforcement in 2000-01)							
High enforcement in 2000-01	0.00252	0.00150	1.75	0.08000	0.14563	-0.00043	0.00546
obs. P:	0.02095						
pred. P (at x-bar):	0.01602						

Table 12: Probit regression on total deforestation in Mato Grosso 2002

Number of observation:	54020
Pseudo R-squared:	0.0556
Likelihood Ratio Chi-squared:	430.94

Variable: total deforestation 2002	dF/dx	Std. Error	z	P|z|	x-bar	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")							
high cover	-0.00291	0.00228	-1.41	0.15900	0.91229	-0.00737	0.00155
Inside/outside permanent preservation areas (omitted "outside")							
within permanent preservation areas (APP)	-0.00652	0.00098	-4.60	0.00000	0.07294	-0.00843	-0.00460
within 300 m buffer around APP	-0.00410	0.00080	-4.89	0.00000	0.35067	-0.00567	-0.00253
Ecoregions (omitted "Amazon")							
Transition	-0.00163	0.00105	-1.48	0.14000	0.16466	-0.00369	0.00042
Cerrado	-0.00452	0.00092	-4.56	0.00000	0.32131	-0.00633	-0.00270
Road distance classes (omitted "0-2 km distance from roads")							
2-5 km distance from roads	-0.00216	0.00086	-2.42	0.01600	0.32668	-0.00385	-0.00046
5-10 km distance from roads	-0.00466	0.00089	-4.48	0.00000	0.16799	-0.00640	-0.00292
> 10 km distance from roads	-0.01106	0.00069	-8.66	0.00000	0.12986	-0.01240	-0.00971
Slope categories (omitted "0-2 degree slope")							
2-5 degrees	0.00025	0.00088	0.29	0.77500	0.30496	-0.00147	0.00197
5-10 degrees	-0.00173	0.00162	-0.99	0.32000	0.06985	-0.00490	0.00144
> 10 degrees	-0.00559	0.00207	-1.87	0.06100	0.03071	-0.00964	-0.00153
Agricultural suitability class (omitted "good, annual & perennial")							
Regular, annual & perennial	-0.00443	0.00083	-5.15	0.00000	0.34937	-0.00605	-0.00281
Resticted, annual & perennial	-0.00548	0.00146	-2.62	0.00900	0.02103	-0.00835	-0.00262
Possible for planted pasture	-0.00798	0.00080	-8.29	0.00000	0.22769	-0.00956	-0.00640
Possible for natural pasture	-0.00876	0.00080	-7.44	0.00000	0.13310	-0.01034	-0.00719
No agricultural value	-0.00972	0.00076	-5.62	0.00000	0.06446	-0.01121	-0.00823
Interaction variable low cover & road distance 0-2 km							
Low cover & road distance 0-2 km	-0.00280	0.00184	-1.33	0.18300	0.05407	-0.00641	0.00081
Enforcement dummy (high enforcement in 2000-01)							
High enforcement in 2000-01	-0.00101	0.00106	-0.92	0.35500	0.14630	-0.00309	0.00106
obs. P:	0.01355						
pred. P (at x-bar):	0.00969						

Table 13: Summary of individual probit regressions for 1996-97, 1998-99, 2000-01 and 2002

	1996-97	1998-99	2000-01	2002
Variable: total deforestation	**dF/dx P|z|**	**dF/dx P|z|**	**dF/dx P|z|**	**dF/dx P|z|**
High/low natural vegetation cover (omitted "low")				
high cover	-0.02762 ***	-0.01871 ***	-0.00975 **	-0.00291
Inside/outside permanent preservation areas (omitted "outside")				
within permanent preservation areas (APP)	-0.00970 ***	-0.01027 ***	-0.00888 ***	-0.00652 ***
within 300 m buffer around APP	-0.00731 ***	-0.00737 ***	-0.00501 ***	-0.00410 ***
Ecoregions (omitted "Amazon")				
Transition	0.00264	0.00406 *	-0.00089	-0.00163
Cerrado	0.00512 **	-0.00106	-0.00583 ***	-0.00452 ***
Road distance classes (omitted "0-2 km distance from roads")				
2-5 km distance from roads	-0.01576 ***	-0.01393 ***	-0.00581 ***	-0.00216 *
5-10 km distance from roads	-0.02240 ***	-0.01858 ***	-0.01008 ***	-0.00466 ***
> 10 km distance from roads	-0.03012 ***	-0.02597 ***	-0.02000 ***	-0.01106 ***
Slope categories (omitted "0-2 degree slope")				
2-5 degrees	-0.00069	0.00216	0.00226 *	0.00025
5-10 degrees	-0.00584 *	0.00221	0.00104	-0.00173
> 10 degrees	-0.00986 *	-0.01222 **	-0.00297	-0.00559
Agricultural suitability class (omitted "good, annual & perennial")				
Regular, annual & perennial	-0.00200	-0.00609 ***	-0.00479 ***	-0.00443 ***
Resticted, annual & perennial	0.00024	-0.00367	-0.00405	-0.00548 **
Possible for planted pasture	-0.00984 ***	-0.01297 ***	-0.00922 ***	-0.00798 ***
Possible for natural pasture	-0.01699 ***	-0.01329 ***	-0.01294 ***	-0.00876 ***
No agricultural value	-0.02122 ***	-0.01674 ***	-0.01185 ***	-0.00972 ***
Interaction variable low cover & road distance 0-2 km				
Low cover & road distance 0-2 km	-0.00793 **	-0.00833 **	-0.00996 ***	-0.00280
Enforcement dummy (high enforcement in 2000-01)				
High enforcement in 2000-01	0.01038 ***	0.00404 **	0.00252	-0.00101

