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Article

The Soy Moratorium in the Amazon Biome Monitored by Remote Sensing Images

Bernardo Friedrich Theodor Rudorff [1,⋆], Marcos Adami [1], Daniel Alves Aguiar [1], Maurício Alves Moreira [1], Marcio Pupin Mello [1], Leandro Fabiani [2], Daniel Furlan Amaral [3] and Bernardo Machado Pires [3]

[1] Remote Sensing Division (DSR), National Institute for Space Research (INPE), Av. dos Astronautas, 1758, São José dos Campos, CEP: 12227-010, São Paulo, Brazil; E-Mails: adami@dsr.inpe.br (M.A.); daniel@dsr.inpe.br (D.A.A.); mauricio@dsr.inpe.br (M.A.M.); mello@ieee.org (M.P.M.)

[2] Globalsat Agriculture Monitoring, Av. Joaquim de Oliveira, 838, Rondonópolis, CEP: 78740-044, Mato Grosso, Brazil; E-Mail: leandro@globalsat.agr.br

[3] Brazilian Association of Vegetable Oil Industries (ABIOVE), Av. Vereador José Diniz, 3707, São Paulo, CEP: 04603-004, São Paulo, Brazil; E-Mails: daniel@abiove.org.br (D.F.A.); bernardo@abiove.org.br (B.M.P.)

⋆ Author to whom correspondence should be addressed; E-Mail: bernardo@dsr.inpe.br ; Tel.: +55-12-3208-6490; Fax: +55-12-3208-6488.

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Abstract: The Soy Moratorium is a pledge agreed to by major soybean companies not to trade soybean produced in deforested areas after 24th July 2006 in the Brazilian Amazon biome. The present study aims to identify soybean planting in these areas using the MOD13Q1 product and TM/Landsat-5 images followed by aerial survey and field inspection. In the 2009/2010 crop year, 6.3 thousand ha of soybean (0.25% of the total deforestation) were identified in areas deforested during the moratorium period. The use of remote sensing satellite images reduced by almost 80% the need for aerial survey to identify soybean planting and allowed monitoring of all deforested areas greater than 25 ha. It is still premature to attribute the recent low deforestation rates in the Amazon biome to the Soy Moratorium, but the initiative has certainly exerted an inhibitory effect on the soybean frontier expansion in this biome.

Keywords: MODIS; satellite images; aerial survey; soybean; Brazilian Amazon; deforestation

1. Introduction

The demand for agricultural products has induced excessive land cover change in recent years. The consequences of these changes on biogeochemical cycles of the Earth system have attributed a new focus to global change studies [1,2]. The conversion of natural forests to agricultural land has become one of the major issues of current debate on global changes [3]. The three causes that currently explain more than 90% of tropical forest conversion in the world are agricultural frontier expansion, wood extraction and infrastructure development [4,5].

Deforestation in the Amazon biome has received increasing attention due to carbon emission and biodiversity loss [6–8]. The deforestation dynamic in the Brazilian Legal Amazon has been monitored by remote sensing imagery since 1988 [9]. The high rates of deforestation observed during this period can be associated to both economic growth and global demand for food [10–19]. Currently, 7.5% (1.7 million ha) of Brazilian soybean is planted in the Amazon biome [20]. To reduce deforestation in response to soybean expansion in the Brazilian Amazon, a campaign was launched in 2006 involving organizations of civil society and companies linked to the soybean commodity that resulted in the announcement of the Soy Moratorium: Soybean produced in legal or illegal deforested areas, after 24th July 2006, would not be bought by the Brazilian Association of Vegetable Oil Industries (ABIOVE) and the National Association of Cereal Exporters (ANEC). This moratorium agreement has been renewed annually and, since 2009, satellite remote sensing imagery has been used to assist the identification of soybean crops in deforested areas after 24th July 2006.

The present study aims to identify soybean crop in deforested areas of the Brazilian Amazon biome based on remote sensing satellite images to detect the presence of annual crops, in a first step, and on aerial survey and field inspection to identify soybean crop, in a second step. Specific objectives were: *(i)* select the deforested polygons, from the PRODES project, that were deforested during the Soy Moratorium period; *(ii)* detect the presence of annual crops within these polygons using MOD13Q1 product and TM/Landsat-5 images; and *(iii)* identify the soybean fields among the annual crops through aerial survey and field inspection.

2. Background

2.1. Land Use Conversion to Agricultural Areas in the Amazon Biome

Deforestation in the Amazon is a process that normally starts with selective logging of species with high economic value followed by the burning of remaining forest [21]. Fire is largely used by small farmers because it requires less labor and machinery and has the advantage of incorporating nutrients in the soil [22–24]. The recently burned land is then used to produce crops for subsistence agriculture for some years until the natural soil fertility is depleted. While the land is no longer productive it will be left fallow for about fifteen years when a new cycle is started [25].

For large farmers the presence of roads and the price of agricultural products are major factors that influence the conversion of forest to agricultural land. In a scenario of medium to low prices the burned forest land will be used during some years for cattle grazing. Years later when the land is fully cleared, it might be used for intensive agricultural production in a year with favorable crop prices. On the other hand, under a scenario of good prices the recently deforested land will first be cropped with rice for one or two years to fully clear the land, and then used for soybean production. When soybean prices are very attractive the recently deforested land will be intensively mechanized for land clearing and soybean will be cultivated in the first year immediately after deforestation [13].

Soybean is planted by farmers on different dates using early, medium and late maturing varieties to minimize losses due to abnormal climatic events. During the soybean sowing period the EVI (Enhanced Vegetation Index derived from MODIS images) values are expected to vary between 0.05 and 0.20. As the crop develops EVI values will increase with maximum EVI values normally above 0.60. Minimum and maximum EVI values will vary according to planting date and soybean cycle duration [26–28].

