TITLE: —Are Brazil's Deforesters Avoiding Detection?"

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Abstract:

Rates of deforestation reported by Brazil‘s official deforestation monitoring system have declined dramatically in the Brazilian Amazon in recent years. Much of Brazil‘s success in its fight against the clearing of monitored forests stems from a series of policy changes put into place between 2004 and 2008. In this research we suggest that one of these policies, the decision to use the country‘s official system for monitoring forest loss in the Amazon as a policing tool, may have incentivized landowners to deforest in ways and places that evade the monitoring and enforcement system. As a consequence, we argue that recent successes in protecting monitored forests in the Brazilian Amazon may be doing less to protect the region‘s forests than previously assumed.

KEYWORDS

Brazil Amazon Deforestation Greenhouse Gas Emissions

Introduction

According to the PRODES deforestation monitoring system, forest loss in Brazilian Amazon dropped from more than 25,000 km² in 2003 to an average of 5,200 km² yr between 2009 and 2013 (INPE, 2015). This decline has been widely hailed as a success story in environmental policy in Brazil (Gibbs et al., 2015; Nepstad et al., 2014; Soares-Filho et al., 2014; Walker et al., 2009). Non-official indicators of forest loss, however, do not necessarily support this success story.

In this research we show that in 2008, after the Brazilian government began using PRODES for enforcements, observations of deforestation dropped significantly in PRODES but not in two unofficial measures of forest loss. We argue that this divergence owes to a transformation in the use of PRODES, which altered landowners‘ clearing strategies. We estimate that as much as 9,000km² of forest loss since 2008 may have leaked to areas unobserved by PRODES, due to changes in how landowners view and interact with the PRODES system.

Governing Forest Loss

Starting in 2004, government and non-governmental groups began implementing numerous interventions to reduce deforestation in the Brazilian Amazon. Over the 2004 to 2007 period, the

Federal Government of Brazil implemented the first phase (i) of the Plan for Preventing and Controlling Deforestation in the Amazon (PPCDAm). PPCDAm i created vast expanses of protected areas (Arima et al., 2014; Soares-Filho et al., 2006); a new agency to manage them (Instituto Chico Mendes); a restructured Brazilian Environment and Natural Resources Institute (IBAMA), to focus exclusively on enforcement and regulation; and initiated the use of ‗real-time' deforestation data to investigate new clearings (Brazil, 2013). Around the same time, in response to the rise in deforestation rates earlier in the decade, private companies and NGOs came together to organize a series of interventions to limit deforestation associated with the soy, beef, and timber supply chains. These interventions, combined with a shift in market favorability for key land uses in the Amazon, led to a substantial drop in deforestation after 2006 (Gibbs et al., 2015; Nepstad et al., 2014).

In 2008, in response to a slight rise in deforestation rates, the Brazilian government initiated a second phase of PPCDAm. PPCDAm ii offered new tools for environmental monitoring and enforcement (Abman, 2014; Assunção et al., 2012). This included using the widely regarded PRODES system as a tool for enforcing environmental laws in the Amazon. Under PPCDAm ii, counties with high levels of forest loss (as measured through PRODES) were subjected to credit restrictions (Duchelle et al., 2014). PRODES deforestation data were also matched with property data to identify the owners of newly cleared areas, or individuals who violated local environmental laws. Thereafter, the owners of land observed as deforested in PRODES could face fines, property embargoes, or even imprisonment (Arima et al., 2014; Assunção et al., 2012).

PPCDAm ii had a substantial and near immediate effect on deforestation as measured by the PRODES system—deforestation fell from 12,000km² in 2008 to just 5,000km² per year in each year since. The program has been hailed for reducing deforestation in the Brazilian Amazon (Arima et al., 2014; Assunção et al., 2012). One source of suggestive evidence of the effect of PPCDAm ii on

deforestation has been the rise of deforestation in other regions of Brazil (Morton et al., 2016) and neighboring South American nations over the same period (de Waroux et al., 2016; Graesser et al., 2015). However, the incomplete scope and extent of forests and deforestation monitored by PRODES means that there was also a potential for an additional response to enforcement, namely deforestation tailored to avoid detection by PRODES. PRODES has never monitored forest of the Amazon biome that are dry or secondary and it does not monitor cleared patches below 6.25 Ha (Asner et al., 2005; Broich et al., 2009; Hansen et al., 2008; INPE, 2013; Rosa et al., 2012; Souza Jr et al., 2003; Souza Jr et al., 2013; Toomey et al., 2013). In the following section we show that, following 2008, a pattern emerged in which deforestation shifted to all three types of forested areas of the Brazilian Amazon unmonitored by PRODES.