*: p<.05, **: p<.01, ***: p<.001

Table 14: Summary of variables used in multi-period logit regression

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Deforestation					
Total deforestation	225210	0.0241996	0.15367	0	1
Deforestation greater 200 hectares	225210	0.0146841	0.12029	0	1
High/low natural vegetation cover (omitted "low")					
low cover	225210	0.0924915	0.28972	0	1
high cover	225183	0.9074975	0.28973	0	1
Inside/outside permanent preservation areas (omitted "outside")					
within permanent preservation areas (APP)	225210	0.073296	0.26062	0	1
within 300 m buffer around APP	225210	0.3477288	0.47625	0	1
Ecoregions (omitted "Amazon")					
Transition	225183	0.1651812	0.37134	0	1
Cerrado	225183	0.3186963	0.46597	0	1
Road distance classes (omitted "0-2 km distance from roads")					
2-5 km distance from roads	225210	0.3241597	0.46806	0	1
5-10 km distance from roads	225210	0.1643888	0.37063	0	1
> 10 km distance from roads	225210	0.1260646	0.33192	0	1
Slope categories (omitted "0-2 degree slope")					
2-5 degrees	225210	0.3043115	0.46012	0	1
5-10 degrees	225210	0.0691843	0.25377	0	1
> 10 degrees	225210	0.0295236	0.16927	0	1
Agricultural suitability class (omitted "good, annual & perennial")					
Regular, annual & perennial	225066	0.3513903	0.47741	0	1
Resticted, annual & perennial	225066	0.0210871	0.14368	0	1
Possible for planted pasture	225066	0.2262492	0.41840	0	1
Possible for natural pasture	225066	0.1297797	0.33606	0	1
No agricultural value	225066	0.062164	0.24145	0	1
Year-dummies (omitted "year 1996-97")					
Year 1998-99	225210	0.2527152	0.43457	0	1
Year 2000-01	225210	0.2455619	0.43042	0	1
Year 2002	225210	0.2400293	0.42710	0	1
Interaction variable road distance 0-2 km & year-dummies (omitted "0-2 km distance & year 1996-97")					
Road distance 0-2 km & year 1998-99	225210	0.0980329	0.29736	0	1
Road distance 0-2 km & year 2000-01	225210	0.0933884	0.29098	0	1
Road distance 0-2 km & year 2002	225210	0.0901292	0.28637	0	1
Interaction variable low cover & year-dummies (omitted "low cover & year 1996-97")					
Low cover & year 1998-99	225210	0.0237867	0.15238	0	1
Low cover & year 2000-01	225210	0.0220994	0.14701	0	1
Low cover & year 2002	225210	0.0210426	0.14353	0	1
Interaction variable low cover & road distance 0-2 km					
Low cover & road distance 0-2 km	225210	0.0573554	0.23252	0	1
Enforcement dummy (high enforcement in 2000-01)					
High enforcement in 2000-01	225210	0.146299	0.353407	0	1
Interaction variable enforceement & year-dummies (omitted "enforcement & year 1996-97")					
Enforcement & year 1998-99	225210	0.036979	0.188710	0	1
Enforcement & year 2000-01	225210	0.035740	0.185642	0	1
Enforcement & year 2002	225210	0.035096	0.184023	0	1

Table 15: Logit regression on deforestation

Number of observation:	225041
Likelihood Ratio Chi-squared (30):	3602.03
Prob > Chi2	0.0000
Pseudo R-squared:	0.0702

