Near real-time deforestation detection for enforcement of forest reserves in Mato Grosso

Carlos M. de Souza Jr. -souzajr@imazon.org.br
Sanae Hayashi - sanae@imazon.org.br
Adalberto Veríssimo - betoverissimo@uol.com.br

Instituto do Homem e Meio Ambiente da Amazônia - Imazon
Rua Domingos Marreiros 2020, 66.060-160, Belém, ParáBrazil

Abstract

We have developed a near-real time deforestation monitoring system, named SAD (*Sistema de Alerta de Desmatamento*) to monitor the Brazilian Amazon states. Here, we present how SAD works and has been used to monitor deforestation in different types of forest reserves in the State of Mato Grosso, and the potential use of this information to stop illegal deforestation in these reserves. The types of forest reserves we have been monitoring are located in Protected Areas (i.e., Indigenous Lands, Conservation Units), agrarian settlements, private lands registered to the state government licensing system and in unclaimed public land. A total of 22,700 square kilometers of forest conversion by deforestation was detected wit SAD from August 2004 to January 2009 in Mato Grosso State. Of this total amount 60% (13,670 square kilometers) were detected in the Amazon Biome, and the remaining 40% (9,000 square kilometers) in transitional forest types. We estimated that 85% of the total deforestation detected with SAD from August 2004 to July 2008 classified as illegal. This information is being widely disseminated to authorities and general society, through the media, to support law enforcement of illegal deforestation which has been the weak component of the chain put in place to implement the forestry code to protected private and governmental forest reserves. As a result of our Forest Transparency initiative – that combines near-real time detection of deforestation with strategic dissemination of the information – the debate about deforestation has been kept alive each month by media. This puts positive pressure on the states and federal governments to act against illegal deforestation in the region.

1. Introduction

The annual average deforestation rate in the Brazilian Amazon from 2000 to 2008 was 18,500 square per year, with the second highest peak of deforestation in 2004 reaching 27,400 square kilometers of forest conversion. Since 2005, annual deforestation rates have been decreasing as a response to the expansion of protected areas, law enforcement campaigns and restriction to rural credits imposed by new policies. However, annual deforestation rates from 2005 to 2008 are still high with an average of 12,500 square kilometers (Figure 1) (PRODES, 2009). According to PRODES, Mato Grosso state has the highest average annual deforestation in the Brazilian Amazon from 2000 to 2008, with 6,800 square kilometer per year (i.e., 37% of the deforestation average for this period; Figure 1). Pará state is in the second position accounting for 34% or 6,300 square kilometers per year, followed by Rondônia (14%). The other six states (Acre, Maranhão, Tocantins, Roraima, Amazonas and Amapá) contribute with 15% of the total deforestation.

Even though the Brazilian government implemented several strategies to stop illegal deforestation in this region, economic drivers have been considered the main cause of the fluctuation of deforestation rates from 2000 to 2008 (Ewers et al. 2008). For example, the region responded to the growing of domestic and international demand for meat, agricultural products, timber, minerals and energy supply from 2000 to 2005, what is being considered the major drives that put

deforestation rates at high levels. In 2007, the drop of annual deforestation rates can be partially explained by the ongoing economic crisis which is creating an unfeasible market conditions to the agriculture sector in Brazil, but preliminary analysis reveal that command and control by the federal government may be the main reason for the recent decrease of deforestation.

There are currently other deforestation drivers that can still push the deforestation rates to high levels, even in an unfavorable macroeconomic scenario. For example, the expansion of biofuels production in other parts of the country – particularly in the southeast –is being pushing ranching and agriculture from the original places to the Brazilian Amazon frontier (Nepstad et al. 2006, Morton et al. 2006). Moreover, the Brazilian Government has restarted several development projects in the region including road paving, opening waterways, issuing licenses for mineral research and exploitation, and planning the construction of major hydropower plants, aiming to accelerate the development in the region[1]. Complex land tenure arrangement, low level of land tenure titling (4% only of the private lands) and weak legal enforcement have also created a culture in which public land can be freely occupied (Barreto et al., 2008). These land tenure factors have kept deforestation relatively high in new deforestation hotspots where the public lands are under dispute.