2.2. MODIS Data to Identify Agricultural Areas

Landsat images with spatial and temporal resolutions of 30 m and 16 days, respectively, have been shown to be useful for routine mapping of semi-perennial (e.g., sugarcane [29]) and perennial crops (e.g., coffee [30]) in Brazil. For annual crops with relatively short growth cycle during persistent cloud cover, especially in tropical regions [31–33], these images have limited use for mapping purposes.

Cloud-free image acquisition can be partially solved by increasing temporal resolution such as the Moderate Resolution Imaging Spectroradiometer (MODIS), on board Terra and Aqua satellites that acquire images on an almost daily basis. The radiometric image characteristics of the MODIS products are of good quality with atmospheric and geometric corrections that allow performing time series analyses [34,35]. The high temporal resolution compromises the spatial resolution that is moderate with 250 m at nadir; however, this is not a major shortcoming for the identification of soybean crops cultivated in large areas. For example, when comparing mapping results obtained with MODIS images and those supplied by the National Agricultural Statistics Service (NASS) of the United States of America, Chang *et al.* [36] observed a 6 and 4% difference for corn and soybean, respectively. Wardlow *et al.* [37] investigated the applicability of MODIS images to discriminate agricultural crops from other land uses and concluded that the 16-day mosaics provided good results. These authors also observed that MODIS images can provide information on vegetation phenology and on regional climactic characteristics. In Brazil, Rudorff *et al.* [38] assessed the potential of MODIS images to identify and map the soybean crop and observed that the mapping accuracy depended on field size as was also observed by Lobell & Asner [39]. Later, Rizzi *et al.* [26] used a procedure to classify soybean areas in Mato Grosso state, Brazil, based on Enhanced Vegetation Index (EVI) images from MODIS and obtained an overall accuracy of 91%.

3. Materials and Methods

3.1. Materials

Deforested areas in the Legal Amazon are represented yearly as polygons in the PRODES project and have been evaluated since 1988 using remote sensing images [9]. Results are available on the Internet (http://www.obt.inpe.br/prodes/) including maps with the spatial distribution of the deforested polygons. In the present study we used the deforested polygons for years 2007, 2008 and 2009 which correspond to the Soy Moratorium period. Table 1 present the deforestation figures (in hectares – ha) for the states of Mato Grosso, Pará and Rondônia during this period. As shown in Figure 1, Mato Grosso state is only partially contained in the Amazon biome, but entirely contained in the Legal Amazon.

Table 1. Annual and total deforested area (ha) by states (Mato Grosso, Pará and Rondônia) within the Amazon biome since the beginning of the Soy Moratorium (Source: [9]).

State	Soy Moratorium Years			
	2007	2008	2009	Total
Mato Grosso	237,142	317,123	68,438	622,703
Pará	552,600	560,700	428,100	1,541,400
Rondônia	161,100	113,600	48,200	322,900
Total	952,849	993,431	546,747	2,487,003

Remote sensing images from the MODIS sensor on board the Terra and from the TM sensor on board the Landsat-5 satellites were used to monitor these polygons. For the MODIS images we used the 16-days composites from the MOD13Q1 product, for the period between day of year (DOY) 241 (30th August 2009) and DOY 017 (17th January 2010), of tiles h11 to h13, v09 and v10. Table 2 presents the dates of the TM/Landsat-5 images used in this study. A small airplane was used to carry out the aerial survey.

3.2. Study Area

The Amazon biome covers almost 50% of the Brazilian territory (4.2 million km^2) and is present in nine states and 553 municipalities. About 7.5% of the area in Brazil planted with soybean [20] is found in the Amazon biome with 99% concentrated in the states of Mato Grosso, Pará and Rondônia. In these three states, 52 municipalities with more than 5,000 ha soybean represent 98% of the soybean in this biome.

The criteria used to define the study area (Figure 1) were: *(i)* to be within the Amazon biome; *(ii)* to be in municipalities with more than 5,000 ha of soybean [20]; *(iii)* to be outside protected areas such as Conservation Units (based on data from IBAMA—Brazilian Institute of Environment and Renewable Natural Resources), indigenous lands (based on data from FUNAI—National Foundation of the Indian) and land reform areas (based on data from Imazon—Amazon Institute of People and Environment).

Table 2. Acquisition dates of the TM/Landsat images in 2009 used to refine the selection of polygons with annual crops.

Row	Path									
	222	223	224	225	226	227	228	229	230	Total
62	10 Aug 30 Nov	17 Aug				28 Jul 17 Nov	23 Oct 24 Nov			7
63	09 Jul 30 Nov	17 Aug				28 Jul 17 Nov				5
66		18 Sep	24 Aug 28 Nov							3
67		18 Sep 21 Nov	12 Nov	02 Oct 03 Nov	07 Sep 26 Nov	28 Jul 17 Nov	20 Aug 08 Nov	28 Sep		12
68		04 Oct 21 Nov	25 Sep 12 Nov 14 Dec	16 Sep 03 Nov	22 Aug 25 Oct 26 Nov	28 Jul 17 Nov	20 Aug 08 Nov	12 Sep	03 Sep 22 Nov	17
69		18 Sep 21 Nov	25 Sep 11 Oct 28 Nov	02 Oct 19 Nov	22 Aug 01 Oct 10 Nov	30 Sep 17 Nov	07 Oct 08 Nov	11 Aug	03 Sep 22 Nov	17
70				18 Oct 19 Nov	09 Oct 10 Nov	30 Sep 17 Nov	04 Aug 08 Nov	27 Aug		17
71						01 Nov	04 Aug 10 Dec	30 Oct		4
Total	4	9	9	8	10	13	12	5	4	74

3.3. Methods

The first step in the present study consisted of selecting the PRODES polygons that were deforested during the period of the Soy Moratorium. In a second step, remote sensing satellite images were used to detect the presence of annual crops within these polygons. In a last step, an aerial survey followed by field inspection was carried out to precisely select the soybean fields among the annual crops detected by the remote sensing images.

