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Conservation challenge at the agricultural frontier: deforestation, fire, and land use dynamics in Mato Grosso

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ABSTRACT

Achieving conservation objectives within the rapidly changing agricultural frontier in Mato Grosso State requires tradeoffs between production and preservation. We provide a description of deforestation, fire, and land use dynamics during 2000-2005 to consider a range of strategies for conservation planning. Long-term conservation of Cerrado, transition forest, and Amazon biomes in the state can benefit from direct consideration of landscape structure, duration of post-clearing land use, and the mosaic of land uses surrounding potential conservation corridors or reserve areas. Although the creation of new protected areas may not be feasible, since few large, uninterrupted forest areas exist within the state, some conservation objectives can be met through greater coordination of the legal reserve system among property owners. We present three examples of landscape-level prioritization based on existing Forest Code regulations stipulating 80% forest reserves on private property. Through a state-mediated system, property owners could augment existing reserve areas on their property through purchase of lands in: 1) buffers surrounding existing conservation units and indigenous reserves; 2) small watersheds with little or no deforestation; 3) forest patches with high connectivity within specified mosaics of different land uses. Any final approach for property-level coordination will depend on the specific conservation goals (e.g., river corridors, bird habitat, or plant biodiversity), but we provide a framework for developing and implementing a conservation plan at the agricultural frontier. Tradeoffs in both conservation value and productive use are required to achieve coordinated conservation at scale.

Key words: Brazilian Amazon; change detection; MODIS; protected areas; conservation strategy.

Desafios para conservação nas áreas de fronteiras agrícolas: desflorestamento, fogo e dinâmica do uso da terra no Mato Grosso

RESUMO

Para atingir os objetivos de conservação em áreas de rápida mudança na fronteira agrícola do Estado do Mato Grosso é requerido um balanço entre produção e preservação. Nós apresentamos uma descrição de desflorestamento, fogo e dinâmica do uso da terra no período 2000 - 2005 para definir estratégias para o planejamento de conservação. A conservação a longo prazo das áreas de Cerrado, floresta de transição e do bioma amazônico no Estado pode se beneficiar diretamente das informações sobre a estrutura da paisagem, a duração do uso da terra após o corte, e o mosaico de uso da terra nos arredores de potenciais corredores de conservação e áreas de reservas. Embora a criação de novas áreas protegidas pode não ser viáveis, devido a existência de poucas grandes áreas contínuas de florestas dentro do Estado, alguns objetivos de conservação podem ser alcançados através da melhor coordenação do sistema de reserva legal entre os proprietários. Apresentamos três exemplos de priorização a nível de paisagem baseado nas normas do Código Florestal que estipula 80% de reserva florestal em propriedades particulares. Através de um sistema gerenciado pelo Estado, os proprietários poderiam aumentar as áreas de reservas existentes em suas propriedades através da compra de terra em: 1) buffers nos arredores das unidades de conservação e reservas indígenas existentes; 2) pequenas bacias hidrográficas com pouca ou nenhuma área desflorestada; 3) conexão entre fragmentos de floresta existentes para conectividade da paisagem dentro de mosaico específico de diferentes usos da terra. Qualquer abordagem final para coordenação a nível de propriedade dependerá da finalidade especifica de conservação (e.g., margem de rios, habitat de aves, ou biodiversidade da flora), mas apresentamos um esquema para desenvolver e implementar um plano de conservação na fronteira agrícola. Um balanço dos valores de conservação e uso produtivo são requeridos para atingir uma conservação coordenada.

Palavras-chave: Amazônia Brasileira; detecção de mudança; MODIS; áreas protegidas; estratégia de conservação.

1. INTRODUCTION

Protected areas are a central component of worldwide efforts for biodiversity conservation, although debate continues over the role of people in parks and successful conservation (Schwartzman et al., 2000; Terborgh, 2000). In the Brazilian Amazon, both formal state and national protected areas, including parks, biological reserves, and sustainable use areas, and indigenous reserves have been effective in deterring deforestation and fire within their boundaries (Nepstad et al., 2006). One strategy to promote additional conservation of tropical forest through decreased deforestation, therefore, would be to create new protected areas as part of a comprehensive strategy for sustainable use of tropical forests.

Creation of new protected areas and declining rates of deforestation in 2005 and 2006 in the Brazilian Amazon can both be considered conservation successes. New parks and sustainable use areas created since 2002 under the auspices of the ARPA program have added 193,000 km^2 of tropical forest to the existing 1,700,000 km^2 of parks, sustainable use areas, national forests, and indigenous reserves within the Brazilian Amazon (Brasil, 2003). At the agricultural frontier, annual deforestation declined from more than 27,000 km^2 in 2004 to 18,800 km^2 in 2005, and a further reduction is anticipated based on preliminary data analyses from 2006 (INPE, 2007).

However, this reduction in deforestation is unrelated to the push for new protected areas, since major reserve creation focused on areas far from the arc of deforestation. The decrease in deforestation is more likely attributable to state level property registration programs (Fearnside; Barbosa, 2004); increased satellite-based enforcement targeting illegal deforestation, such as DETER (Anderson et al., 2005; Shimabukuro et al., 2005); and declining prices for soybeans and other agricultural commodities (Morton et al., 2006). One notable exception is the mosaic of new biological reserves and national forests in the Terra do Meio region and bordering the federal highway BR-163 in central Pará State (Campos; Nepstad, 2006). These reserves were specifically designed to influence future development along important transportation corridors in anticipation of increased deforestation pressure from the paving of federal highways in coming years (Soares Filho et al., 2006).

The lack of protected areas at the current agricultural frontier presents two important questions. Are new protected areas in regions of rapid land cover change possible, practical, or desirable, given the tradeoffs between production and preservation that would be necessary to achieve conservation objectives? Or, are other strategies more viable to achieve specific conservation goals? We consider the case of Mato Grosso State to illustrate the opportunities and constraints of conservation planning at the agricultural frontier (Figure 1).