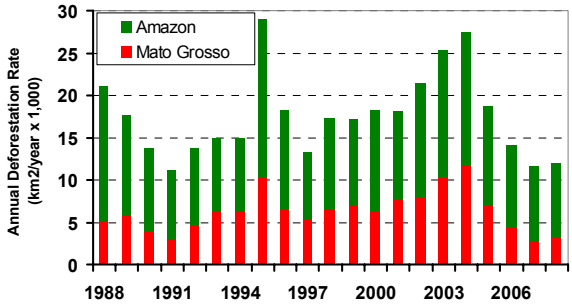

Figure 1. *Deforestation rate in the Brazilian Amazon and Mato Grosso State (source: INPE @ http://www.obt.inpe.br/prodes/).*

With the objective to monitor the impact of governmental policies to develop and protected the Brazilian Amazon, and detected deforestation Imazon developed and put operational the first non-governmental deforestation alert system, name SAD (*Sistema de Alerta de Desmatamento*). In this article, we present how SAD works and has been used to monitor deforestation in different types of forest reserves in the State of Mato Grosso, and the potential use of this information to stop illegal deforestation in these reserves. The types of forest reserves we have been monitoring are located in Protected Areas (i.e., Indigenous Lands, Conservation Units), agrarian settlements, private lands registered to the state government licensing system and in unclaimed public land

2. SAD – *Sistema de Alerta de Desmatamento*

We developed a deforestation change detection technique based on MODIS (Moderate Resolution Imaging Spectroradiometer) daily image composites. Because the MODIS pixels (250 m) can be contaminated by clouds, we use only high bit quality pixels in the forest change detection analysis. Then, deforestation change detection is performed based on novel spectral index named NDFI (Normalized Difference Fraction Index; Souza et al.,2005). All pixels that showed NDFI < 125 are classified as deforestation, while those with NDFI values between 125

[1] See the new development program for Brazil, PAC – Programa de Aceleração de Crescimento. V67.5.0 – August, 29, 2008, @ https://www.pac.gov.br/.

and 165 are forest degradation. The deforestation that occurred before July 2004 is masked out in order to detect only new deforested areas after this baseline date.

The deforestation polygons detected with SAD are validated using higher resolution satellite images when available (at least 50% of the cases are validated every month). All new deforested areas are incorporated to the deforestation mask so that in the next change detection period only new deforested areas are mapped (Figure 2). Because of the coarse resolution of MODIS, deforestation detected by SAD represents a fraction of the total deforestation detected with PRODES – the Brazilian government deforestation monitoring system.

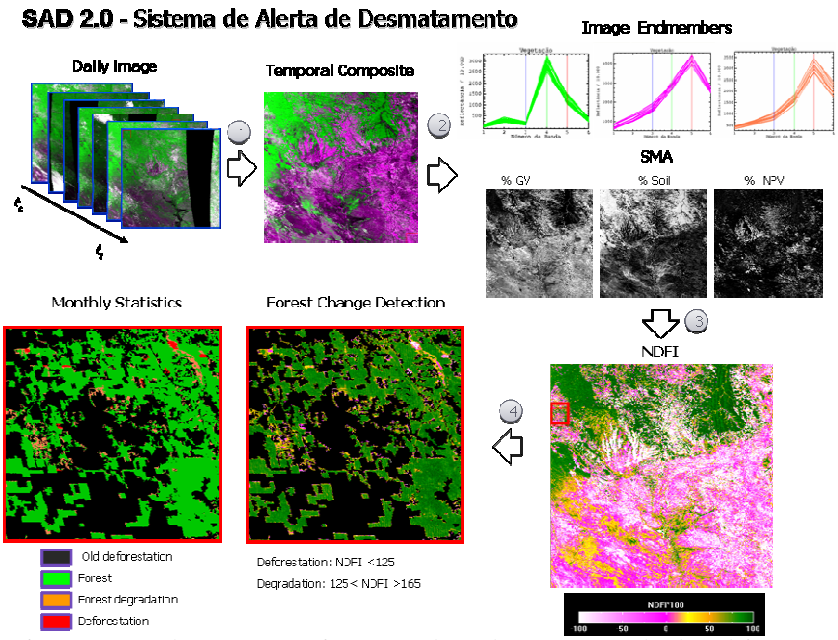

***Figure 2**. Deforestation Alert System of Imazon, based on NDFI calculated from MODIS 250 meter spatial resolution images.*