3.4. PRODES Deforested Polygons

The deforested PRODES polygons evaluated during the years 2007, 2008 and 2009 were selected following the criteria used to define the study area (section 3.2). The smallest size of a deforested polygon identified by PRODES is limited to at least 6.25 ha. Considering that the smallest pixel size of the MODIS images is also 6.25 ha, the smallest deforested polygon to be monitored in the present study was defined to be at least 25 ha. However, adjacent polygons deforested in different years were fused; therefore, deforestations of less than 25 ha per year were monitored if the sum of the adjacent deforestations, during the moratorium period, was greater than 25 ha. For example, Figure 2 illustrates the fusion of four adjacent polygons. Before fusion, two polygons measured less than 25 ha, but after fusion the new polygon measured more than 25 ha and consequently was monitored.

Figure 1. Selected study area based on: Amazon biome; 52 municipalities with more than 5,000 ha soybean; and outside conservation units, indigenous lands and areas of land reform.

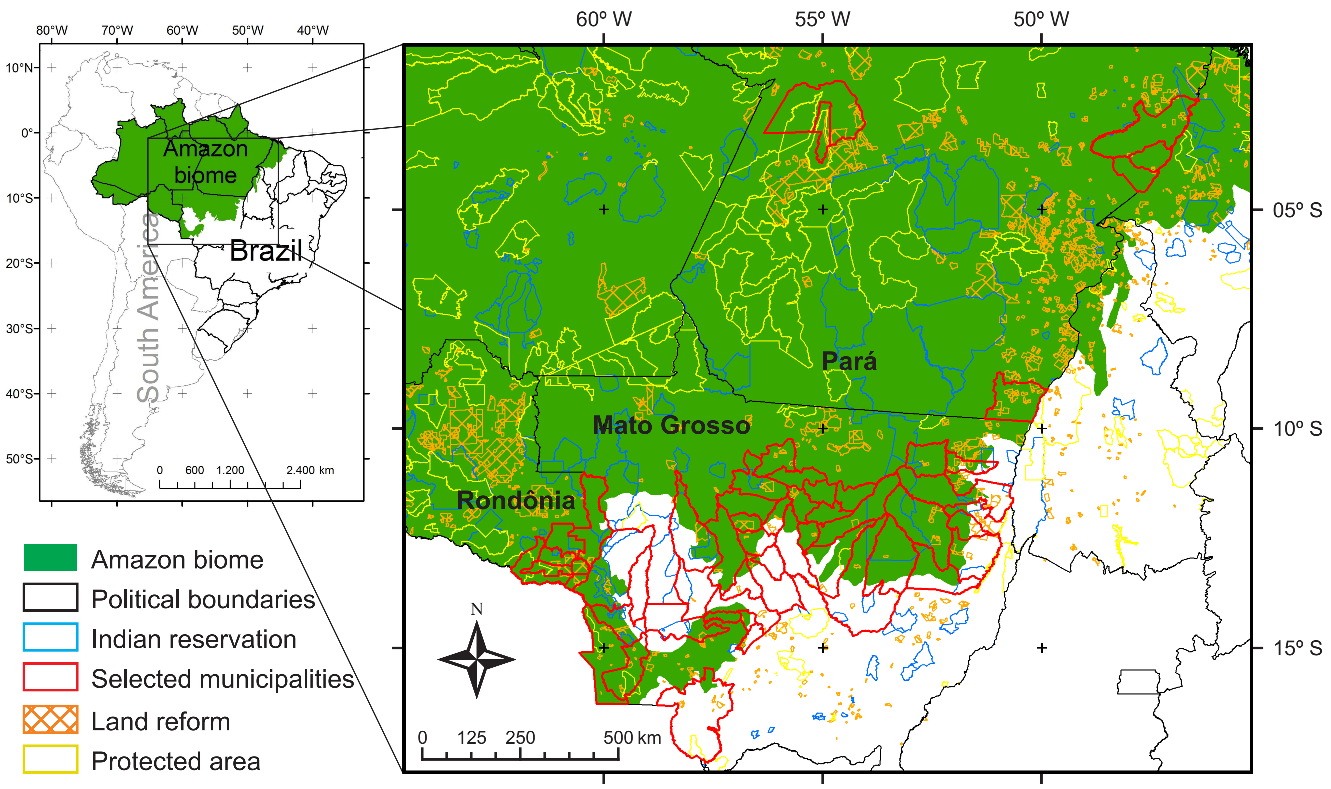
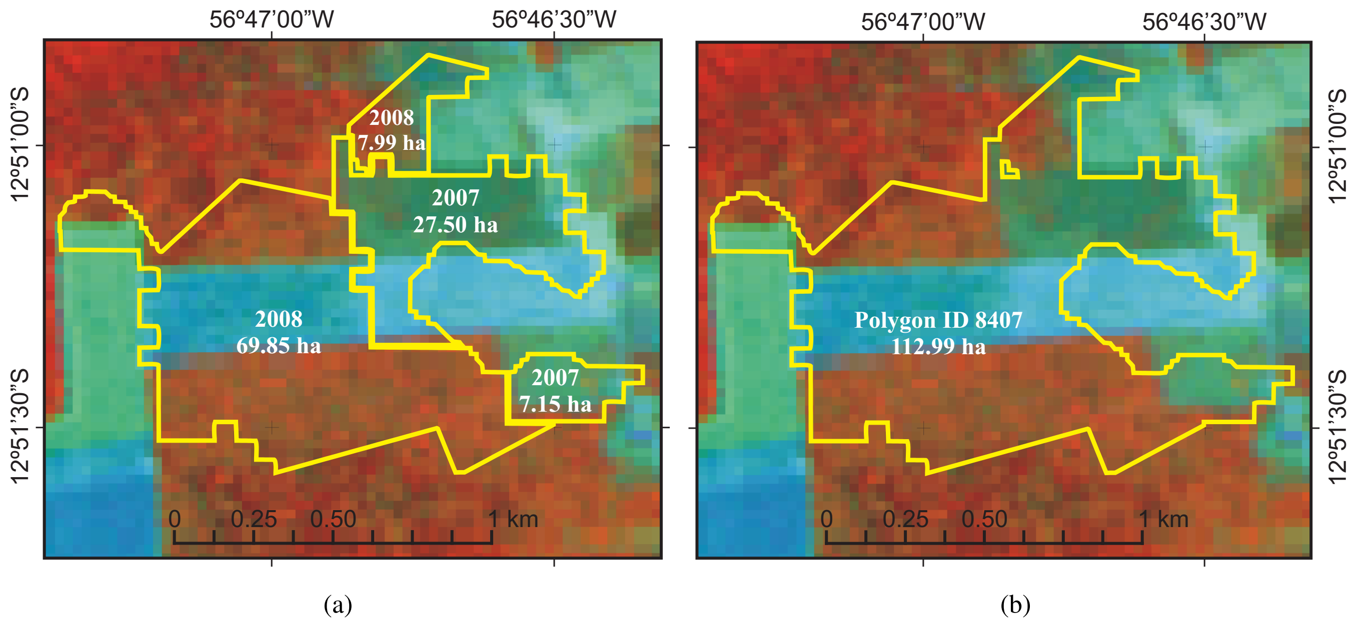


