COMPARISON AMONG TIME SERIES MAPS OF DEFORESTATION IN THE AMAZON: HOW INDEPENDENT MONITORING SYSTEMS RELATE TO OFFICIAL DATA

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ABSTRACT

This study compares raster maps of Amazon deforestation during annual time intervals from 2008 to 2020 that derive from three sources: Global Forest Change (GFC), MapBiomas, and PRODES. We perform pairwise map overlays between PRODES and each of GFC and MapBiomas. Each overlay generates a square contingency table, which reveals Misses, Hits, and False Alarms. GFC shows more deforestation than PRODES while MapBiomas shows less deforestation between 2008 and 2020. Both MapBiomas and GFC have more disagreement than agreement with PRODES. False Alarms constitute 64% of GFC's deforestation and 27% of MapBiomas's deforestation with respect to PRODES. GFC missed 8% of PRODES deforestation while MapBiomas missed 33% between 2008 and 2020. We report Misses, Hits, and False Alarms for each of the 13 years.

Key words — Amazon, deforestation, monitoring system, concordance.

1. INTRODUCTION

The intensification of human activities has altered forest characteristics, including species composition, diversity, and abundance, compared to its natural state, affecting the supply of ecosystem services such as climate regulation at global and regional scales, watershed regulation, conservation of indigenous cultures, and human health [1]. In addition, in the Amazon biome, carbon emissions from forest degradation and deforestation have been increasing in recent years, compromising its resilience [2] and ability to remove carbon from the atmosphere [3].

The deforestation rate of the primary forest in the Amazon showed a reduction of more than 80% from 2004 to 2012 [4], according to official data generated by the Program for Monitoring the Brazilian Amazon Forest by Satellite (PRODES) [5]. The reduction was due to coordinated efforts of federal, state, and municipal agencies, such as the creation of protected areas and homologation of indigenous lands [6]. An important component for combating deforestation was monitoring data from the Real-Time Deforestation Detection System (DETER) [7], which has generated daily deforestation alerts since 2004 so that environmental agencies can carry out faster and more coordinated enforcement operations to identify and punish violators. Subsequently, other alert systems emerged, such as the Deforestation Alert System (SAD) [8], the Radar Indication System of Deforestation in the Xingu Basin (SIRAD X) [9], and MapBiomas Alert [10] as independent sources of information about forest loss in the Amazon biome.

With the advancement of cloud data processing technologies, several other monitoring initiatives have emerged at regional and global scales as data sources that map forest land use and occupation dynamics. Global Forest Change (GFC) [11] was one of the first global initiatives to produce data on forest extent, loss, and gain using satellite images from the Landsat sensor. The MapBiomas Project [12] performs the mapping of a time series of land use and land cover of the Brazilian biomes also using Landsat images through the Google Earth Engine platform [13], producing a series of deforestation and secondary vegetation data from the annual transitions of the maps.

Several sources of monitoring data for the Amazon biome indicate the occurrences of forest loss so that public policies can be adopted to contain the advance of deforestation, while official deforestation rates show consecutive increases since 2013 [14]. Our study evaluates deforestation at the pixel level of the MapBiomas and Global Forest Change initiatives concerning the PRODES data, quantifying the agreement and disagreement between them in the Amazon biome region from 2008 to 2020.

2. MATERIAL AND METHODS

2.1. Study area

The Amazon biome is the largest of the six Brazilian biomes, with an area of approximately 4 million km², corresponding to 49% of the national territory [15] (Figure 1). This region is our study area because it is the biome with the highest deforestation rates among all biomes [16] and has the historical deforestation data series from various sources and mapping scales.

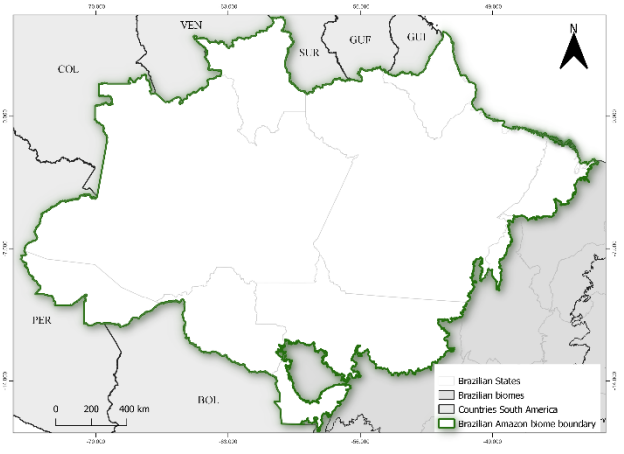

Figure 1. Map of the study area about the Brazilian Amazon biome located in South America.

2.2. Database

We used as reference data the deforestation information by PRODES from 2008 to 2020. The beginning of the time series is 2008 because 2008 is the year that the National Institute for Space Research (INPE) makes the PRODES data available annually in raster format. We acquired independent data sources from Collection 7 of the MapBiomas project and the GFC, both in raster format. The datasets were inserted into the Google Earth Engine platform to compare map pairs, using PRODES as the reference data.