In Mato Grosso, SAD detected 75% of deforestation detected with PRODES for the period of 2004 through 2007. The total deforestation detected with PRODES in this period was 25,970 square kilometers while SAD detected 19,440 square kilometers. This was possible because in Mato Grosso 75% of the deforestation create clearing sizes are usually greater than 25 hectares (Souza et al., 2006). Therefore, SAD is a suitable tool to monitor deforestation in this state and has the advantage to do so at near real time.

3. Land Categories and Forest Reserves

The state of Mato Grosso is located in the center-western region of Brazil, with an area of 903.357 square kilometers. Most of its territory is inserted in the Amazon Legal region. The Amazon biome comprises 47% of the state, followed by *Cerrado* or savannas (39%) and natural grass fields (14%). The tropical humid climate predominates in the region with high precipitation levels of 2,000 millimeters. The Mato Grosso econmy is largely based on ranching, mechanized agriculture (specially, soybean and cotton) and logging.

Five types of land categories can be found in Mato Grosso (Figure 3). The legally protected areas include Indigenous Lands with 14% (128,216 square kilometers) and Conservation Units with 5%

(41,089 square kilometers). Rural Settlements for agrarian reform occupies 5% (42,161 square kilometers) of the territory. Private lands are obliged by law to be registered in the State Environmental Licensing System of Rural Properties (SLAPR). Currently, 21% (191,347 square kilometers) of the territory of Mato Grosso is covered by private lands registered in SLAPR. The remaining 55% (500,543 square kilometers) of the territory are either private lands not registered in SLAPR or lands that belong to the either federal or state governments that had not been assigned to particular land uses or protection categories.

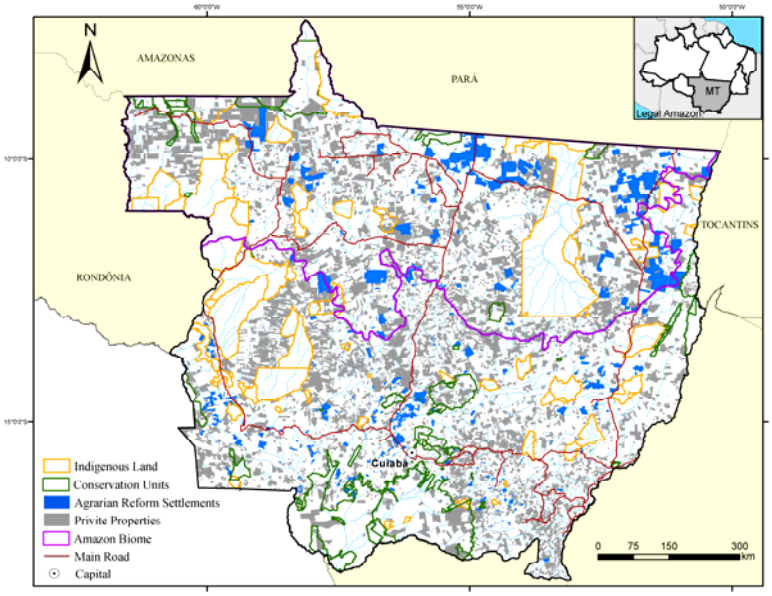

***Figure 3**. Land categories found in Mato Grosso state. White regions outside of Indigenous Lands and Conservation Units are undesignated governmental lands.*

The SLAPR system started to be implemented in 1999, and became operational in 2000, with the aim to support environmental licensing, enforce the Brazilian Forestry Code, and support land tenure regularization (Fearnside, 2003; Souza and Barreto, 2001; ISA, 2005). Up to 2007, 9,700 private properties had been registered into SLAPR, with an average size of properties of 2,350 hectares (source: SEMA - (SEMA – *Secretaria Estadual de Meio Ambiente* of Mato Grosso). This represents an area of 191,000 square kilometers – 10% of all properties in the State or 28% of the private lands and undesignated governmental lands in Mato Grosso. The annual adhesion rate to SLAPR is of about 1%. At this pace, it would take 70 years to register all properties in Mato Grosso, according to the SEMA..