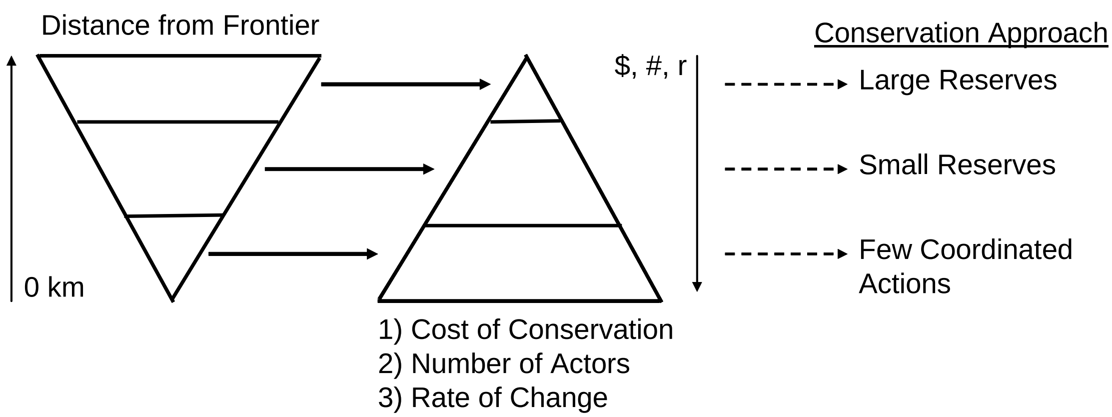


Figure 1. Tradeoffs present in conservation planning at varying distance from the agricultural frontier. The complexity of conservation action increases exponentially as the area in question becomes closer to the existing frontier, measured in terms of cost, time, number of actors, or other similar variables. Historically, these higher costs of conservation along the frontier have limited conservation action in favor of forest conversion for other uses.

Mato Grosso State is the most active land use change frontier in the Brazilian Amazon in terms of total forest loss (INPE, 2007). The mosaic of land uses on existing cleared areas adds pressure for more forest loss, creating a complicated environment in which to achieve conservation objectives because of the myriad actors and rapid rate of change. However, four scientific and practical rationales exist for promoting conservation along the existing agricultural frontier. First, Mato Grosso contains most of the dry forest ecoregion (WWF, 2004) in the southern Amazon (Figure 2). The dry forest, also referred to as transition forests given their ecotonal location between Cerrado vegetation in the south and more moist tropical forests to the north, is the most affected biome from recent land cover changes, yet least protected. At present, six small conservation units encompass less than 2% of the ecoregion within Mato Grosso, although the Xingu Indigenous Reserve does include this forest type. Second, forest dieback as a result of climate change in the central Amazon Basin (Oyama; Nobre, 2003; Cox et al., 2004) may relegate forests at the current agricultural frontier zone as climatic refugia for tropical forests in the future. Third, existing legal framework in the Brazilian Forest Code provides a mechanism for coordinating property-level conservation in legal reserves. These opportunities have not been realized at scale given the difficulty in designing and implementing a coordinated scheme for property development. Finally, present opportunities for conservation are rapidly diminishing, and restoration of degraded forests and abandoned agricultural land is often more expensive than initial preservation.

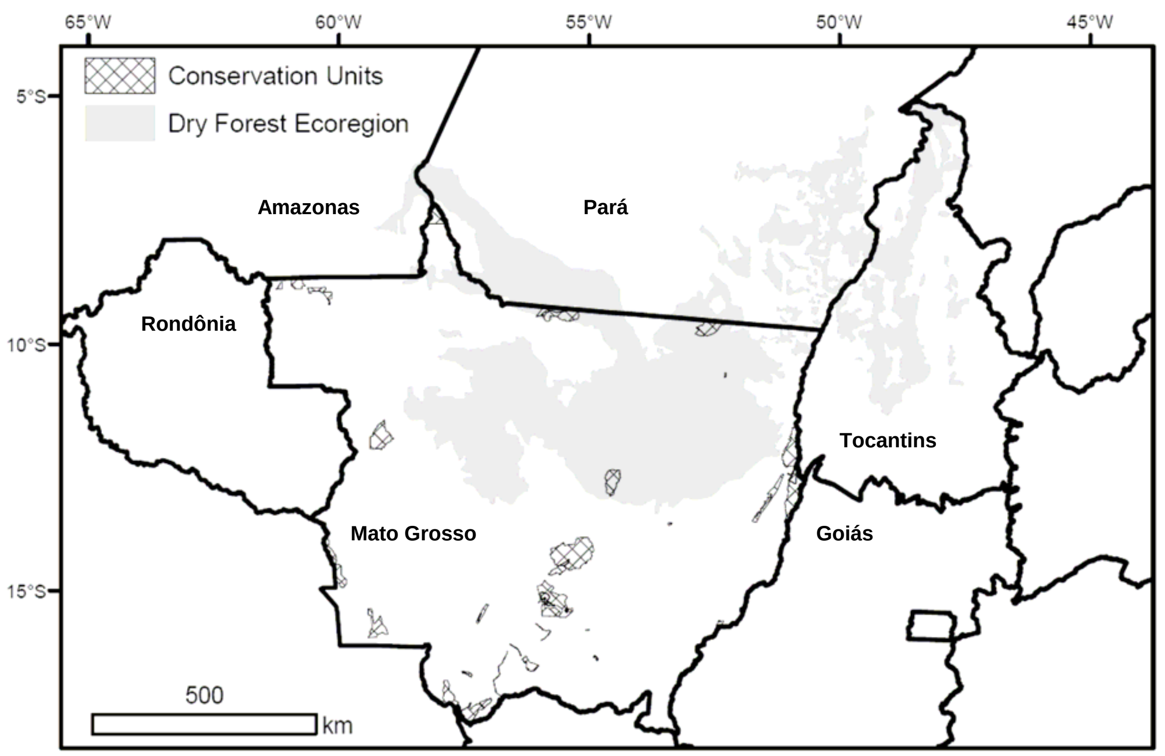


Figure 2. The dry forest ecoregion in relation to state boundaries within the Brazilian Amazon. Existing conservation units in Mato Grosso state have limited coverage of this unique biome.

