Monitoring of the Soy Moratorium through satellite images:

Supplementary Material

ABIOVE
Associação Brasileira das Indústrias de Óleos Vegetais

INPE

agrosatélite
applied geotechnology

SUMMARY

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Introduction

The Soy Moratorium is an agreement between civil societies and signatory companies not to acquire or finance soy from farms with soy crops in areas deforested after 22nd July 2008 in the Amazon Biome. The objective of this agreement is to eliminate most of the deforestation associated with soy production since its signatories account for almost all the soy produced in the Biome.

This initiative has proved to be extremely effective, as it has not prevented the development of the soy agricultural activity in the Amazon Biome, but it has mitigated the advance of soy onto new deforestation by prioritising the use of the ample stocks of land that were already cleared before the Soy Moratorium was implemented.

The rules and criteria governing the Soy Moratorium are defined by the Soy Working Group (GTS), which is made up of the members of ABIOVE and ANEC, the government and civil society organisations. The GTS annually assesses both the results of soy monitoring through satellite images, carried out by Agrosatélite, and the audit of deforestation-free soy purchases by the companies, coordinated by Imaflora.

The purpose of this report is to detail the methodological aspects involved in the monitoring, through satellite images, of the farms with soy crops on post-Moratorium deforestation.

The history of the monitoring process

The Soy Moratorium was established on 24th July 2006 and this remained the reference date for zero-deforestation for the signatories of the agreement until the 2013/14 crop. When the 2012 Forest Code came into effect defining 22nd July 2008 as the base date to establish the consolidated rural areas, the GTS agreed to adopt this date as the new base date for the Soy Moratorium, effective from the 2014/15 crop year.

In the first crop year of the Moratorium (2007/08), the non-compliant soy area was not assessed as it would not be feasible to cut down the forest after 24th July 2006 and plant soy in September or October of the same year. In the second crop year (2008/09), samples were taken from some regions in Mato Grosso state, but

no non-compliant soy crops were identified. It was from the third year of the Soy Moratorium (2009/10) that surveys were widely conducted, combining the use of satellite images with flyovers that took panoramic aerial photographs. This phase lasted until the 2012/13 crop year (sixth year), when the growing soy expansion in the Amazon Biome and the increase in accumulated deforestation since the beginning of the Moratorium, added to the logistical difficulty of overflying the Amazon region, led to the decision to stop the flyovers as from the 2013/14 crop year because the analysis of remote-sensing satellite images was providing high quality results for the purposes of the Moratorium, in spite of the complexity involved in identifying soy crops in the Amazon region in the images.

Starting in the 2014/15 crop year, the new base date of 22nd July 2008 was adopted as the reference for zero-deforestation, and the monitoring of soy on deforested land was updated for the 2012/13 and 2013/14 crop years using this new date, giving a 10-year monitoring series (2012/13 to 2021/22) based on the 22nd July 2008.

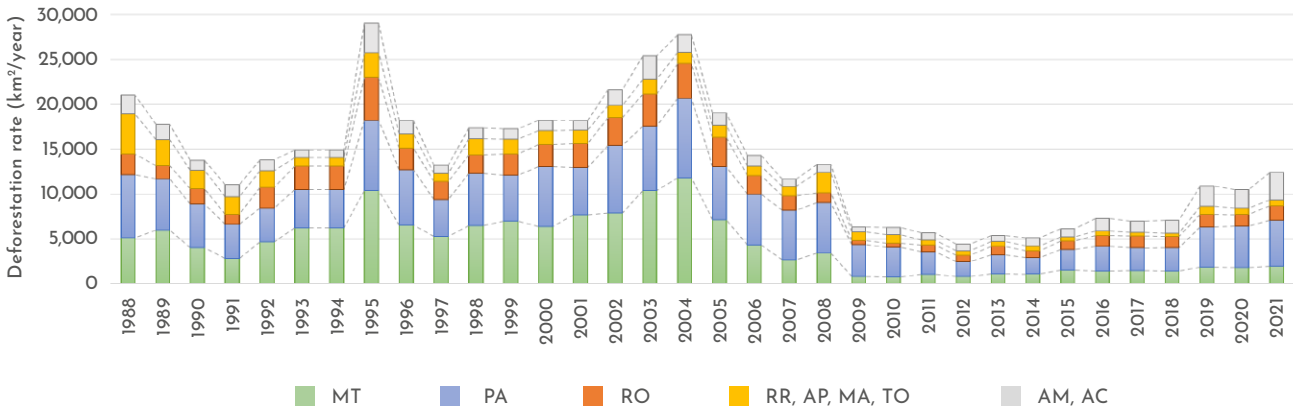
PRODES – Deforestation in the Amazon

The mapping of deforestation in the Amazon region started in 1978 and was based on images acquired by the first three satellites of Landsat, the pioneer NASA programme to observe the planet Earth. At that time, the question of the growing deforestation in the Amazon was already considered a serious environmental problem, and the first assessment of deforestation in the region between 1975 and 1978 resulted in a Parliamentary Inquiry Commission (CPI).

Considering the relevance of monitoring the Amazon Forest, in 1988, the Brazilian government set up the Programme for Satellite Monitoring of the Brazilian Amazon Forest (PRODES), in the National Institute for Space Research (INPE), which since then has annually mapped the deforestation in the Legal Amazon (Figure 1). At the same time, it has implemented innovations in advanced technology, both in the quality of the images available for mapping and in the procedure for analysing these images. The historic series for deforestation since 1988 is available only for the Legal Amazon and, since 2002, in shapefile format, for the Amazon Biome.