Variable: deforest	Coef.	Std. Error	z	P|z|	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")						
high cover	-0.77569	0.08089	-9.59	0.0000	-0.93424	-0.61714
Inside/outside permanent preservation areas (omitted "outside")						
within permanent preservation areas (APP)	-0.63154	0.06866	-9.20	0.0000	-0.76610	-0.49697
within 300 m buffer around APP	-0.33762	0.03193	-10.57	0.0000	-0.40020	-0.27503
Ecoregions (omitted "Amazon")						
Transition	0.04952	0.04072	1.22	0.2240	-0.03029	0.12933
Cerrado	-0.08949	0.03646	-2.45	0.0140	-0.16095	-0.01803
Road distance classes (omitted "0-2 km distance from roads")						
2-5 km distance from roads	-0.76099	0.05239	-14.52	0.0000	-0.86368	-0.65830
5-10 km distance from roads	-1.26438	0.06516	-19.40	0.0000	-1.39209	-1.13667
> 10 km distance from roads	-2.83666	0.12847	-22.08	0.0000	-3.08845	-2.58487
Slope categories (omitted "0-2 degree slope")						
2-5 degrees	0.04328	0.03111	1.39	0.1640	-0.01769	0.10425
5-10 degrees	-0.07568	0.06485	-1.17	0.2430	-0.20278	0.05142
> 10 degrees	-0.58657	0.14432	-4.06	0.0000	-0.86943	-0.30370
Agricultural suitability class (omitted "good, annual & perennial")						
Regular, annual & perennial	-0.23408	0.03313	-7.07	0.0000	-0.29902	-0.16915
Resticted, annual & perennial	-0.19710	0.09296	-2.12	0.0340	-0.37929	-0.01490
Possible for planted pasture	-0.64545	0.04216	-15.31	0.0000	-0.72808	-0.56282
Possible for natural pasture	-1.01173	0.06343	-15.95	0.0000	-1.13605	-0.88741
No agricultural value	-1.44954	0.11728	-12.36	0.0000	-1.67940	-1.21967
Year-dummies (omitted "year 1996-97")						
Year 1998-99	-0.14939	0.06206	-2.41	0.0160	-0.27103	-0.02774
Year 2000-01	-0.06357	0.06222	-1.02	0.3070	-0.18552	0.05838
Year 2002	-0.42091	0.06981	-6.03	0.0000	-0.55774	-0.28408
Interaction variable road distance 0-2 km & year-dummies (omitted "0-2 km distance & year 1996-97")						
Road distance 0-2 km & year 1998-99	0.05322	0.07245	0.73	0.4630	-0.08878	0.19523
Road distance 0-2 km & year 2000-01	-0.48843	0.07711	-6.33	0.0000	-0.63956	-0.33730
Road distance 0-2 km & year 2002	-0.59614	0.08919	-6.68	0.0000	-0.77096	-0.42132
Interaction variable low cover & year-dummies (omitted "low cover & year 1996-97")						
Low cover & year 1998-99	-0.09658	0.08935	-1.08	0.2800	-0.27171	0.07855
Low cover & year 2000-01	-0.39643	0.10656	-3.72	0.0000	-0.60528	-0.18759
Low cover & year 2002	-0.28230	0.12364	-2.28	0.0220	-0.52463	-0.03996
Interaction variable low cover & road distance 0-2 km						
Low cover & road distance 0-2 km	-0.50325	0.07909	-6.36	0.0000	-0.65827	-0.34824
Interaction variable enforceement & year-dummies (omitted "enforcement & year 1996-97")						
Enforcement & year 1998-99	-0.19056	0.08933	-2.13	0.0330	-0.36565	-0.01548
Enforcement & year 2000-01	-0.21977	0.09888	-2.22	0.0260	-0.41357	-0.02597
Enforcement & year 2002	-0.48706	0.12360	-3.94	0.0000	-0.72930	-0.24482
Enforcement dummy						
High enforcement in 2000-01	0.38057	0.05824	6.53	0.0000	0.26641	0.49472
Constant	-1.67888	0.08460	-19.84	0.0000	-1.84470	-1.51306

Table 16: Logit regression on deforestation

Number of observation:	225041
Likelihood Ratio Chi-squared (30):	3602.03
Prob > Chi2	0.0000
Pseudo R-squared:	0.0702

Variable: deforest	Odds Ratio	Std. Error	z	P|z|	[95% confidence intervall]	
High/low natural vegetation cover (omitted "low")						
high cover	0.46039	0.03724	-9.59	0.0000	0.39289	0.53949
Inside/outside permanent preservation areas (omitted "outside")						
within permanent preservation areas (APP)	0.53177	0.03651	-9.20	0.0000	0.46482	0.60837
within 300 m buffer around APP	0.71347	0.02278	-10.57	0.0000	0.67019	0.75955
Ecoregions (omitted "Amazon")						
Transition	1.05077	0.04279	1.22	0.2240	0.97016	1.13807
Cerrado	0.91440	0.03334	-2.45	0.0140	0.85133	0.98213
Road distance classes (omitted "0-2 km distance from roads")						
2-5 km distance from roads	0.46720	0.02448	-14.52	0.0000	0.42161	0.51773
5-10 km distance from roads	0.28241	0.01840	-19.40	0.0000	0.24855	0.32089
> 10 km distance from roads	0.05862	0.00753	-22.08	0.0000	0.04557	0.07541
Slope categories (omitted "0-2 degree slope")						
2-5 degrees	1.04423	0.03248	1.39	0.1640	0.98246	1.10987
5-10 degrees	0.92711	0.06012	-1.17	0.2430	0.81646	1.05276
> 10 degrees	0.55623	0.08028	-4.06	0.0000	0.41919	0.73808
Agricultural suitability class (omitted "good, annual & perennial")						
Regular, annual & perennial	0.79130	0.02622	-7.07	0.0000	0.74155	0.84438
Resticted, annual & perennial	0.82111	0.07633	-2.12	0.0340	0.68435	0.98521
Possible for planted pasture	0.52443	0.02211	-15.31	0.0000	0.48283	0.56960
Possible for natural pasture	0.36359	0.02306	-15.95	0.0000	0.32108	0.41172
No agricultural value	0.23468	0.02752	-12.36	0.0000	0.18649	0.29533
Year-dummies (omitted "year 1996-97")						
Year 1998-99	0.86124	0.05345	-2.41	0.0160	0.76259	0.97264
Year 2000-01	0.93841	0.05839	-1.02	0.3070	0.83067	1.06012
Year 2002	0.65645	0.04583	-6.03	0.0000	0.57250	0.75271
Interaction variable road distance 0-2 km & year-dummies (omitted "0-2 km distance & year 1996-97")						
Road distance 0-2 km & year 1998-99	1.05467	0.07641	0.73	0.4630	0.91504	1.21559
Road distance 0-2 km & year 2000-01	0.61359	0.04731	-6.33	0.0000	0.52752	0.71370
Road distance 0-2 km & year 2002	0.55093	0.04914	-6.68	0.0000	0.46257	0.65618
Interaction variable low cover & year-dummies (omitted "low cover & year 1996-97")						
Low cover & year 1998-99	0.90794	0.08113	-1.08	0.2800	0.76208	1.08171
Low cover & year 2000-01	0.67271	0.07168	-3.72	0.0000	0.54592	0.82896
Low cover & year 2002	0.75405	0.09323	-2.28	0.0220	0.59177	0.96083
Interaction variable low cover & road distance 0-2 km						
Low cover & road distance 0-2 km	0.60456	0.04782	-6.36	0.0000	0.51775	0.70593
Interaction variable enforceement & year-dummies (omitted "enforcement & year 1996-97")						
Enforcement & year 1998-99	0.82649	0.07383	-2.13	0.0330	0.69375	0.98464
Enforcement & year 2000-01	0.80270	0.07937	-2.22	0.0260	0.66129	0.97436
Enforcement & year 2002	0.61443	0.07594	-3.94	0.0000	0.48225	0.78285
Enforcement dummy						
High enforcement in 2000-01	1.46312	0.08522	6.53	0.0000	1.30527	1.64005