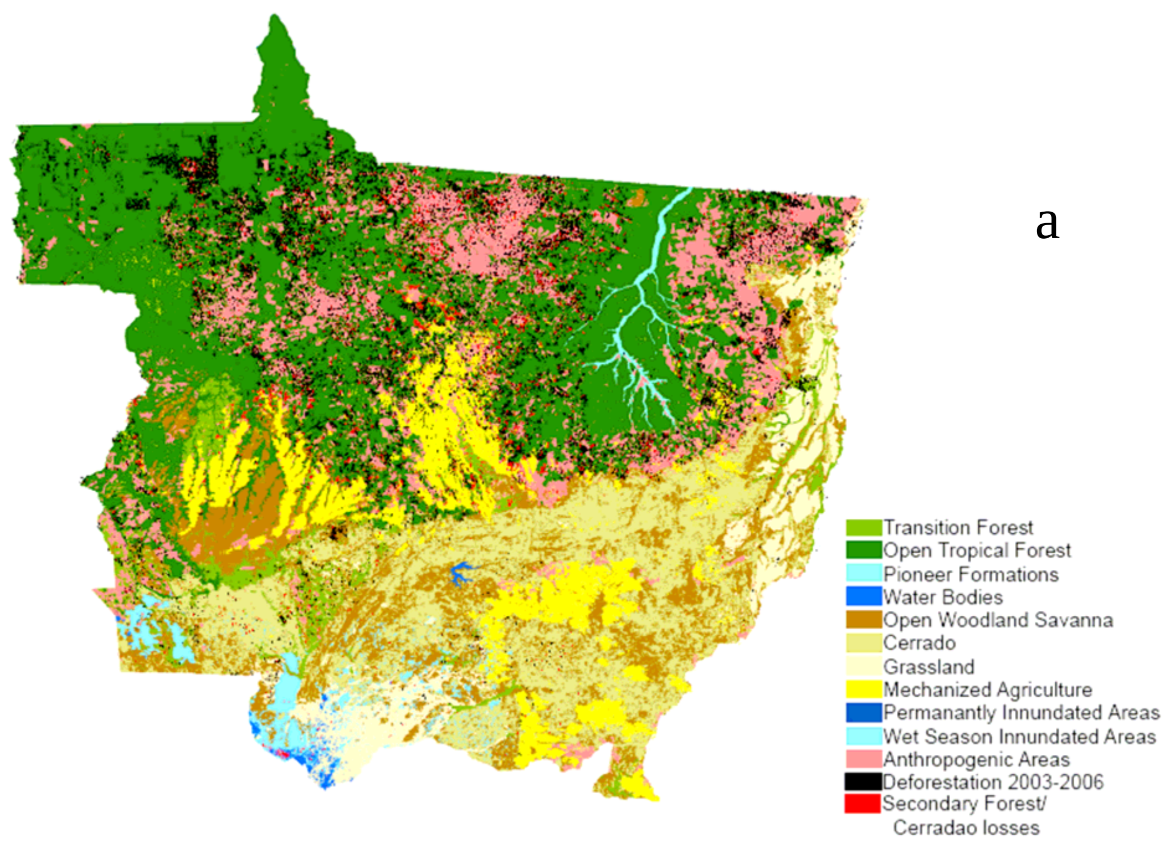
We consider the context for developing forest conservation strategies in Mato Grosso based on remote sensing data on land cover and land use change. Remote sensing analyses provide a wealth of information about landscape properties, rates of change, and available regions for implementing different conservation approaches such as corridors, reserves, or local-scale coordination among landowners. The goal of this paper is to combine various perspectives on recent changes in Mato Grosso to examine the opportunities and challenges for effective conservation planning at the agricultural frontier.

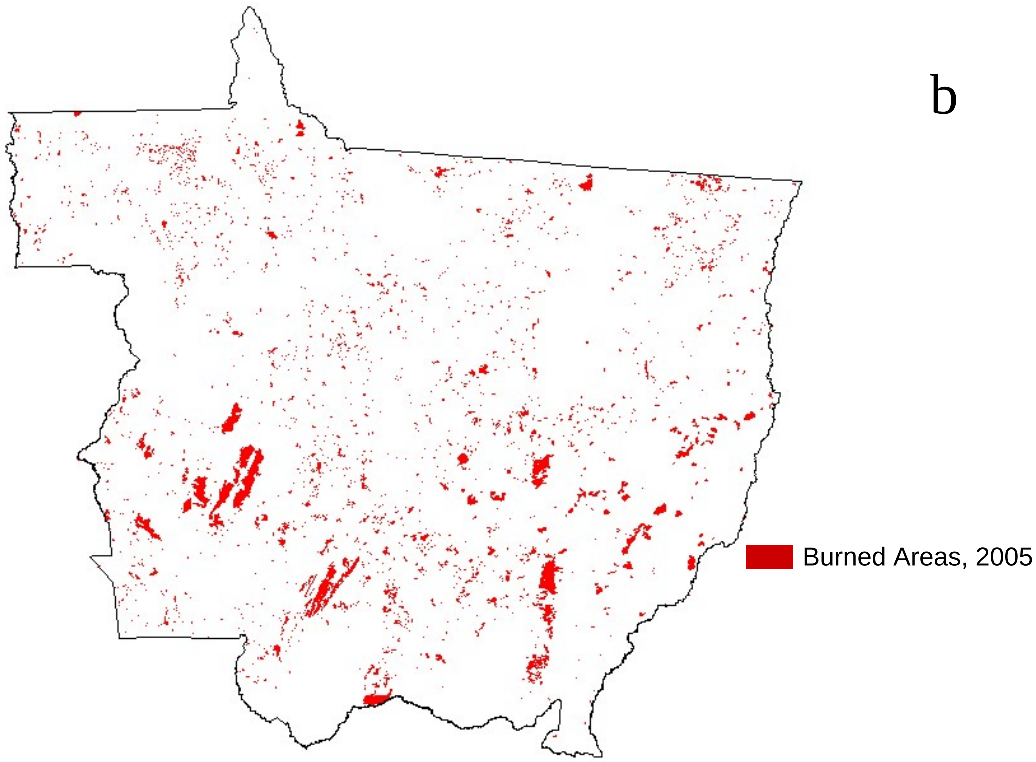
2. MATERIAL AND METHODS

To access land cover and land use dynamics, we combine data from a variety of recent studies to analyze the available information from satellite remote sensing for conservation planning (Figure 3). A land cover classification from 2002 (Anderson et al., 2005) was updated to include land cover changes through 2004 (Lima et al., 2007) and forest losses from the INPE PRODES program through August, 2006 (INPE, 2007). In addition, we incorporate spatial detail for the conversion of secondary forest and Cerradão within Mato Grosso during this period (Morton et al., 2007). The distribution of post-clearing land uses is also critical for conservation planning, since habitat quality, species dispersal, and potential impacts of agrotoxins or livestock waste depend on the matrix of nonforest land cover within a given watershed or region. Morton et al. (2006) provide the first estimate of land use following recent deforestation (2001-2004); we provide updated information including analysis of 2005 deforestation.