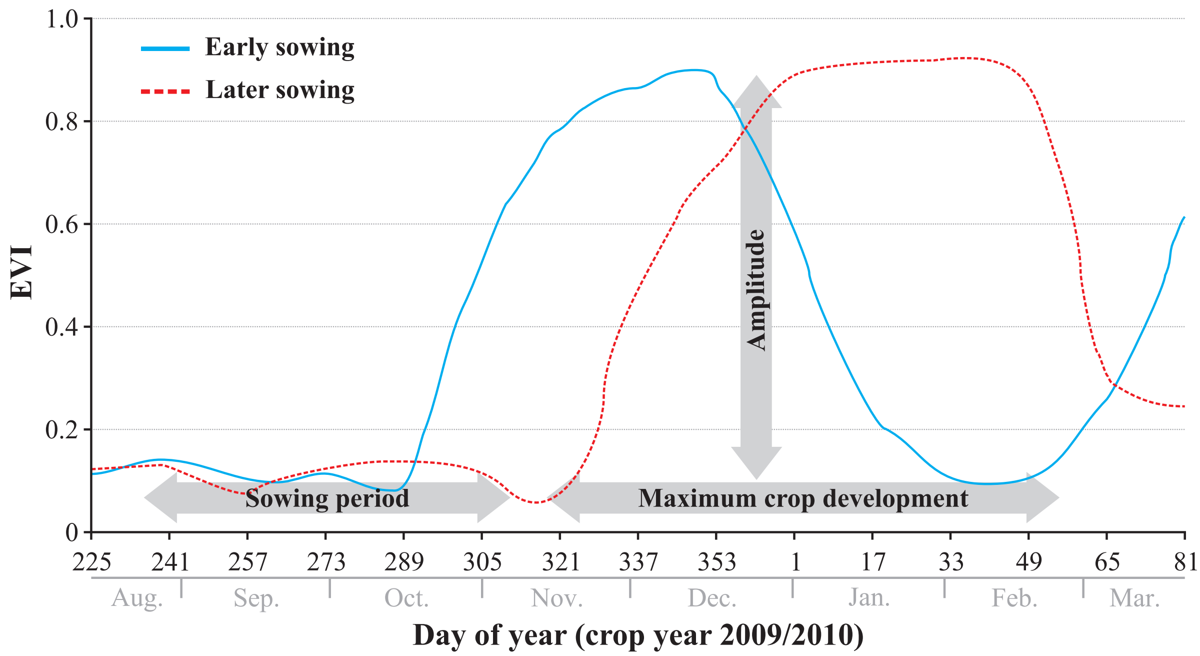
Figure 2. Example of the fusion of four PRODES polygons. Without fusion **(a)**, two polygons would not be monitored because they measure less than 25 ha. After fusion **(b)** a single polygon was formed with an area greater than 25 ha.



3.5. Identifying Polygons with Annual Crops by Remote Sensing Imagery

The procedure described by Rizzi *et al*. [26] was adapted to identify the presence of annual crops in the PRODES deforested polygons selected for monitoring. In this procedure, EVI/MODIS images (product MOD13Q1 [40]) were used to classify annual crops based on images acquired during the sowing period, between DOY 241 and DOY 305, when EVI values were at minimum, and during the period of significant crop development, between day of year (DOY) 353 and DOY 17, when EVI values were at maximum. This algorithm is based on the typical temporal trajectory of non-filtered EVI values for annual crops as shown in Figure 3. A pixel to be classified as an annual crop must meet two requirements simultaneously: *(i)* the minimum EVI/MODIS value should be between 0.05 and 0.36; and *(ii)* the amplitude, which is the difference between maximum and minimum EVI/MODIS values, should be ≥0.18. The minimum EVI and amplitude values were conservative to reduce omission errors.