Multiple comparisons show divergence between PRODES and other deforestation data after 2008

If the transformation of the PRODES system into a tool for identifying deforesters and enforcing environmental law affected its ability to provide a consistent measurement of forest loss, then (1) PRODES deforestation rates should correlate with other metrics before 2008, but diverge after 2008; and (2) divergence should be greatest in areas where landowners would be most aware of the PRODES system and its importance for enforcing environmental laws, and have the greatest incentive to avoid detection. We show evidence of both of these trends through several analyses. In this section we compare annual trends in deforestation data in PRODES vs. two other datasets (Global Forest Change (GFC) dataset (Hansen et al., 2013) and Fire Information for Resource Management Systems (FIRMS, 2015)); analyzing where, when and how these datasets diverge; and examine the spatial patterns which underlie their divergence.

PRODES deforestation diverged from other deforestation indicators after 2008

From 2002-2008, PRODES estimated that, on average, approximately 19,000km² of forest were lost annually in the Amazon Biome. Deforestation was highest from 2002 to 2005, when forest loss rates exceeded 20, 000km² per year. Rates then fell over the course of 2006 to 2008 to approximately 10,000km². After PPCDAm ii, they fell even further, to 5,000km² per year.

From 2002 to 2008, the Global Forest Change data estimated that, on average, about 20,000km² of forest were lost per year. Just as with PRODES, GFC recorded the highest forest loss rates during the early part of the decade. Rates then dropped in 2006 and 2007, to approximately 15,000km² per year. However, loss rates did not drop to the same extent as the PRODES estimates. From 2009 to 2013 deforestation rates in the GFC data remained around 10,000km² per year, or roughly double PRODES levels. Significant deforestation spikes occurred in 2010 and 2012, when loss rates increased to approximately 15,000km² per year.

The FIRMS data follow the GFC data. Fires were prolific during the early 2000s. The number of fire incidents reached a nadir in 2005, but fell to lower levels in 2006. From 2009 to 2013, the number of fires recorded per year fell, on average, fell to less than half of levels observed earlier in the decade. Significant spikes in fire incidents were observed in 2010 and 2012, the same years for which deforestation spikes were observed in the GFC data.

A paired t-test of annual differences in deforestation in the Amazon Biome revealed no significant difference between the PRODES and GFC data for the years 2002 to 2008 ($t = 0.73$; $df = 6$, $p = 0.49$). The same test revealed a sharp divergence in the datasets over the period 2009-2014 ($t = 5.19$; $df = 4$; $p = 0.0066$). The GFC and FIRMS data show similar trends over this latter period.

Sources of PRODES divergence

Much of the difference between the GFC and the PRODES classifications stemmed from clearings in small patches, the clearing or destruction of scrub or riverine forests, and secondary forest clearings (Table S10 in SI). Annually, per the GFC data, approximately 5,000-6,000km² of forest was

deforested in plots smaller than 6.25ha, the minimum threshold for inclusion in the PRODES based statistics (Table S4). Deforestation rates in the drier portions of the biome, or in riverine areas, also remained steady across the entirety of the time period. In total, we estimated that about 500km² of GFC forest loss occured each year in areas which PRODES pre-classifies non-humid forest. Another 2,500km² of forest is cleared in areas classified as already deforested in the PRODES data. Deforestation in these areas was not deterred by PRODES, given that these areas were not monitored under the PRODES system (see Figure 1 for several illustrations of these clearings).