Fires used for land clearing and management influence the conservation potential of neighboring forest vegetation. We analyze active fire detections from the Moderate Resolution Imaging Spectroradiometer (MODIS), two NASA satellites that provide daily coverage of the entire Amazon Basin, and burn scar maps derived from MODIS imagery in 2005 to assess the influence of fire activity on existing, planned, and possible additional conservation areas. The burn scar map was produced using MODIS (MOD09) data acquired in 2005 following the methodology presented by Anderson et al. (2005). Burn scars were identified using the shade fraction image derived from a Linear Spectral Mixing Model (Shimabukuro; Smith, 1991), similar to the PRODES and DETER methodology (Shimabukuro et al., 2005).

Finally, we identify regions with high potential for future conservation action, using metrics of landscape structure for fragmentation and isolation. We follow a framework outlined by Lima (2005) to describe conservation opportunities in Mato Grosso. Existing conservation units are considered in terms of biome representation, overall area, and degree of encroachment by other land uses (e.g., pasture, cropland) and fire. We also consider the role of indigenous areas in these aspects to assess the effectiveness of formal and informal conservation areas. Possible conservation corridors are considered in the context of representation of unique biomes within the state, size of potential reserve area, and neighboring land uses to illustrate tradeoffs involved with conservation planning at the rapidly changing agricultural frontier. Small watershed areas included in this analysis were derived from the United States Geological Survey topographic map at 30 arc second resolution (GTOPO30).





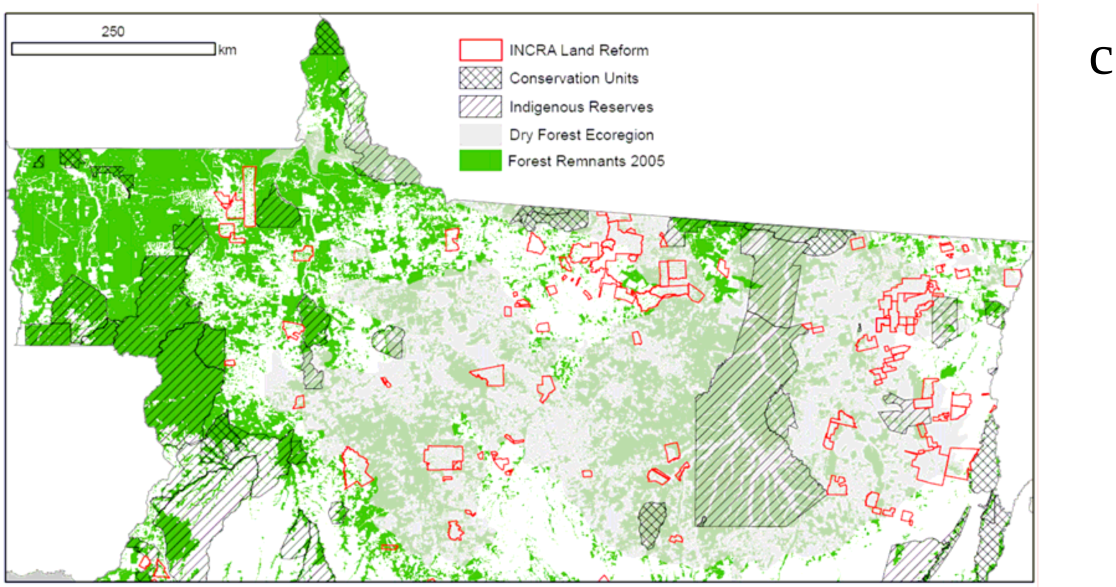


Figure 3. Statewide land cover and recent land cover changes, highlighting deforestation and secondary forest losses during 2003-2006 (a). Fire is also a critical seasonal component of the landscape that influences conservation actions (b). The forest conservation context, relative to ecoregion boundaries, remaining forest fragments, and existing conservation units and indigenous reserves (c) summarizes the challenges for designing and implementing a conservation strategy at the agricultural frontier.

3. RESULTS AND DISCUSSION

3.1. Land Use and Land Cover Change Context

Mato Grosso State contains a variety of important biomes for conservation and productive regions for cropland agriculture and cattle ranching. Figure 3 shows the division of forested and nonforest land cover types roughly split between the north and south, respectively. We focus on the forested region to illustrate the complexity of possible future conservation scenarios, although a similar analysis could be done for Cerrado or Pantanal wetland ecosystems. Within the forested region, two important patterns of development exist. First, within the Xingu River watershed, recent deforestation pressure has advanced nearly to the boundary with the Xingu Indigenous Reserve, led by the advance of soybean and other crops (Figure 4). Second, the central development corridor that follows the Cuiabá-Santarém highway (BR-163) has almost completely separated forested regions east and west of the road.