Table 17: Summary statistics for variables used in land value regression

Variable	Observation	Mean	Std. dev.	Min	Max
Agricultural suitability					
Good, annual & perennial	145	0.2656851	0.2118	0.0000	0.911442
Regular, annual & perennial	145	0.3151295	0.2386	0.0000	0.928442
Possible for natural pasture	145	0.2391833	0.2292	0.0000	0.9483814
Interaction variable biome 1 (Amazon), biome 2 (Transition) & agricultural suitability class 1 (good, annual & perennial)					
Amazon & Transition & good for annual & perennial crops	145	0.1754606	0.1910	0.0000	0.911442
Interaction variable biome 1 (Amazon), biome 2 (Transition) & agricultural suitability class 2 (regular, annual & perennial)					
Amazon & Transition & regular for annual & perennial crop:	145	0.2181696	0.2310	0.0000	0.928442
Road proximity					
Road distance 0-2 km	145	0.5485718	0.1495	0.0699	0.8690476

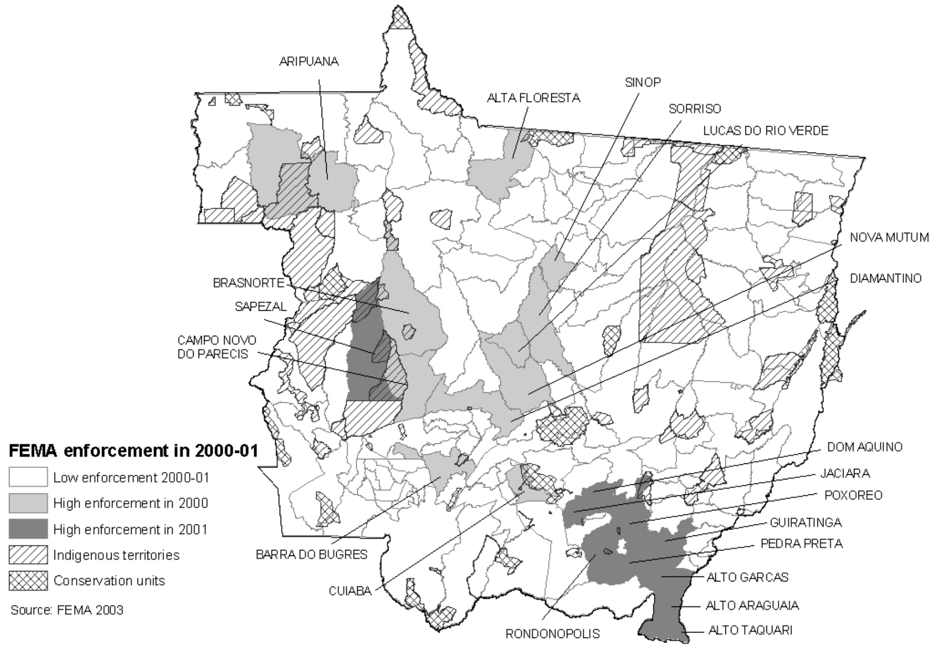
Table 18: Robust regression on INCRA land value