Approximately 73% of forest loss reported by PRODES was identified as forest loss by the GFC dataset. However, only 51% of total GFC forest loss (2001-2013) was reported in PRODES during the period 2002-2013 (see SI). Much of the difference between the GFC and the PRODES classifications stemmed from clearings in small patches, the clearing or destruction of scrub or riverine forests, and secondary forest clearings (Table S10 in SI). Annually, per the GFC data, approximately 5,000-6,000km² of forest was deforested in plots smaller than 6.25ha, the minimum threshold for inclusion in the PRODES based statistics (Table S4). Deforestation rates in the drier portions of the biome, or in riverine areas, also remained steady across the entirety of the time period. In total, we estimated that about 500km² of GFC forest loss occurs each year in areas which PRODES pre-classifies non-humid forest. Another 2,500km² of forest is cleared in areas classified as already deforested in the PRODES data.

Locations of PRODES divergence

Several clear spatial differences emerged when comparing the GFC and PRODES data. To highlight these differences, we aggregated deforestation pixels from both the PRODES and GFC data into a layer of 30km x 30km grid cells (n=4931). Had the divergences between the GFC and PRODES datasets been attributable to systemic error, the differences would be randomly distributed

across the region. The differences between the PRODES and GFC data, however, are clearly concentrated in several key regions.

The largest discrepancies between the GFC and PRODES data were found in northern Mato Grosso, where a thriving soybean sector is creating high demand for land; and in northeastern Pará, where investments in cattle processing, soybean production (in the region around Paragominas) and palm oil production are transforming the region into one of the most rapidly growing rural economies in the Amazon (Figure 2). We argue that these areas are those where landowners would have both the greatest incentives to avoid detection, and be more likely to have knowledge on how to avoid the monitoring system.

In the mid-2000s, the States of Pará and Mato Grosso began requiring large landowners to register their properties in their Rural Environmental Registry, known more commonly as CAR (Azevedo and Saito, 2013; Chomitz and Wertz-Kanounnikoff, 2005; Richards and VanWey, 2016). To register in the CAR system, property owners needed to create geospatial information on property boundaries and forest cover. To accomplish this task, many landowners sought the help of technical experts knowledgeable in geospatial data. In addition to creating the data needed for the CAR, these experts also needed to understand local environmental laws and the official forest classifications. By extension, we would expect that many of the more-capitalized farms in Mato Grosso and northeastern Pará would have had more knowledge of the country‘s monitoring systems, and more importantly, how their land (and potential land acquisitions) is classified in PRODES.

These same landowners would have also had a stronger incentive to open new lands. Opening new land has long been seen as a key means for increasing property values. The greatest returns to opening new land may be in these higher valued regions in north-central Mato Grosso, and in northeastern Pará. Landowners in these areas, presumably, would thus have had both the greatest incentive to continue opening land, and more awareness with respect to which lands could be opened

without triggering a deforestation observation. Smallholder farmers and ranchers, in contrast to their more capitalized counterparts, may not have had access to the same technical knowledge. They also would have had less incentive to avoid deforestation detection. Small farming areas are less likely to be subject to environmental enforcement, despite higher rates of forest loss (Godar et al., 2014; Richards and VanWey, 2016; Schneider and Peres, 2015).

Implications for Deforestation Accounting

To estimate the amount of deforestation missed by PRODES, as forest clearing leaks to unobserved portion of the Amazon Biome, we performed a differences-in-differences analysis of deforestation levels using the layer of 30km x 30km grid cells. The results reveal a significant negative bias effect on PRODES deforestation in years following 2008 ($p<0.01$). The results also offer a counterfactual measure of deforestation, or a proxy estimate deforestation ―dst" due to the new enforcement application of PRODES. In total, we estimate that nearly 9,000km² of deforestation has been missed by the PRODES system, due to local level incentives to avoid observation. This area corresponds to an area roughly the size of Puerto Rico (See Figure 3; full regression results and alternative specifications are included in the SI).