Recent forest loss in Mato Grosso has been rapid, although estimated deforestation in both 2005 and 2006 show reductions from the peak clearing activity in 2002-2004 (Table 1). In addition to losses of tropical forest, the state also had net losses of secondary forest on previously cleared areas (Morton et al., 2007). Rapid turnover of regrowing forest provides an additional indication of the permanence of forest losses in the state. Net loss of secondary forest, where the rate of secondary forest clearing exceeds that of land abandonment to forest regeneration, suggests that the landscape does not include a variety of forest habitats in different age classes. Finally, losses of tall, closed-canopy Cerradão vegetation mirrored rates

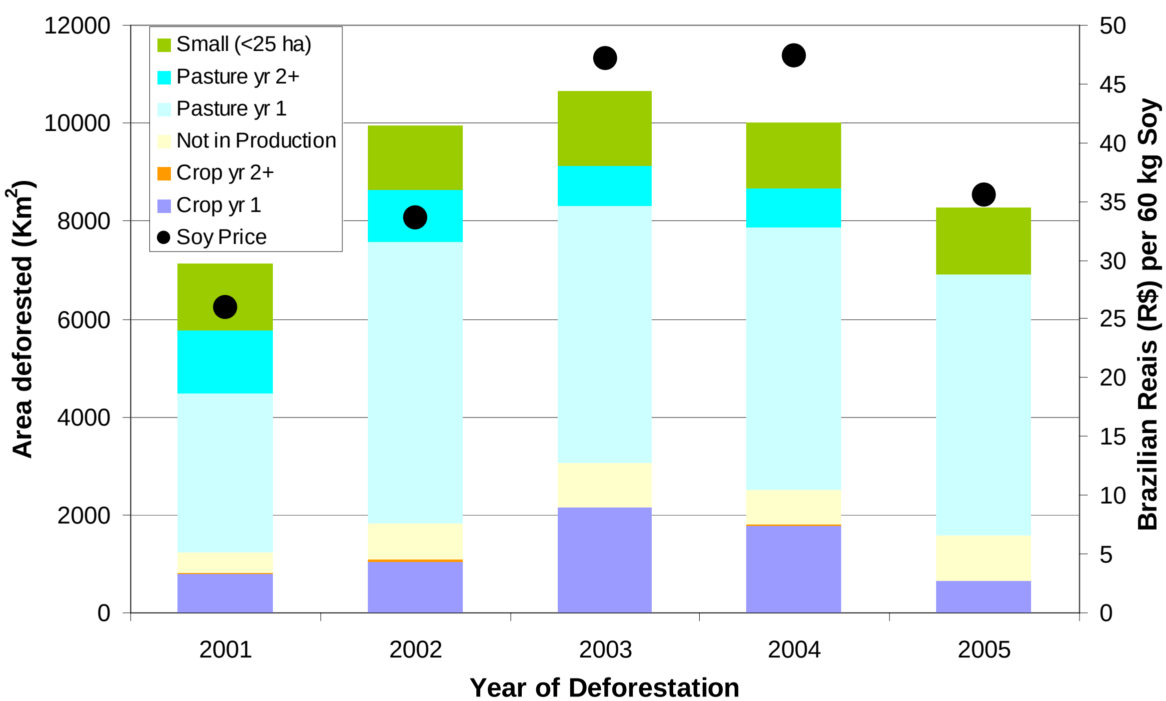


Figure 4. Post-clearing land use for 2001-2005 deforestation in Mato Grosso State based on MODIS phenology data from 2002-2006, following methods outlined in Morton et al., (2006). The amount of forest cleared directly for cropland expansion is related to inflation-adjusted soybean prices. Inter-annual variability in deforestation dynamics illustrates the roles of different actors (soybean growers, ranchers, smallholders) in potential conservation action.

Table 1. Estimated deforestation, net loss of secondary forest cover, and Cerradão conversion for 2002-2006. Deforestation estimates are derived from PRODES digital data (INPE, 2007); Morton et al. (2007) provide secondary forest and Cerradão loss estimates.

	2002	2003	2004	2005	2006
Deforestation	10.036	10.773	10.245	8.480	4.438*
Net Secondary Forest Loss	235	651	683		
Cerradão Loss	398	640	613	250	

** Based on the analysis of 24 Landsat scenes in Mato Grosso, including both deforestation and residual classes.*

of forest clearing in 2002-2005. As shown in Figure 3a, these open woodland regions are found in very few locations along the forest-Cerrado transition; rapid rates of clearing in Cerradão therefore provide a rationale for conservation of remaining fragments of this unique species assemblage.

Fire use for land clearing and maintenance of fire-dependent land uses, such as pasture, introduces a second complication for conservation at the forest frontier. Figure 3b shows the statewide extent of burning during 2005, including evidence for understory fires within remaining forest fragments. Forest damage from understory fires can lead to a positive feedback cycle, whereby initial burning opens the canopy, drying fuel loads from fire-killed vegetation, making future fires more likely (Cochrane et al., 1999). Whether land use surrounding existing protected areas or possible future conservation zones require fire use is an important consideration for conservation planning.

The land cover and land use change context in Mato Grosso forms the basis of any plans for future conservation action. Figure 4 shows the variety of actors and an example of the role of market forces that influence current trends in deforestation. Conservation options must be balanced with the statewide interest in sustainable agricultural production, and farmers and cattle ranchers are likely to bring unique demands to the discussion of conservation goals. Recent action by ABIOVE, an industry group representing soybean producers, in response to a European boycott of soybeans from the Amazon suggests that farmer-led conservation initiatives are both desirable and imminent (ABIOVE, 2006). Similar interest may exist within the ranching community as a means to certify beef production in terms of both management and safety (Nepstad et al., 2006). Figure 3c provides an overview of the landscape-level situation for forest conservation in Mato Grosso. Few large forest fragments remain east of the Xingu Indigenous Reserve. East-west connectivity among forest patches is also restricted. However, large forest areas remain in the western Xingu Basin, in addition to potential buffer zones around indigenous reserves in northwest Mato Grosso.

3.2. Existing and Planned Conservation Units

According to data from FEMA (2006), the state of Mato Grosso has 43 conservation units, 5 of which are federally protected areas and the remaining 38 are under state control. The majority of the conservation units (35) have protected status (Proteção Integral). The remaining 8 conservation units are considered sustainable use areas. In all, these conservation units protect 2,887,481 hectares (ha), or roughly 3% of the state's land area. This level of protection is well below the threshold of 10% conservation of the legal Amazon in conservation units set by the national congress. Recent reserve creation in other Amazon states through the ARPA program has not yet designated new reserves in Mato Grosso towards this goal.