The method for comparing the maps considered deforestation a Present or Absent during each year. A square contingency table was constructed with four central entries: Hits, False Alarms, Misses, and Correct Rejections (Table 1). Hits are where the two datasets agree on presence of deforestation. False Alarms are commission of deforestation. Misses are omission of deforestation. Correct Rejections are where the two datasets agree on absence of deforestation [17].

		Reference		
		Presence	**Absence**	**Sum**
Diagnosed	**Presence**	Hits	False Alarms	Diagnosed Presence
	Absence	Misses	Correct Rejections	Diagnosed Absence
	Sum	Reference Presence	Reference Absence	Extent

Table 1. Contingency table for a binary variable.

3. RESULTS

From the contingency table (Table 2), we quantify pixel occurrences for the Hits, False Alarms, Misses, and Correct Rejections categories for the time interval from 2008 to 2020. Where GFC shows deforestation, 64% is False Alarms according to PRODES. Where MapBiomas shows deforestation, 27% is False Alarms according to PRODES. GFC missed 8% of PRODES deforestation while MapBiomas 33% of PRODES deforestation. Hits are smaller than the disagreement for both GFC and MapBiomas.

		PRODES		
		Deforestation	**Other**	**Sum**
GFC	**Deforestation**	81	188	**269**
	Other	25	4452	**4,477**
	Sum	**107**	**4,641**	**4,747**
MapBiomas	**Deforestation**	59	39	**98**
	Other	48	4602	**4,650**
	Sum	**107**	**4,641**	**4,747**

Table 2. Contingency table of the millions pixels from PRODES compared to GFC and MapBiomas during from 2008 to 2020.

Figure 2 shows that the GFC data has more False Alarms than the size PRODES deforestation. The False Alarm Quantity component shows how much more deforestation GFC shows compared to PRODES. On the other hand, MapBiomas shows less deforestation than PRODES, as the Miss Quantity component shows. Hits account for a larger proportion of the MapBiomas bar than the GFC bar in figure 2.

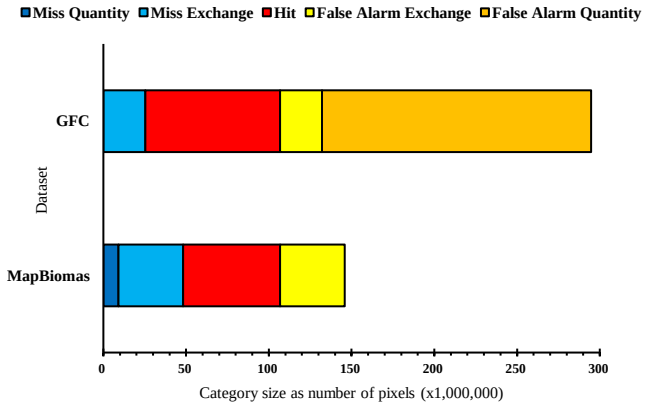

Figure 2. The number of pixels as Misses, Hits, and False Alarms for GFC and MapBiomas with respect to PRODES.

Figure 3 shows the spatial distribution of Misses, Hits, and False Alarms. GFC has a high occurrence of False Alarms in the northeast, southwest, and central regions of the Amazon biome while MapBiomas has more Misses scattered around the map. Hits have a similar spatial pattern in both the GFC and MapBiomas, with the highest occurrences in the central-eastern and southwestern regions.

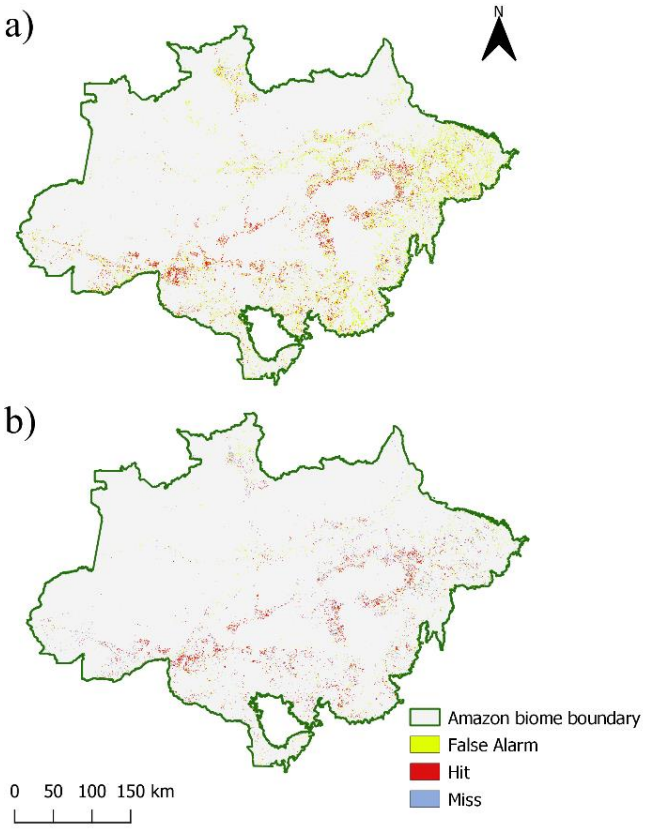

Figure 3. Deforestation data overlay map between a) PRODES and GFC; and b) PRODES and MapBiomas.