Forest reserves can be classified in three major categories based on the degree of protection defined by law. The first type is forest reserve in protected areas (i.e., Indigenous Territories and Conservation Units). Deforestation in most types of Conservation Units is illegal according to the Brazilian laws, but can be legally allowed in Indigenous Land, Extractive Reserve and in Sustainable Development Reserves at very small scale only for subsistance practices of the local population. Unprotected forest reserves are subject to the Brazilian Forestry Code which establishes Legal Reserves – the second category of forest reserve – in private lands. In the Amazon Biome, the Legal Reserve requires that 80% of the private land should be maintained with native vegetation (except in areas where de Ecological_Economic Zoning indicate 50%),

and 35% in *Cerrado* (ISA, 2005). Private properties in transitional forests between the Amazon Biome and *Cerrado* should maintain 50% of the original vegetation according to State of Mato Grosso law (Fearnside, 2003). The third type of forest reserves, Areas of Permanent Protection (APP) are those along rivers, steep slopes and watershed divisors, and top of hills.

4. Illegal Deforestation in Forest Reserves

A total of 22,700 square kilometers of forest conversion by deforestation was detected wit SAD from August 2004 to January 2009 in Mato Grosso State (Table 1). Of this total amount 60% (13,670 square kilometers) were detected in the Amazon Biome, and the remaining 40% (9,000 square kilometers) in transitional forest types. Less than 2% (432 square kilometers) of deforestation happened inside Protected Areas, mostly in Indigenous Lands.

The amount of deforested areas within each private property cannot exceed 20% in order to respect the Legal Reserve law. Additionally, any deforestation in private lands that are not registered in the rural licensing system (SLAPR) is considered illegal. We estimated the amount of illegal deforestation in private lands combining three spatial analysis results. First, we estimated the amount of deforestation detected with SAD inside SLAPR that disrespected the Legal Reserve Law (i.e., more than 20% of the property size deforested). To do that, we had to combine SAD from August 2004 to July 2008 with cumulative deforestation detected with PRODES before 2004 to estimate the amount of Legal Reserve deforested detected with SAD in this period. Secondly, we identified deforestation outside SLAPR not in protected areas which is also considered illegal because deforestation permits require registering the property into this licensing and control system. Finally, we estimated the amount of illegal deforestation detected with SAD in Protected Areas. All these three estimates resulted in 85% of the total deforestation detected with SAD from August 2004 to July 2008 classified as illegal (Figure 4).

Table 1. *Deforestation detected with SAD from August 2004 to Januray 2009 in different types of lands and biomes of the Mato Grosso State.*

Land Categories and Biomes	Aug04-Jul05 Area (km^2)	Aug05-Jul06 Area (km^2)	Aug06-Jul07 Area (km^2)	Aug07-Jul08 Area (km^2)	Total
Total Deforestation in the Amazon Biome	**6.387**	**4.167**	**1.722**	**1.274**	**13.673**
Rural Settlements	876	663	416	177	2.160
Indigenous Land	187	55	39	73	354
State Conservation Unit	17	31	9	10	68
Federal Conservation Unit	3	2	4	1	9
SLAPR	**2.110**	**1.333**	**394**	**376**	**4.245**
Outside SLAPR	**3.194**	**2.084**	**861**	**637**	**6.837**
Transitional Forests	**2.350**	**1.919**	**790**	**833**	**5,769**
Total Deforestation	**8.737**	**6.086**	**2.512**	**2.107**	**19,442**

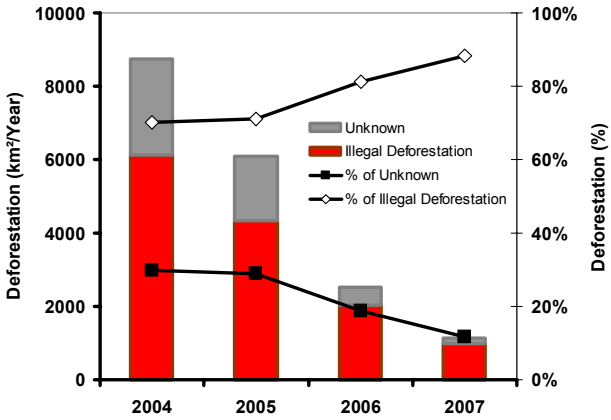

***Figure 4**. Illegal deforestation identified by combining SAD data with properties registered in Mato Grosso's environmental licensing system (SLAPR) and maps of Protected Areas, for the period of 2004 through November 2007. Because information on deforestation permits is not available, the remaining deforested areas outside SLAPR and protected areas were classified as unknown with respect to legality, since permits are required for forest clearing.*