As a result of the low proportion of the state formally protected in federal and state conservation units, coverage of individual biomes is well below the suggested minimum areas required for biodiversity conservation recommended by Noss and Coperrider (2004). Lima (2005) highlights an additional problem with the current system of protected areas in the state—evidence for anthropogenic land uses within the boundaries of several conservation units, suggesting that current levels of oversight for protected areas has been unable to deter illegal land clearing.

A more important base of conservation of natural ecosystems within Mato Grosso is the network of indigenous reserves within the state. As of April 2004, there were 70 indigenous reserves occupying roughly 12,500,000 ha, equivalent to 14% of the land area in Mato Grosso. Although indigenous reserves are not legally required to provide environmental protection of natural ecosystems within their territories, forested indigenous reserves within Mato Grosso have been equivalent or better than formal conservation units at limiting deforestation and fire (Nepstad et al., 2006). Over time, this trend may change. Studies carried out in southern Brazil, where contact between indigenous populations and populations outside of reserves have occurred for much longer periods than in Mato Grosso, suggest that indigenous reserves are inefficient for natural resource protection in older frontier zones (Galetti, 2001). Already in Mato Grosso, the presence of soybean cultivation has been identified within indigenous reserves in the Chapada dos Parecis region (Ribeiro, 2004; Lima, 2005).

As recently as 2004, State zoning documents showed 15 proposed new conservation areas (Mato Grosso, 2004). Of these 15, the 4 slated for full protection all experienced new deforestation in 2005 and 2006 for other non-forest land uses. The remaining 11 proposed conservation units were slated for sustainable use designations, of which 4 experienced deforestation by 2006. Low levels of representation of major biomes within the existing protected area system, combined with recent land cover change trends in existing and planned conservation units, suggest that a new strategy for conservation may be necessary at the agricultural frontier.

3.3. Landscape Assessment for Conservation Opportunities

The current landscape context of land cover and land use change provides the opportunity to explore a variety of forest conservation options within the fragmented landscape to identify remnant forest patches that satisfy specific conservation goals. We use forest vegetation as the organizing bases for conservation objectives, but mammal habitat, insect diversity, or the presence of endangered species could also serve as the framework for a statewide conservation strategy. We begin with the premise that large reserve creation is desirable, but no longer practical, given the degree of fragmentation at the forest frontier. Therefore, we focus on the possibility to prioritize smaller areas for state-coordinated investment, possibly as part of a market framework to allow property owners to compensate for missing legal reserve areas on their own properties. Prioritizing these additional areas of conservation interest could be done based on a variety of landscape properties (Figure 5).

The small watershed is a landscape unit that incorporates elements of ecosystem function, and could therefore provide an ecological basis for conservation planning. Figure 5a shows the small watersheds with more than 80% forest cover remaining, based on deforestation and land use change statewide through 2005. The numbers are encouraging; 80-89% forested (n = 153, 42,400 km^2), 90-99% forested (n = 252, 63,300 km^2), 100% forested (n = 47, 4,300 km^2). The highest concentration of forested watersheds is in northwest Mato Grosso, including a number of watersheds that extend into neighboring Rondônia (35), Amazonas (22), and Pará (16) states. Within the dry forest ecoregion, 122 small watersheds remain with high forest cover. Some watersheds are already partially included in protected areas and indigenous reserves; these watersheds might be of highest priority for additional conservation, given the potential down-stream influence of land use change in other portions of these watersheds.

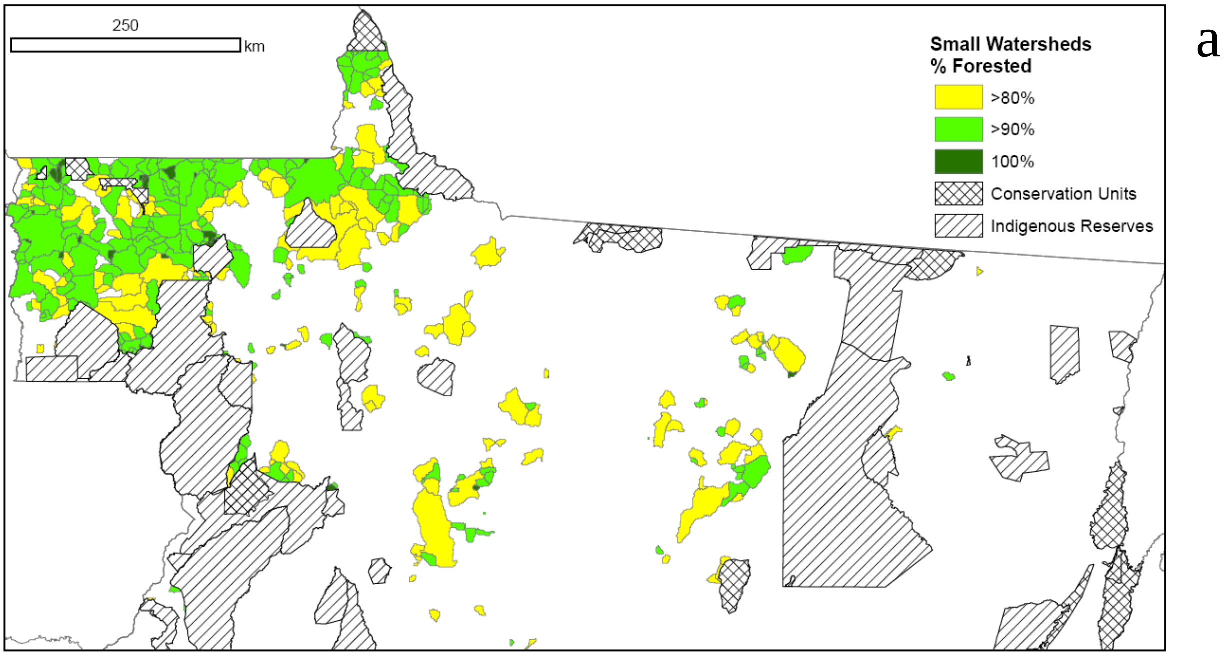
A second framework for prioritizing addition forest protection could be to add conservation value to existing protected areas using a system of buffers (Figure 5b). As noted previously, little connectivity exists between the Xingu Indigenous Reserve and forest fragments on the eastern side. However, connectivity is much higher on the western edge, including potential linkages within 20 km to established conservation units.