Number of observation:	138
F(6, 131)	19.07
Prob > F	0.0000

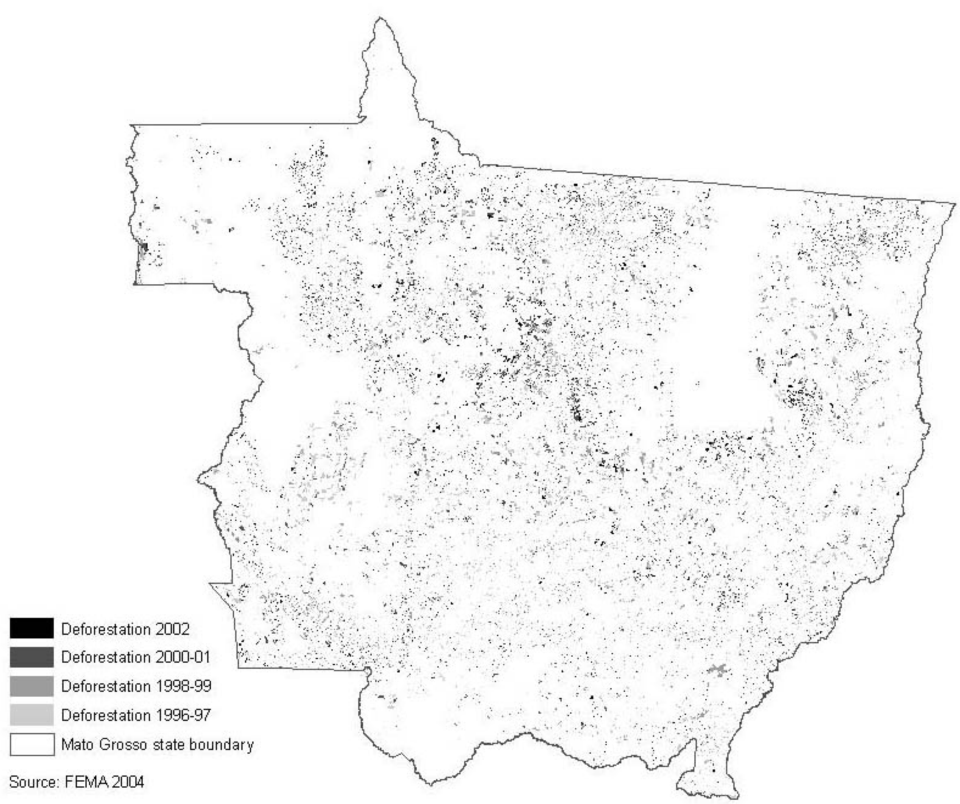
Variable	Parameter	Std. Error	t	P|t|	[95% confidence intervall]	
Agricultural suitability						
Good, annual & perennial	705.3849	149.6558	4.71	0.0000	409.3301	1001.44
Regular, annual & perennial	323.1482	135.3111	2.39	0.0180	55.47057	590.8258
Possible for natural pasture	378.68	82.02694	4.62	0.0000	216.4111	540.9488
Interaction variable biome 1 (Amazon), biome 2 (Transition) & agricultural suitability class 1 (good, annual & perennial)						
Amazon & Transition & good for annual & perennial crops	-370.3335	155.8632	-2.38	0.0190	-678.6681	-61.99883
Interaction variable biome 1 (Amazon), biome 2 (Transition) & agricultural suitability class 2 (regular, annual & perennial)						
Amazon & Transition & regular for annual & perennial crops	-181.0117	133.129	-1.36	0.1760	-444.3726	82.34911
Road proximity						
Road distance 0-2 km	504.0456	99.44561	5.07	0.0000	307.3185	700.7728
Constant	-95.29536	65.88713	-1.45	0.1500	-225.6358	35.04511

Maps

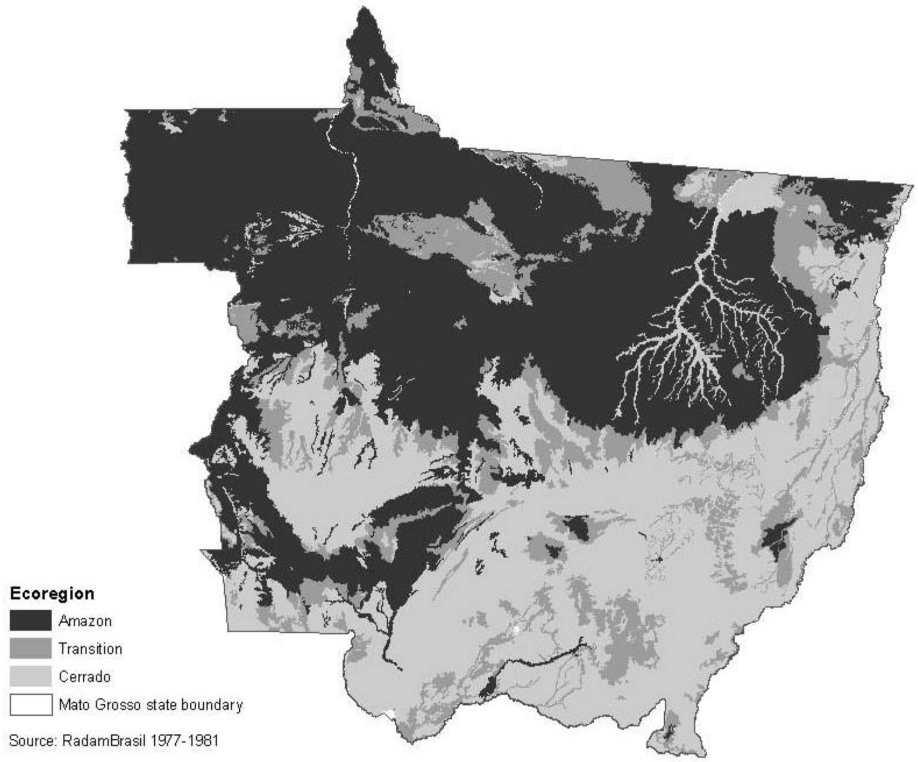
Map 1: Targeted FEMA enforcement in 2000-01 (FEMA 2002)