Figure 3. Temporal trajectory of EVI/MODIS values for a typical annual crop indicating the periods of minimum and maximum EVI values and the amplitude. Source: adapted from Rizzi *et al*. [26].



After the first polygon selection, based on MODIS images, they were further selected through a visual interpretation using the most recently available TM/Landsat-5 images (Table 2). This step was meant to refine the list of polygons initially selected for aerial survey. For successful identification of soybean crop among the annual crops it is relevant to carry out the aerial survey at the right time. Therefore, the MODIS images used to identify the annual crops have to be acquired relatively early in the season (late-December to mid-January).

4. Results and Discussion

4.1. Selecting the PRODES Polygons

The criteria defined to select the study area showed that since the beginning of the Soy Moratorium 14,865 polygons were deforested, which correspond to an area of 385,327 ha (Table 3). After fusion of adjacent polygons (section 3.4) the total number of polygons was reduced to 10,580 (Table 3) corresponding to a reduction of 29%. It can be observed that this reduction was caused by the fusion of polygons from the classes <25 ha and 25 to 50 ha that decreased from 11,803 to 7,625 (35%) and from 1,703 to 1,466 (14%), respectively (Table 3). Conversely, for the classes from 50 to 100 ha and >100 ha the number of polygons increased from 771 to 796 (3.2%) and from 588 to 693 (17.8%), respectively (Table 3). The fusion process not only reduced the total number of polygons by 29% (4,285) but also included 4,179 polygons from the <25 ha class that after fusion became >25 ha. It was also interesting to note that the polygon class with the largest increase in number of polygons was the >100 ha class. These data confirms the practice of successive and adjacent deforestation as described by Alves [41] and Aguiar *et al*. [42].

Table 3 also shows that the total deforested area did not vary substantially with the fusion process. However, the total area of fused polygons for the ≥25 ha classes increased about 10% (27,522 ha) due to the fusion of adjacent polygons from the < 25 ha class that after fusion became single polygons with ≥25 ha. Based on the selection criteria of the fused polygons (≥25 ha) 2,955 polygons were selected that corresponded to the sum of: 1,466 polygons from the 25 to 50 ha class; 796 polygons from the 50 to 100 ha class; and 693 polygons from the >100 ha class (Table 4). These 2,955 polygons cover an area of 302,149 ha, corresponding to 78.4% of the deforestation in the study area (Tables 3 and 4). Table 4 presents the number of polygons and the deforested area for each one of the three states analyzed. The greatest number of deforested polygons was observed for Mato Grosso state (1,881 polygons) representing 63.6% of the deforested polygons and 71.0% of the deforested area monitored within the Soy Moratorium during the 2009/10 crop year. Based on the same criteria, Pará accounted for 25.3% (921 polygons) and Rondônia for 3.7% of the deforested area (153 polygons) within the study area.

Table 3. Number of polygons (n) and deforested area (ha) classified by size (ha) before and after fusion of adjacent polygons.

Classes	Before fusion		After fusion	
(ha)	n	(ha)	n	(ha)
<25	11,803	110,700	7,625	82,893
25 to 50	1,703	58,526	1,466	50,557
50 to 100	771	53,347	796	56,011
>100	588	162,754	693	195,581
Total	14,865	385,327	10,580	385,042

The monitored area in the 2009/10 crop year (Table 4) represents only 12% of the deforested area observed during the Soy Moratorium period (Table 1); however, this area is concentrated in municipalities that account for 98% of the soybean area in the Amazon biome.

Table 4. Number of polygons (n) and deforested area (ha) monitored in the states of Mato Grosso, Pará and Rondônia during the 2009/10 crop year.

Classes	Mato Grosso		Pará		Rondônia		Total	
(ha)	n	(ha)	n	(ha)	n	(ha)	n	(ha)
25 to 50	878	30,714	498	16,924	90	2,929	1,446	50,557
50 to 100	499	35,307	256	17,790	41	2,915	796	56,011
>100	504	148,542	167	41,781	22	5,256	693	195,581
Total	1,881	214,563	921	76,495	153	11,100	2,955	302,149