Currently, state highway MT-130 passes between these two areas, nicknamed the “Rodovia da Economia.” Balancing proposed development in this corridor with potential conservation goals may require a change of course at the state level. With this type of conservation connectivity becoming increasingly rare at the landscape scale, tradeoffs between conservation and development may become more likely. A similar approach could be used to identify regions with small gaps between large remaining forest fragments as a means for protecting large tracts of forest, regardless of the regularity of the new reserve shape.

A third approach to identifying possible conservation opportunities on the landscape is to examine the matrix of forest cover, including the distance between fragments of varying size, fire-dependence of intervening land uses, and recent rates of deforestation (Figure 5c). This strategy combines concepts from population ecology (minimum viable population), landscape ecology (fragment shape and edge effects), and current land use as a proxy for future fire risk. By maximizing the size of remaining forest fragments, restricting the distance between fragments to <2 km, and favoring land uses that do not use fire, such as soybean cultivation, the landscape in Figure 5c could be the basis for an integrated production and protection zone with potential conservation value for bird species. The key to implementing this type of conservation strategy is to clearly define the mosaic composition, allowing for restoration or expansion of forest areas within the mosaic to meet these needs, and monitoring the success of such a reserve design over time.

Any scientifically-based approach for additional forest conservation in Mato Grosso is likely to consider the approaches presented here, although other strategies exist. Prioritizing buffer areas around existing protected areas and indigenous reserves can be seen as enhancement; this approach assumes that the initial allocation of lands to protected areas or indigenous reserves was consistent with current conservation goals, or that conservation areas would be more effective if they were larger. The approaches built around intact forested watersheds or landscape mosaics with a concentration of large forest patches are predicated on the need for expansion of existing conservation coverage. In addition to the examples described here, the selection of these areas could also prioritize specific habitat qualities, such as forest or Cerradão on flat terrain, or seek to minimize the influence of a different suite of specific land uses or land cover changes. We provide a summary of the available satellite data with which to develop the landscape context; specific conservation objectives may then be tested against the landscape context to provide the scientific rationale for prioritizing conservation action.

Such a coordinated statewide conservation program will undoubtedly require more active participation from both government and civil society, since the planning process is only the first stage of conservation. Continued pressure for development at the agricultural frontier


250
km
Small Watersheds
% Forested
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Conservation Units
Indigenous Reserves
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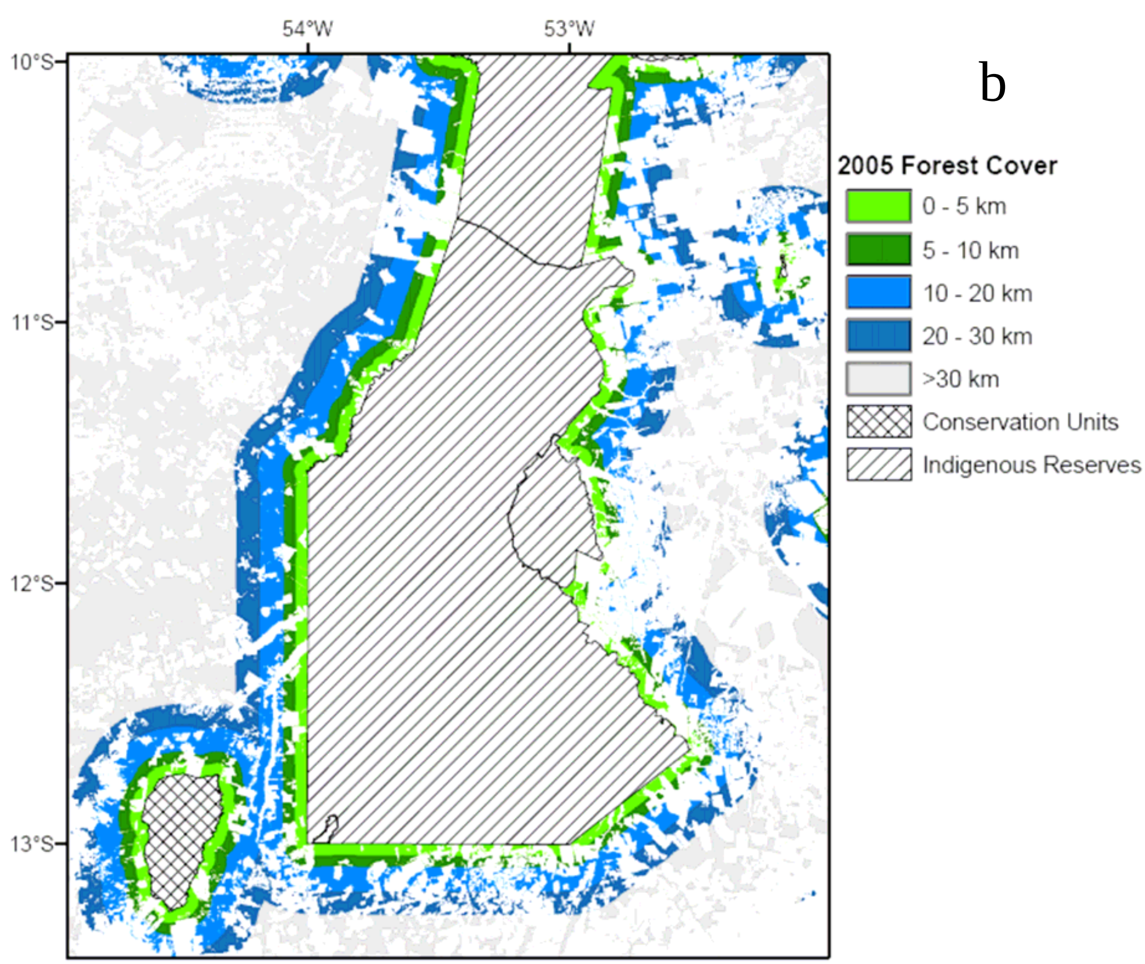
54°W
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5 - 10 km
10 - 20 km
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Conservation Units
Indigenous Reserves