5. Supporting Forestry Law Enforcement

We went beyond deforestation detection and monitoring with SAD. First, in November 2007, we signed a formal technical cooperation agreement with the state and federal public prosecutor offices of several Amazonian states (i.e., Mato Grosso, Pará, Amapá and Roraima). Through this technical agreement, Imazon provides detailed information of deforestation detected in Protected Areas so that public prosecutors can start official enforcement processes. The information provided by Imazon requires three steps. First, we use SAD to identify the deforestation cases in the Protected Areas. The second step consists in the validation of the deforestation detected by SAD with more detailed satellite imagery and/or field information (if available) and gathering of information about the creation of the Protected Area (i.e., decree that creates the Protected Area, date of creation, type of protection, among others). The last step is to present all the information acquired about the deforestation in an official document (*representation*) to the public prosecutors.

The second effort to support forest law enforcement is a partnership with the State Environmental Agencies (SEMA) from the Amazonian states. As part of this collaboration, we have submitted the SAD results to these environmental agencies to support field enforcement campaigns. Recently, in January 2009, SEMA from Mato Grosso announced in their official web site[2] that land owners received environmental fines based on SAD information. Even though this represents a great progress towards forest law enforcement, the effectiveness of these fines has been compromised by the low efficacy of the judiciary system in Brazil to judge these types of cases (Brito and Barreto, 2006). The formal agreement with SEMA also provides access to the rural property cadastral and licensing database, and GIS database with several geographical data layers (i.e., deforestation, vegetation, protected areas and zoning maps, number of property registry per month, among others). Access to these databases allowed us to evaluate the quality and credibility of the SLAPR data and to perform detailed geographical analyses of illegal deforestation, as the one showed in Figure 4.

[2] SEMA announcement can be found @ http://www.sema.mt.gov.br/noticia/mostraInforme.aspx?cod=1696.

Thirdly, we established a strong dissemination strategy to inform the Brazilian society about deforestation threats of the Amazon forest reserves to support enforcement of the forestry code. The dissemination strategy has two components. The first one is our web-GIS portal, named ImazonGeo[3], which aims to provide geographical information about different kinds of threats to the Brazilian Amazon forests, such as deforestation, fires, roads, logging. Additionally we release a monthly report, named Forest Transparency Bulletin, with deforestation statistics, trends, geographical hot spots and spatial analysis. Examples of deforestation analyses include: i) the identification and estimation of illegal deforestation in Protected Areas (i.e., Conservation Units and Indigenous Land) and outside the Rural Property Cadastral and Licensing System (SLAPR) (Figure 4); and ii) identification of critical deforestation hot spots in terms of deforestation rates and pressure on remaining forests. Our analyses have showed that most of deforestation in Mato Grosso concentrates in rural properties not registered in the SLAPR system. The analyses also reviewed that, in Mato Grosso, illegal deforestation is frequent in Areas of Permanent Protection and Legal Reserves within the private properties registered into SLAPR. This information is being use to guide law enforcement actions to fight illegal deforestation in Mato Grosso, and to question the efficacy of the SLAPR system to fight illegal deforestation.

The second component of the dissemination strategy includes a strong connection with the news media aiming to keep general society information about deforestation threats in the Amazon region. Since the release of the first Forest Transparency Bulletin in August 2006, more than 800 news appeared in the media (TV, radio, news papers and magazines). For example, the main headline of the first quarter of 2008 was that deforestation doubled in this period compared to prior year. As a result, 30 media insertions were obtained in this period, being 10 in newspapers, 7 on TV, 13 in the internet.