4.2. Identification of Annual Crops in Deforested Polygons

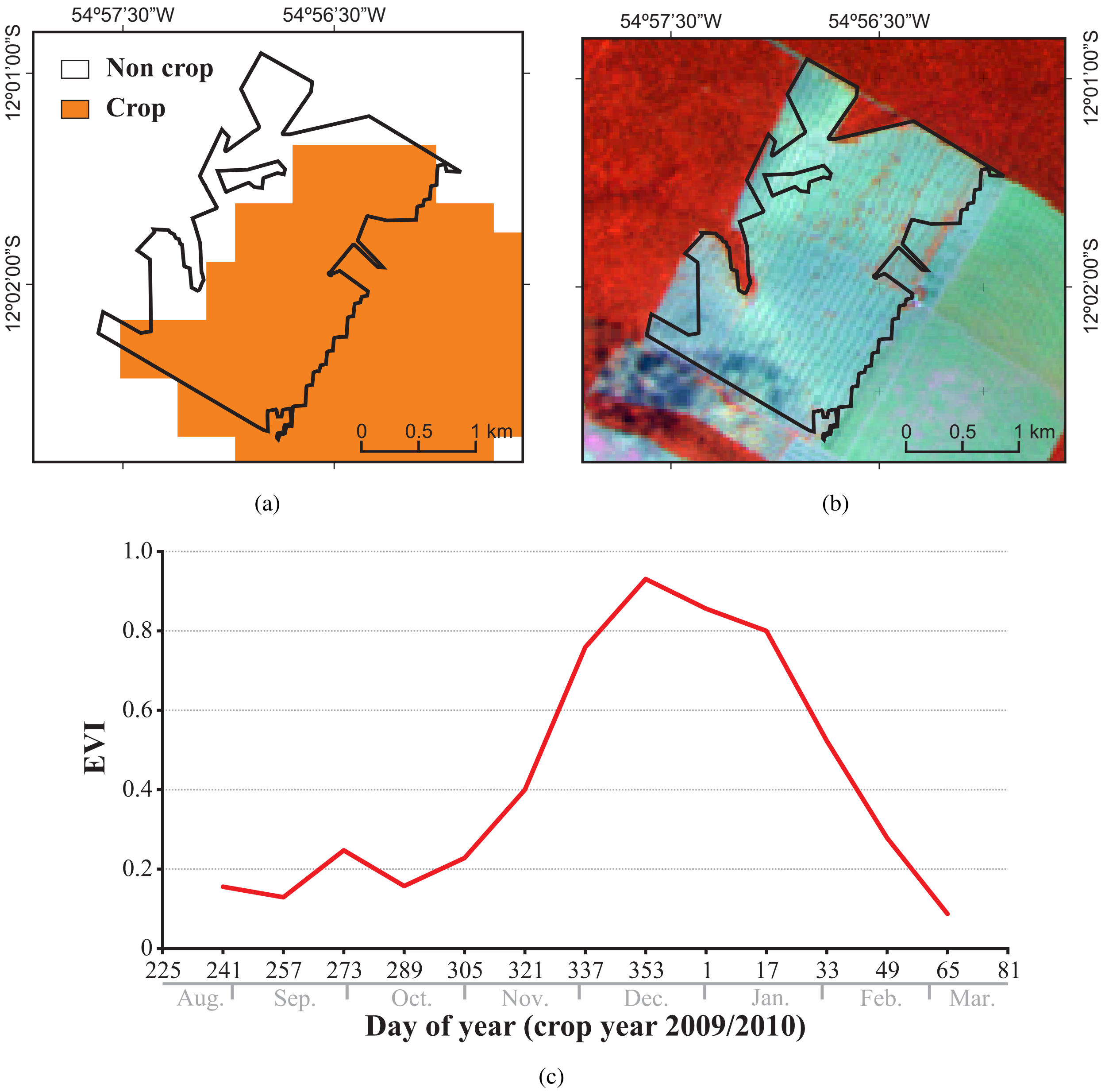
From the analysis of the 2,955 polygons selected for monitoring with MODIS images acquired up to 15th January 2010, together with the visual analysis of available TM images, 194 polygons were classified as having annual crops (Table 5) that corresponded to 6.6% of the monitored polygons. It is also pointed out that with the use of remote sensing imagery there were no indications of the presence of annual crops in 2,761 polygons (93.4% of the total polygons selected for monitoring). Therefore, the aerial survey could be concentrated on only 194 polygons that had a high probability of the occurrence of annual crops, distributed as follows: 92 polygons in the 25 to 50 ha class with an average area of 32 ha; 41 polygons in the 50 to 100 ha class with an average area of 68 ha and 61 polygons in the >100 ha class with an average area of 275 ha (Table 5).

Table 5. Number of selected polygons based on MODIS image classification followed by visual analysis on TM images.

Classes	Number of selected polygons			
(ha)	Mato Grosso	Pará	Rondônia	Total
25 to 50	75	16	1	92
50 to 100	25	16	–	41
>100	39	20	2	61
Total	139	52	3	194

Figure 4 shows as an example a selected polygon, and the EVI/MODIS time profile of the period corresponding to day of year (DOY) 241 of 2009 to the DOY 49 of 2010, referring to the central pixel of this polygon. Figure 4 also presents the TM image of path 226 row 68 acquired on 25th October 2009 used to indicate that this polygon presented an annual crop pattern. The acquired and available TM images for the 2009/10 crop year improved the selection of the polygons with the presence of annual crops indicated by MODIS images.

Figure 4. Example of a polygon selection procedure: **(a)** limit of polygon ID 6220 overlaid on the classification result of MODIS images; **(b)** polygon overlaid on the TM image from 25th October 2010 of path 226 row 68 (color composition 4R5G3B); **(c)** EVI temporal profile referring to the central pixel of the polygon.



4.3. *Soybean Identification by Aerial Survey*

During the aerial survey of the 194 selected polygons, soybean crops were identified in 77 polygons representing a soybean area of 6,323 ha (Table 6). This indicated that the land conversion from forest to soybean was 2.1% since the start of the moratorium within the study area. Therefore, the current influence of soybean on deforestation in the Amazon biome in municipalities with more than 5,000 ha of soybean, outside conservation units, outside indigenous reserves and outside land reform areas is relatively small. When the total deforestation in the Amazon biome for the states of Mato Grosso, Pará and Rondônia during the Soy Moratorium is considered (2.49 million ha; Table 1) the soybean contribution is even smaller (0.25%). Despite the influence of soybean on deforestation [10–18], this number indicates that, currently, soybean has almost no influence on deforestation. Under a scenario of increasing soybean prices this might change [13].