PRODES-derived greenhouse gas emissions estimates increasingly inaccurate

PRODES is used as the basis for greenhouse gas emissions estimates for Brazilian forest loss, and thus as an important part of Brazil's climate change mitigation policy. A downward distortion in deforestation levels therefore carries implications for Brazil's greenhouse gas emissions. To illustrate the implication of using PRODES, as opposed to an unofficial and universal indicator of forest loss as the basis for emissions accounting we estimated post-2008 emissions using both the GFC and PRODES datasets, and two widely cited measures of above ground live biomass: the Amazon Basin Aboveground Live Biomass (ABALB) distribution map (Saatchi et al., 2009) and the Pantropical National Level Carbon Stock (PNLCS) dataset (Baccini et al., 2012).

Total emissions from Amazon deforestation based on the GFC data are nearly twice as high as estimates based on PRODES. GFC-based greenhouse gas estimates suggested that more than 500Tg of carbon were released through deforestation in the Amazon Biome over the 2009-2013 period. Estimates using the same methods and the PRODES data suggested approximately 250Tg of emissions (see SI). Estimated losses in emissions *per hectare*, however, were significantly higher for PRODES statistics (93.16t to 98t/ha) than for the GFC data (82.5 to 84.8t/ha). This follows intuitively, given that the PRODES data only considers deforestation of relatively biomass-rich regions, while the GFC data also accounts for forest loss on relatively biomass-poor secondary and scrub forests.

Conclusion

PRODES does an admirable job of meeting its objectives, albeit with some well-established technical shortcomings (Asner et al., 2005; Souza Jr et al., 2013). Using PRODES as a foundation for regulating forest loss in the Amazon has also likely helped to deter the clearing of large patches of primary forests. However, in this research we show that some of this deforestation has simply shifted to other portions of the Amazon Biome not monitored by PRODES. We thus suggest that since 2008, PRODES monitored deforestation has become less representative of all deforestation in the Brazilian Amazon and therefore has become less accurate as a component of the system Brazil uses to estimate GHG mitigation from avoided deforestation.

This article is not a specific critique of PRODES nor an argument that GFC (Tropek et al., 2014) or FIRMS are suitable replacements; rather it is a general warning about the increased challenges to accurate monitoring of deforestation in the presence of strong enforcement activities reliant on the same monitoring scheme. We expect that the more stringent the enforcement tied to PRODES, the less accurate the PRODES estimate of annual forest loss can be expected to be. Thus

as enforcement tightens to meet Brazil‘s GHG and deforestation policy objectives, we expect that PRODES forest loss estimates will become progressively less accurate as the basis for Brazil‘s accounting of GHG emissions from deforestation.

We see two solutions to the problem we have identified. First, the development of next generation deforestation monitoring systems with more reach, higher resolution, and better accuracy will be critical, especially for emissions monitoring. Notably, many of the limitations on data processing, spatial resolution, and data access which the original architects of PRODES once faced no longer exist. Landsat 8 features newer, and higher resolution imagery, and ultra-high resolution data are becoming increasingly available at greater temporal frequencies. Forest loss monitoring could be updated to be made more dynamic with respect to reporting (a) non-anthropogenic forest loss, (b) the loss of secondary forests, (c) the forest loss in the drier portions of the basin, and (d) forest degradation, or forest loss in small clearings. Second, monitoring systems and enforcement mechanisms should be separated. Tying the enforcement of environmental laws explicitly to a tool for scientific monitoring distorts landowners‘ clearing incentives, and pushes clearing activities to areas less likely to be observed. This has the perverse impact of overstating any deforestation reductions associated with new enforcement tools. Transparently achieving Brazil‘s GHG mitigation commitments will require more than the antiquated and incomplete approach to tropical forest monitoring that is the status quo. Our findings suggest that a focus on large patches of primary forests is likely to leave Brazil far from truly ending deforestation and far from ready to transfer a system for ending tropical forest loss to other developing countries. While Brazil can rightly celebrate the reduction in large-scale clearing of primary forest, continued clearing threatens the country‘s ambitious targets. It is time to develop a new system that tackles the problem of illegal deforestation comprehensively by monitoring the cerrado, secondary forests, and the persistent number of small clearings.