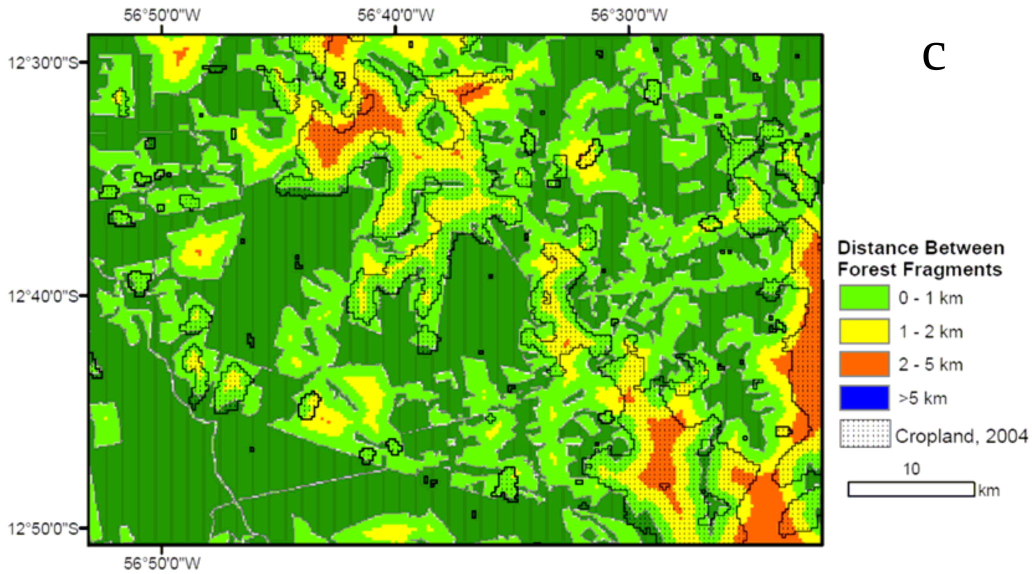

Figure 5. Forest conservation strategies in Mato Grosso based on small watersheds outside of existing conservation units with high percentages of remaining forest cover in 2005 (a), buffer zones surrounding existing conservation units and indigenous reserves (b), and landscape mosaics with large forest patches separated by cropland areas <2 km wide (c).

will therefore necessitate both commitment to and enforcement of the conservation plan (Nepstad et al., 2002). The decision to augment existing conservation approaches in the state will require tradeoffs, both in development restrictions and conservation quality. Forest areas near the frontier are likely to have been logged, burned, or hunted—possibly “lower quality” conservation areas than regions with less development pressure. However, we highlight a series of landscapes within the current development context in Mato Grosso where conservation, rather than more costly methods of restoration, is still feasible, albeit with more intensive methods for coordination among conservation units and private landholders. The alternative to increased, coordinated conservation in the near-term is likely to be additional forest fragmentation along the frontier, with remnant forest patches occupying a shrinking mosaic of steep slopes, poor soils, areas far from roads, and small, property-level fragments of natural vegetation as stipulated by the Forest Code.

3.4. Leverage for Conservation Action

We have focused on the possibility of a state-led program for purchasing conservation lands as the mechanism for additional conservation within the existing legal framework. Groundwork for such a system is already highly advanced. The majority of private properties in Mato Grosso have already been registered through a state environmental licensing effort, SLAPR (Sistema de licenciamento Ambiental em Propriedades Rurais no estado do Mato Grosso). One environmental non-profit organization, Conservation International, has already developed a localized system for compensation near Parque das Emas in Goiás State when landholders have insufficient legal reserves on their property (Buchanan et al., 2007). A similar system for conservation planning is under development for the entire state of Goiás (Ferreira Junior et al., 2007). Building on these successes in the region, a state-led effort for coordination among private landowners seems promising.

Additional leverage for conservation action within the state may come from three seemingly different sources. The state receives important revenue from eco-tourism; visitors interested in birding, wildlife viewing, and fishing have a unique opportunity to explore the Pantanal wetlands, Cerrado, and Amazon forest in Mato Grosso. These constituents are likely to favor the creation of more small reserve sites, especially if limited access is allowed for ecotourism purposes. Second, large agribusiness interests realize their market share is directly tied to environmental conditions in the state. A recent boycott of soybeans from the Amazon in Europe has prompted industry action on a number of new conservation and product certification schemes[1]. Third, the nascent ecosystem services sector may soon provide a legal and market framework for new conservation efforts similar to that of the legal reserve system on private property. Recent discussions of "averted deforestation" (Santilli et al., 2005) have introduced the potential for different ecosystem service payments as part of the planning process for post-Kyoto Protocol actions to regulate greenhouse gases. Given the high rates of recent forest loss in Mato Grosso, the state could benefit financially from implementing the SLAPR system for deforestation reduction and conservation planning.

4. CONCLUSIONS

Conservation within the matrix of fragmented land cover and continuing deforestation is complex, and may require difficult tradeoffs between production and preservation. Additional complications for conservation planning arise from the narrow time window for new conservation action within any rapidly changing environment. We provide the landscape context of land use and land cover change based on analyses of satellite remote sensing data. Although most conservation units and indigenous reserves are still serving as barriers to deforestation, proposed areas for future reserves have not fared well in recent years. The prospect for new, large conservation units at the agricultural frontier is not promising. However, a variety of conservation opportunities do exist for forest conservation when contributions can be made from both private and public land holdings.

The new property registration system in Mato Grosso, SLAPR, combined with legal requirements for 80% protection of forest on private property, provides a framework for a statewide system to purchase additional lands for conservation. We highlight several methods for prioritizing areas for conservation, including buffers surrounding existing protected areas, small watersheds with little or no deforestation, and areas that retain high connectivity among large forest remnants. In each case, remote sensing data are essential to develop a coordinated, landscape scale approach. Any final approach for property-level coordination will depend on the specific conservation goals (e.g., river corridors, bird habitat, or plant biodiversity), but we provide a framework for developing and implementing a conservation plan at the agricultural frontier.

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[1] Communication provided by Carlos Scaramuzza in São Paulo, October 2006.

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