Table 6 shows the number of polygons and the respective soybean area by class and by state. It also shows that from the 194 polygons (Table 5) with high probability of having annual crops, only 116 indeed presented annual crops. This indicated that the procedure to classify the areas with agricultural crops by remote sensing imagery was conservative and might be more restrictive in future years to reduce the aerial survey of polygons that tend to increase each year. For example, between 2007 and 2009 the deforested area in the Amazon biome increased 2.6 times from 952,849 to 2,487,003 ha (Table 1). Major causes for the large amount of selected polygons without annual crops are: *(i)* forest regrowth and cultivated pasture land may appear similar to annual crops on remote sensing images during initial growth cycle immediately after the beginning of the wet season; and *(ii)* border influence of EVI values from large areas of annual crops next to relatively small or complex shaped polygons.

Table 6. Number of polygons (n) and area (ha) with soybean identified during aerial survey, by classes of deforested polygon size, in the states of Mato Grosso, Pará and Rondônia.

	Soybean polygons							
Classes	Mato Grosso		Pará		Rondônia		Total	
(ha)	n	(ha)	n	(ha)	n	(ha)	n	(ha)
25 to 50	23	675	6	132	–	–	29	807
50 to 100	9	323	5	256	–	–	14	588
> 100	25	3,701	8	1,198	1	29	34	4,928
Total	57	4,698	19	1,596	1	29	77	6,323

Fifty-seven polygons were identified in the state of Mato Grosso (within the Amazon biome) that infringed the rules of the moratorium, representing a soybean area of 4,698 ha (Table 6) in a total deforested area of 622,703 ha (Table 1). Nineteen polygons were identified in the state of Pará with 1,596 ha of soybean in a total deforested area of 1,541,400 ha. In Rondônia only one polygon was identified with 29 ha of soybean in a total deforested area of 322,900 ha. Thus, Mato Grosso was the state where soybean was cultivated most in recently deforested areas, corresponding to 0.7%.

From the 194 polygons selected for aerial survey, 61 were from the > 100 ha class and soybean was identified in 34 of these polygons. The area of soybean in these polygons was 4,928 ha (Table 6) and corresponded to 77.9% of the total soybean area in the 77 polygons identified with soybean. In other words, less than a third of the polygons (61; Table 5) selected for aerial survey represented almost 80% of the soybean planted in deforested areas after the Soy Moratorium. On the other hand, the identification of soybean in small polygons, with low representativeness in area, demonstrated that the procedure was also efficient to detect soybean in relatively small deforestations. Figure 5 shows an example of oblique aerial photographs from a deforested polygon with soybean.

Figure 5. Oblique aerial photographs showing a soybean field in a deforested polygon.

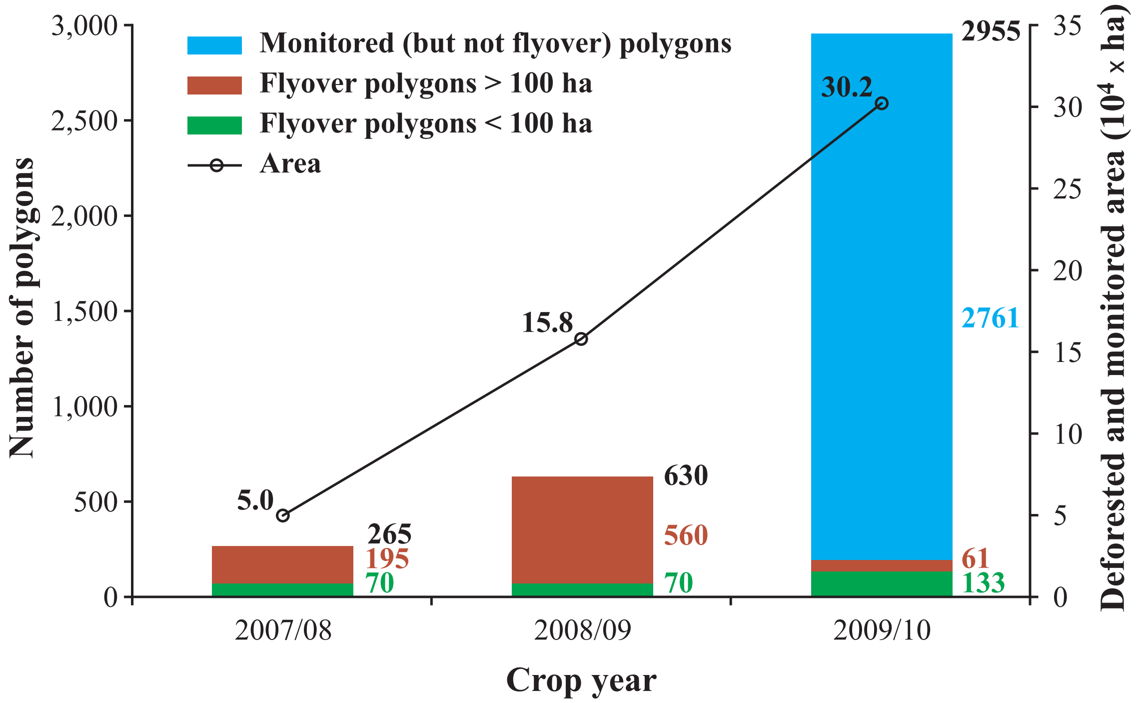
4.4. Comparison Among Monitored Crop Years

All deforested polygons from PRODES greater than 100 ha were monitored during the three last crop years (2007/08, 2008/09 and 2009/10) within the Soy Moratorium context. In the first crop year after the moratorium no soybean was identified within deforested areas after 24th July 2006. In the second crop year (2008/09) soybean was identified in 12 polygons greater than 100 ha. In 2009/10, 693 polygons greater than 100 ha had been deforested since the beginning of the Soy Moratorium. The remote sensing images selected 61 polygons (8.8%) greater than 100 ha for the aerial survey and soybean was found in 34 polygons, corresponding to a 2.8-fold increase compared to the previous year. In the remaining 632 polygons (91.2%) greater than 100 ha, the land use was mainly associated with pasture or grassland and forest regrowth.