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Figure 1

Title: Deforestation and Fire in Mato Grosso, Brazil

Caption: Close up examples of land clearing classifications in three areas of Mato Grosso Brazil. Post deforestation classifications by GFC are shown in black; PRODES deforestation classifications are in blue; FIRMS fire incidents are marked with yellow dots. At left, a large area in the center of the image is burned and marked as deforested in the GFC data, but PRODES records no clearing. In PRODES, this area was masked from monitoring as "non-forest". At center, an area marked as already deforested in PRODES is classified as burned and cleared in the FIRMS and GFC datasets. At right, small clearings associated with logging are observed in the GFC dataset but not in PRODES. Fire is sparsely used in logging operations, and no fires are observed in these areas.

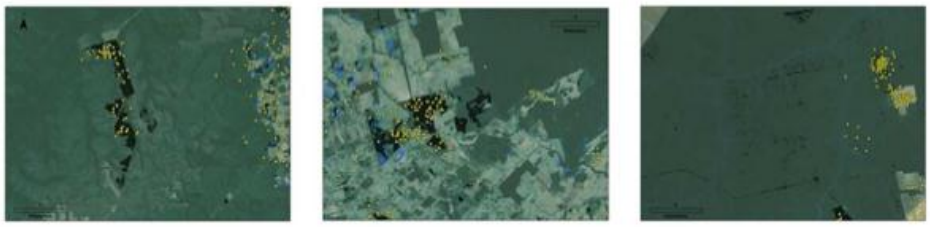

Figure 2

Title: Spatial distribution of differences between deforestation observed in GFC and PRODES deforestation classifications after 2008.

Caption: Differences in total observed deforestation, in 30km² grid cells, in GFC and PRODES data from 2009-2013. Darker shades indicate the largest levels of discrepancies between the official and unofficial deforestation indicators. The greatest differences are found in Northeast Pará State and North-Central Mato Grosso.

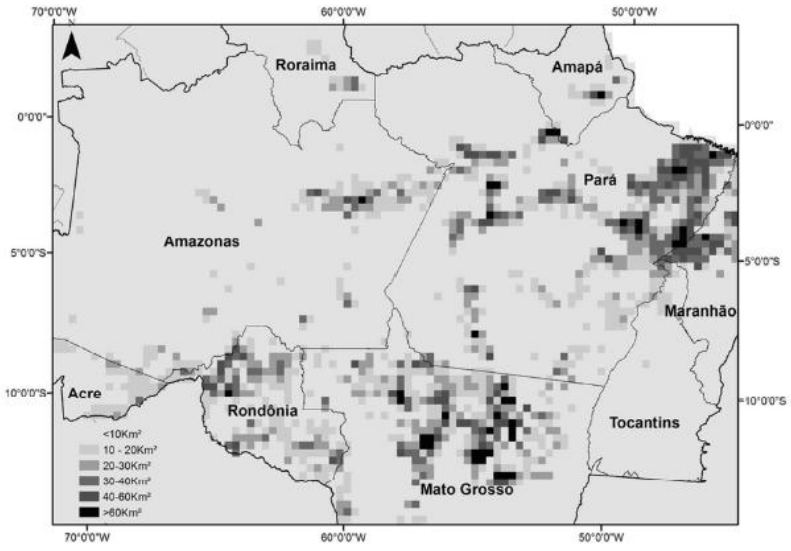

Figure 3.

Title: PPCDAm ii caused PRODES to underestimate 900,000 hectares of deforestation

Caption: A differences in differences analysis revealed PRODES and GFC to have had similar trends in deforestation between 2003 and 2008, but that PRODES deforestation declined while GFC deforestation did not post 2008. The finding is consistent with our hypothesis that deforesters sought to avoid PRODES, but not GFC monitoring. The red segments depict the GFC deforestation rate over the two periods as predicted by our statistical analysis. The blue segments depict the PRODES deforestation rate over the two periods as predicted by our statistical analysis. The grey segment depicts a counterfactual of the PRODES deforestation rate over the period 2008-2012 had it been the same as the GFC rate over the period. The results of the counterfactual simulation reveal an estimated discrepancy of greater than 900,000 hectares over the period.