Map 2: Deforestation in Mato Grosso from 1996-2002 (FEMA 2003)

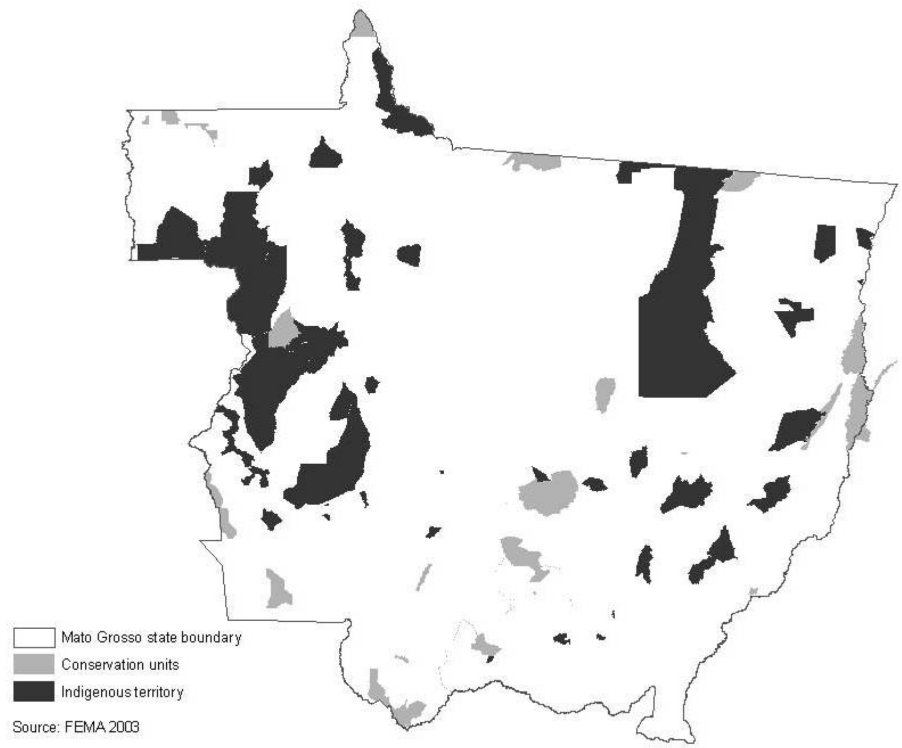


Map 3: Ecoregions of Mato Grosso (RadamBrasil 1977-1981)

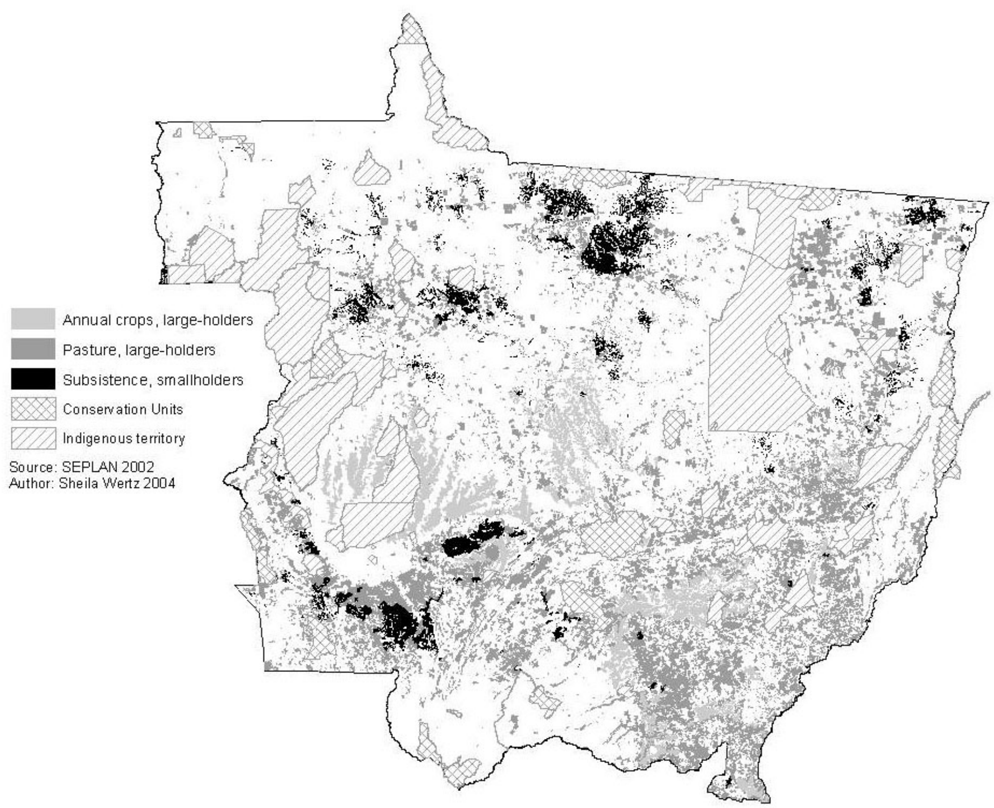


Map 4: Areas of permanent preservation of Mato Grosso (FEMA 2003)