For the two first monitored crop years (2007/08 and 2008/09) only a small and non-representative sample of deforested polygons with less than 100 ha was checked by aerial survey. In the last crop year (2009/10) all polygons greater than 25 ha were monitored; therefore, the number of polygons that were checked by aerial survey increased significantly in the last year (Figure 6). In the 2009/10 crop year, 92 polygons were checked by aerial survey from the 25 to 50 ha class and 41 polygons from the 50 to 100 ha class using remote sensing images (Table 5). These polygons were selected from a total of 1,466 polygons of the 20 to 25 ha class and 796 of the 50 to 100 ha class (Table 4). This shows that only 6.3% of the polygons from the 25 to 50 ha class and 5.1% of the polygons from the 50 to 100 ha class had to be checked by aerial survey to monitor all the deforested polygons between 25 and 100 ha.

The use of remote sensing satellite images to monitor 2,955 polygons indicated that aerial survey would not be necessary for 2,761 polygons, as shown in Figure 6. When compared with the previous methodology, a considerable reduction was observed in the number of polygons that had to be checked by aerial survey (630 polygons in 2008/09 and 194 polygons in 2009/10). The number of polygons to be monitored increased significantly from year to year and is likely to continue to increase. Therefore, the use of remote sensing satellite images with high temporal resolution is important to reduce aerial surveying to identify soybean planting, since it is not feasible to perform the survey for a large number of polygons in a short period of time, particularly in the Amazon region.

Figure 6. Comparison of three years of Soy Moratorium monitoring.



4.5. Soybean in Recently Deforested Areas in the Amazon Biome

The increase in soybean in deforested areas from the 2008/09 to the 2009/10 crop year in polygons >100 ha class can be attributed to the following factors: *(i)* fusion of the polygons in 2009/10 that increased the number of polygons from 588 before the fusion to 693 after the fusion (Table 3); *(ii)* fewer polygons in 2008/09 (560, Figure 6); *(iii)* favorable market conditions to produce soybean in Brazil; and *(iv)* more time elapsed between deforestation and onset of soybean planting since it is a usual practice to plant rice for one or two years prior to soybean in recently deforested areas [13,25].

The 2009/10 soybean crop year has been the greatest to date in Brazilian history with a production of 67.9 million tons. This record was reached not due to increase in area but due to a significant increase in crop yield as was also observed for the states of Mato Grosso and Rondônia that had record soybean production without increase in area [43].

There is a dynamic in land use change for soybean in which old cropped areas change their use and new areas become part of the production system [13,25]. However, it is difficult to quantify and attribute causes to these changes for all the Brazilian territory. It is likely that the Soy Moratorium contributed to inhibiting the advancement of soybean in recently deforested areas in the Amazon biome. From the findings of this study, soybean was planted in only 0.25% of the deforested areas which represents 0.027% of the Brazilian soybean area and 0.37% of soybean cultivated in Mato Grosso, Pará and Rondônia states (Table 7). The highest percentage of soybean in deforested areas was observed in Pará state (2.52%) and the lowest percentage in Rondônia state (0.03%) as shown in Table 7. Therefore, soybean in deforested areas during the last three years, within the Amazon biome, is small and of little significance within the soybean production context in Brazil.

Table 7. Area in ha detected with soybean in the polygons of the Soy Moratorium compared with the total soybean area in ha within the Amazon biome, by state.

State	Soybean in Amazon biome		
	Total area (ha)	Inside deforested polygons (ha)	% of total
Mato Grosso	1,559,059	4,698	0.30%
Pará	63,425	1,596	2.52%
Rondônia	108,900	29	0.03%
Total	1,731,384	6,323	0.37%

4.6. Future Adjustments for the Next Monitoring

In order to improve the monitoring approach of the Soy Moratorium for the 2010/2011 crop year, the soybean sowing period needs to be better understood for the different regions of the study area. In the central part of Mato Grosso, sowing occurs in October and November, in the western and eastern part of Mato Grosso and Rondônia, sowing occurs a little later, between November and December, and in Pará, sowing occurs much later, in December and January. Knowing the regional sowing differences, the key periods of minimum and maximum plant development can be better selected on satellite images and, therefore, soybean should be identified more efficiently.

Another adjustment in the methodology is the use of Bayesian networks [44] to associate a probability level of occurrence of annual crops in deforested polygons. These adjustments should reduce commission error and increase the reliability of the Soy Moratorium monitoring procedure.

5. Conclusions

Remote sensing images combined with aerial survey identified 6.3 thousand ha of soybean planted in deforested polygons post Soy Moratorium during the 2009/10 crop year. This area corresponded to 0.25% of the total deforestation in the Amazon biome since the beginning of the moratorium in the states of Mato Grosso, Pará and Rondônia which was 2.49 million ha. Mato Grosso had the greatest area of soybean planting with 4,698 ha followed by Pará with 1,596 ha. Rondônia had negligible participation with 29 ha soybean.

The deforested area in the Amazon biome during the period 2007–2009 was very significant although it was the lowest observed during the last 22 years [9]. Attributing this recent reduction in deforestation in part to the Soy Moratorium is still premature, but the initiative has certainly exerted an inhibitory effect on the soybean frontier expansion in the Amazon biome. The monitoring procedure also included field inspection and document collection in local public notary offices allowing the companies participating in the Soy Moratorium to keep the commitment to not acquire soybean produced in areas deforested after 24th July 2006.

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