Conclusion

Our near-real time deforestation monitoring system, SAD, has been proved to be a valuable tool to monitor forest reserves in the Brazilian Amazon. In the state of Mato Grosso, which has the most advanced cadastral and licensing system of private lands, SLAPR, SAD has been used to qualify deforestation in terms of legality. Most of the deforestation detected in private lands in this region is illegal, according to SAD and spatial analyses that combine property boundaries and maps of protected areas and private properties. This information is being widely disseminated to authorities and general society, through the media, to support law enforcement of illegal deforestation which has been the weak component of the chain put in place to implement the forestry code to protected forest reserves. As a result of our Forest Transparency initiative – that combines near-real time detection of deforestation with strategic dissemination of the information – the debate about deforestation has been kept alive each month by media. This puts positive pressure on the states and federal governments to act against illegal deforestation in the region. For example, as a result of our monthly deforestation report, published in September 2007, that showed an increase of deforestation in Mato Grosso State, the Ministry of Environment announced a deeper review of the Governments current plan to reduce deforestation. And more recently the Brazilian Government has announced a tighter plan to control illegal deforestation by targeting the top 36 municipalities with high deforestation rate in the last three years (2005-2007). Therefore, our preliminary results are encouraging which leads us to conclude that near-real time monitoring of deforestation with wide dissemination of this information has the potential to protect forest reserves in private and governmental lands in this region.

[3] ImazonGeo can be accessed @ http://v2.imazongeo.org.br/imazongeo.php.

Acknowledgement

The Forest Transparency initiative is being financially supported by the David and Lucile Packard Foundation to whom we are thankful. We also would like to thank Amintas Brandão and Rodney Salomão for generating the spatial analysis presented in this manuscript.

References

Barreto, P.; Pinto, A.; Brito, B. & Hayashi, S. 2008. Quem é Dono da Amazônia: Uma análise do recadastramento de imóveis rurais Belém, Imazon: 74p.

Brito, B. and Barreto, P. 2006. A eficácia da aplicação da lei de crimes ambientais pelo Ibama para proteção de florestas no Pará. Revista de Direito Ambiental. São Paulo: Ed. Revista dos Tribunais, n. 43, 2006. 35-65. (in Portuguese).

ISA 2005. Desmatamentos de florestas em propriedades rurais integradas ao Sistema de Licenciamento Ambiental Rural entre 2001 e 2004. Instituto Socioambiental – ISA, Brasília, 18p.

Ewers, R., Laurance, W., Souza Jr., C., 2008. Temporal Fluctuations in Amazonian Deforestation Rates. Environmental Conservation, 35(4): 303-310.

Fearnside, P. M. 2003. Deforestation Control in Mato Grosso: A New Model for Slowing the Loss of Brazil's Amazon Forest. AMBIO, 32(5):343-345. 2003.

ISA 2005. Desmatamentos de florestas em propriedades rurais integradas ao Sistema de Licenciamento Ambiental Rural entre 2001 e 2004. Instituto Socioambiental – ISA, Brasília, 18p.

Morton, DC; DeFries, RS; Shimabukuro, YE; Anderson, LO; Arai, E; Espirito-Santo, FdB; Freitas, R; Morisette. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. J. Proc Natl Acad Sci USA.103:14637–14641.

Nepstad, D., C. Stickler, O. Almeida. 2006. Globalization of the Amazon beef and soy industries: opportunities for conservation. Conservation Biology 20(6): 1595-1603.

PRODES – Monitoramento da Floresta Amazônica por Satélite. 2009. Home Page: http://www.obt.inpe.br/prodes/.

Souza Jr., C., Barreto, P., 2001. Sistema de fiscalização, licenciamento e monitoramento de propiedades rurais de Mato Grosso. In: Ministério do Meio Ambiente. Causas e dinâmicas do desmatamento da Amazônia. 307-341.

Souza Jr., C. M., Roberts, D. and Cochrane, M. A. 2005. Combining Spectral and Spatial Information to Map Canopy Damages from Selective Logging and Forest Fires. Remote Sensing of Environment. 98. 329-343.

Souza Jr, C.; Veríssimo, A.; Micol, L. & Guimarães, S. 2006.Transparência Florestal do Estado de Mato Grosso (*Forest Transparency Bulletin)* N. 2, Sep 2006.