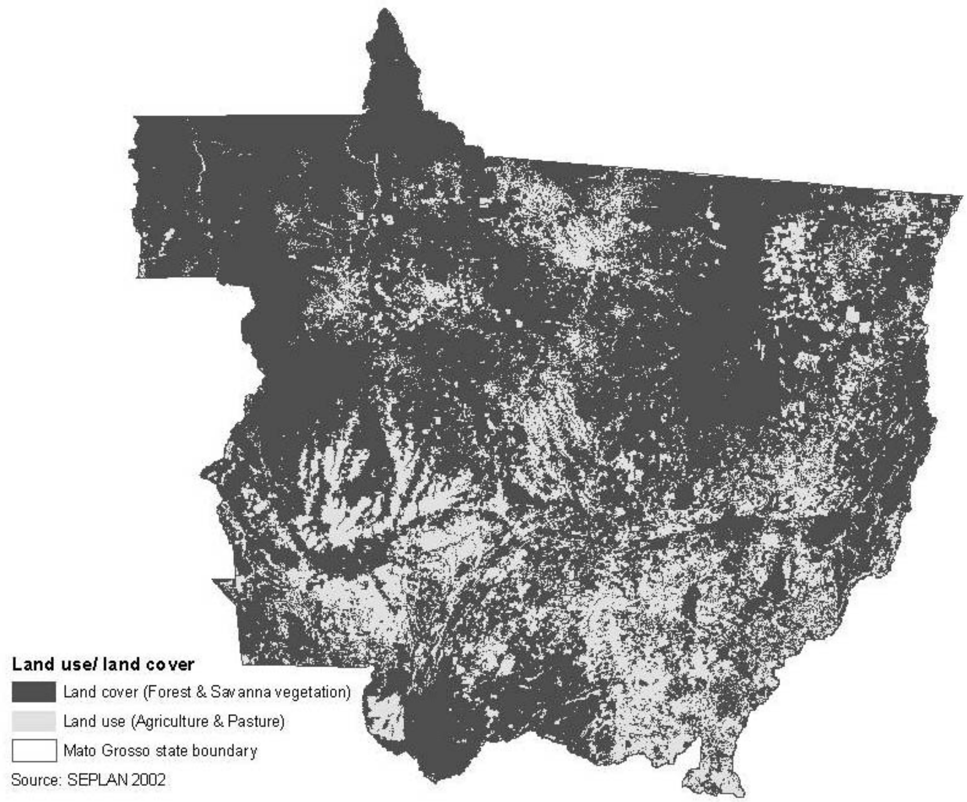
Map 5: Protected areas in Mato Grosso (FEMA 2003)



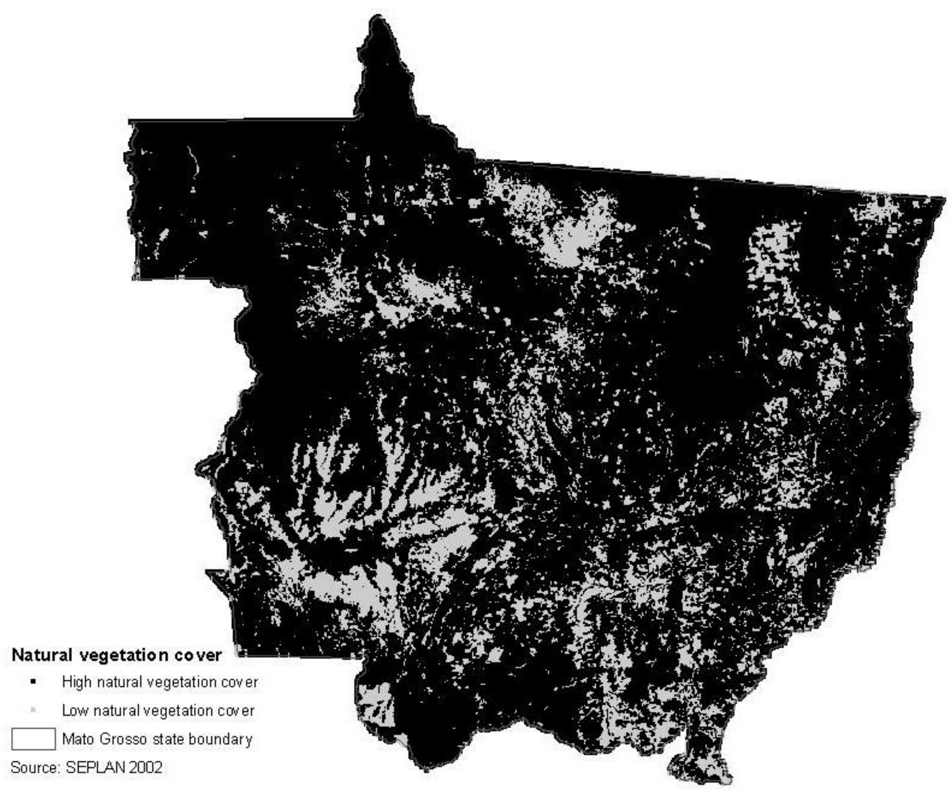
Map 6: Land use/land cover map as of 1995(SEPLAN 2002)