Figure 4 shows the size of Misses, Hits, and False Alarms during each year. False Alarms are greater than Misses during all years for GFC, which indicates GFC shows more deforestation than PRODES during all years. Misses are greater than False Alarms during many years for MapBiomas, which indicates MapBiomas shows less deforestation than PRODES during many years. GFC's overestimation of deforestation and MapBiomas' underestimation causes Hits to be greater for GFC than MapBiomas for all years.

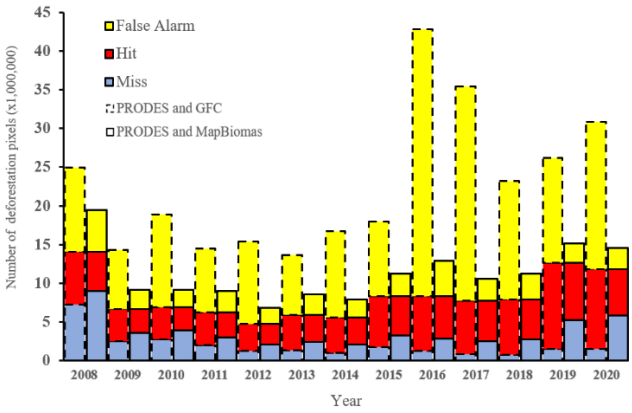

Figure 4. Number of Miss, Hit, and False Alarms pixels for each map pair.

4. DISCUSSION

Both the GFC and MapBiomas data indicated greater occurrences of deforestation mapping disagreement than agreement with the PRODES data. The divergences between the independent monitoring systems and the reference data may be associated with methodological differences between the systems. For example, GFC uses the time interval from January to December to map the areas of forest loss, while MapBiomas also uses the same time interval to generate its annual land use and land cover maps, from which it derives the deforestation data from the transitions between forest classes for uses such as agriculture and pasture. PRODES, on the other hand, uses the calendar from August to July as the deforestation calendar, concentrating on detecting forest loss in the Landsat scenes from June to August, considering the Amazon summer and less cloud cover on the images.

PRODES uses, in addition to Landsat images, data from the Sino-Brazilian CBERS-2/2B, the Indian IRS-1, and the England UK-DMC2 satellites. Although the further use of these sensors may contribute to deforested areas that MapBiomas and GFC do not detect or detect late, we characterize them as Misses in this study because the independent monitoring systems use Landsat images in their monitoring exclusively.

Another methodological difference between the systems refers to the minimum area mapped. PRODES considers deforestation to be the clear-cutting of forests larger than 6.25 hectares, while MapBiomas detects areas starting at 1 hectare, and GFC captures forest losses larger than 0.09 hectares. Therefore, a fraction of the False Alarms mapped by GFC and MapBiomas may be associated with early-stage forest loss or conversion to use with areas smaller than what PRODES can detect. In this case, a quantitative and qualitative assessment is needed to investigate the deforestation pixels from the monitoring systems not agreeing with the reference data [18].

PRODES and MapBiomas consider deforestation the loss of primary forest, whereas GFC quantifies tree cover loss, including forest plantation rotations, fires, logging, and natural disturbances [19]. This broader definition of forest from GFC may be expressed in the quantities of pixels classified in the False Alarm Quantity component in Figure 2, representing a larger area of change than PRODES and MapBiomas detected in the analyzed time interval. In addition, the error metrics of these globalized surface products vary by geographic region and validation datasets used [20].

Further studies are needed to understand the causes of the differences between independent monitoring data and PRODES. The False Alarms may indicate, for example, both an overestimated deforestation by the independent systems and the underestimation of deforestation by PRODES. The quantitative differences presented in this study should be presented clearly and objectively for users of this information

so that they know the limitations and potentials of each data source.

5. CONCLUSIONS

The study reveals that both GFC and MapBiomas disagree more than they agree with PRODES. GFC shows more deforestation than PRODES, while MapBiomas shows less deforestation than PRODES from 2008 to 2020. Contingency tables and stacked bar figures express the differences between the GFC and MapBiomas data with respect to PRODES. False Alarms constitute 64% of GFC's deforestation and 27% of MapBiomas's deforestation with respect to PRODES. GFC missed 8% of PRODES deforestation, while MapBiomas missed 33% of PRODES deforestation from 2008 to 2020.

The largest differences between GFC and PRODES are False Alarms during the years 2016 to 2020. MapBiomas showed the greatest differences as Misses during 2008, 2019, and 2020.

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