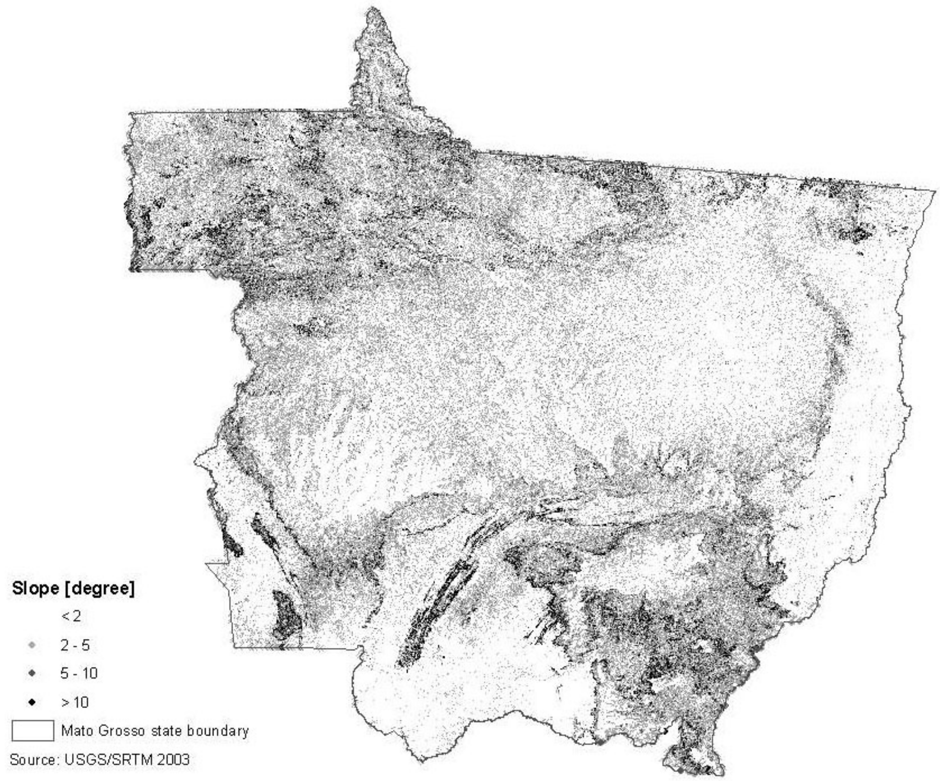
Map 7: Natural vegetation cover as of 1995(derived from SEPLAN 2002)



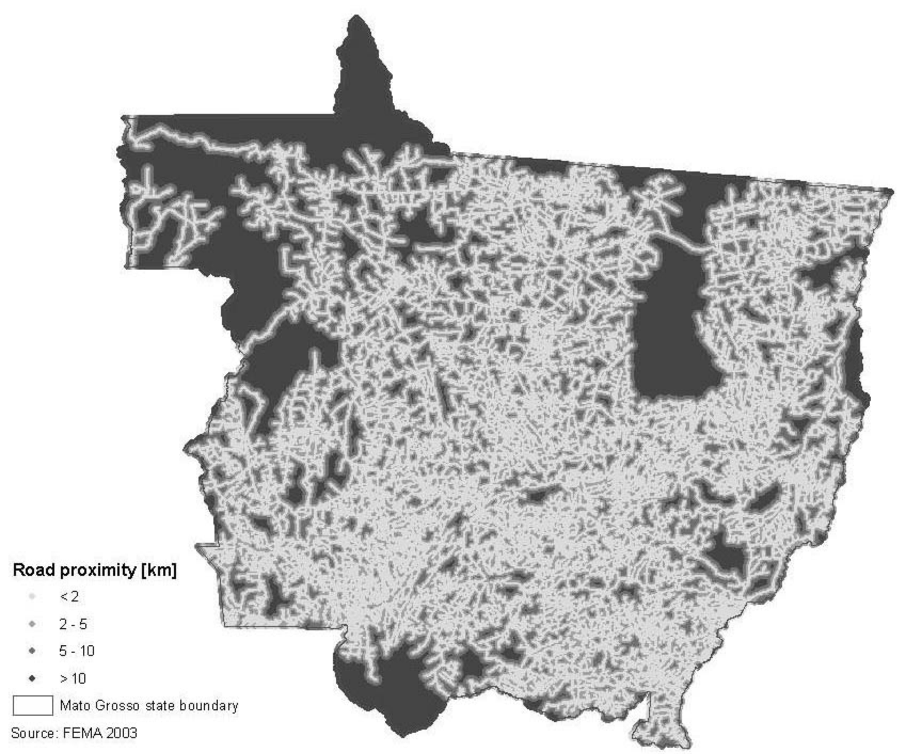
Map 8: High/low natural vegetation cover in Mato Grosso (own calculation)



Map 9: Slope in Mato Grosso (derived from USGS 2003)



Map 10: Road proximity in Mato Grosso (derived from FEMA 2003)



Map 11: Agricultural suitability in Mato Grosso (SEPLAN 2002)