Figure 1

PRODES/INPE deforestation rates (km²/year) for the Legal Amazon from 1988 to 2021



Source: Adapted from INPE (terrabrasilis.dpi.inpe.br). The PRODES year refers to deforestation between 1st August and 31st July of the given year.

The PRODES deforestation mapping is done by analysts using visual interpretation techniques and a minimum mapping area of 6.25 hectares. Furthermore, the analysis is restricted to deforestation in the phytophysiognomies of forest formation, whose definition is based on images from 1988, with a view to excluding areas with savanna vegetation. Another point that should be mentioned is that PRODES in essence maps the deforestation occurring in primary forest or where the secondary forest is no different from the secondary forest in the 1988 satellite images. Therefore, areas of secondary forest regenerated after the beginning of PRODES in 1988 were not monitored, although some of them might have been converted to soy.

Measures for the mitigation of deforestation in the Amazon

If, in the 1970s, the forest cover in the Amazon had already been reduced by 5%, the PRODES data indicate that, in the 2020s, we will be reaching the critical level of 20%. Therefore, measures that can mitigate new deforestation are necessary for climatic and biodiversity reasons, as well as being opportune since Brazil has ample cleared and underused land stocks.

In the first years of the 2000s, there was a significant increase in deforestation rates (Figure 1), attributed by Greenpeace as being largely the responsibility of the soy industry present in the Amazon Biome (Eating up the Amazon), and culminating with a campaign in Europe to raise the awareness among consumers of soy products, alleging their direct relationship with the deforestation of the world's largest tropical forest: the Amazon.

In order to dissociate soy production from deforestation in the Amazon, an unprecedented initiative was created, called the Soy Moratorium. This initiative brings together non-governmental organisations and the government committed to environmental preservation, as well as the soy industry seeking to have the sustainable production demanded by consumers, around the same objective: eliminate the soy footprint from deforestation in the Amazon Biome.

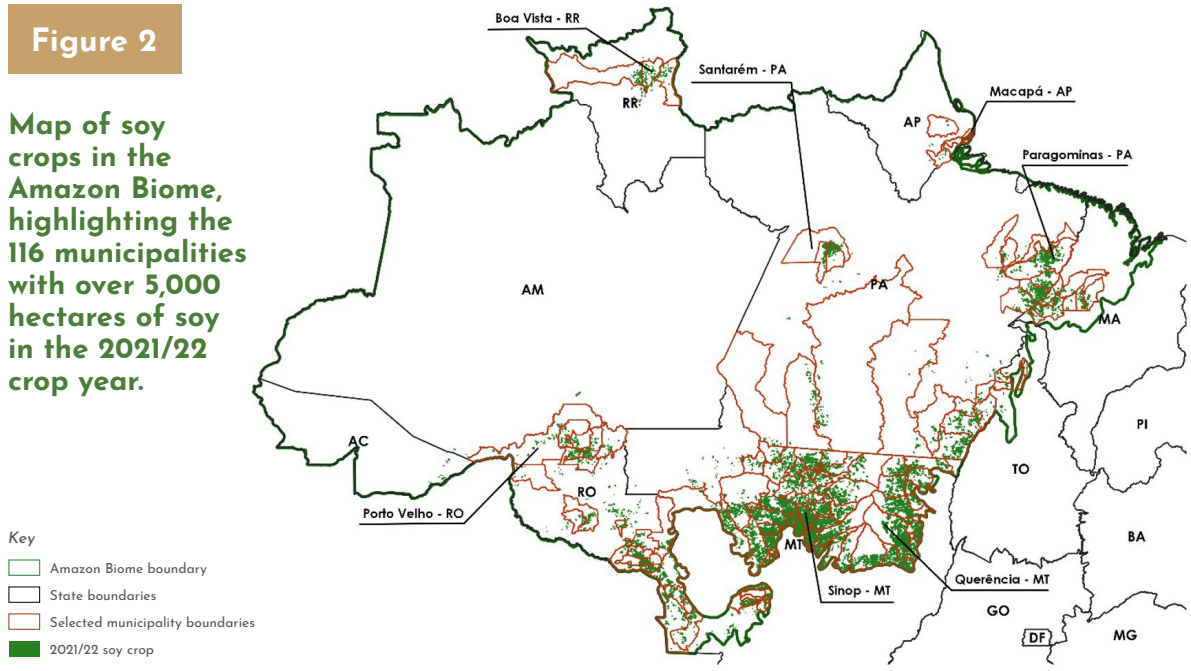
Methodology for Monitoring Soy on Deforestation

Selection of soy-producing municipalities

The study area of the Soy Moratorium is restricted to the Amazon Biome and covers the private rural properties located in municipalities that grow over 5,000 hectares of soy. The municipalities are selected based on soy mapping using satellite images for the entire Amazon Biome[1], as shown in Figure 2, which highlights the 116 municipalities with over 5,000 hectares of soy in the 2021/22 crop year and which represent 98% of the soy grown in the Biome.

Figure 2

Map of soy crops in the Amazon Biome, highlighting the 116 municipalities with over 5,000 hectares of soy in the 2021/22 crop year.

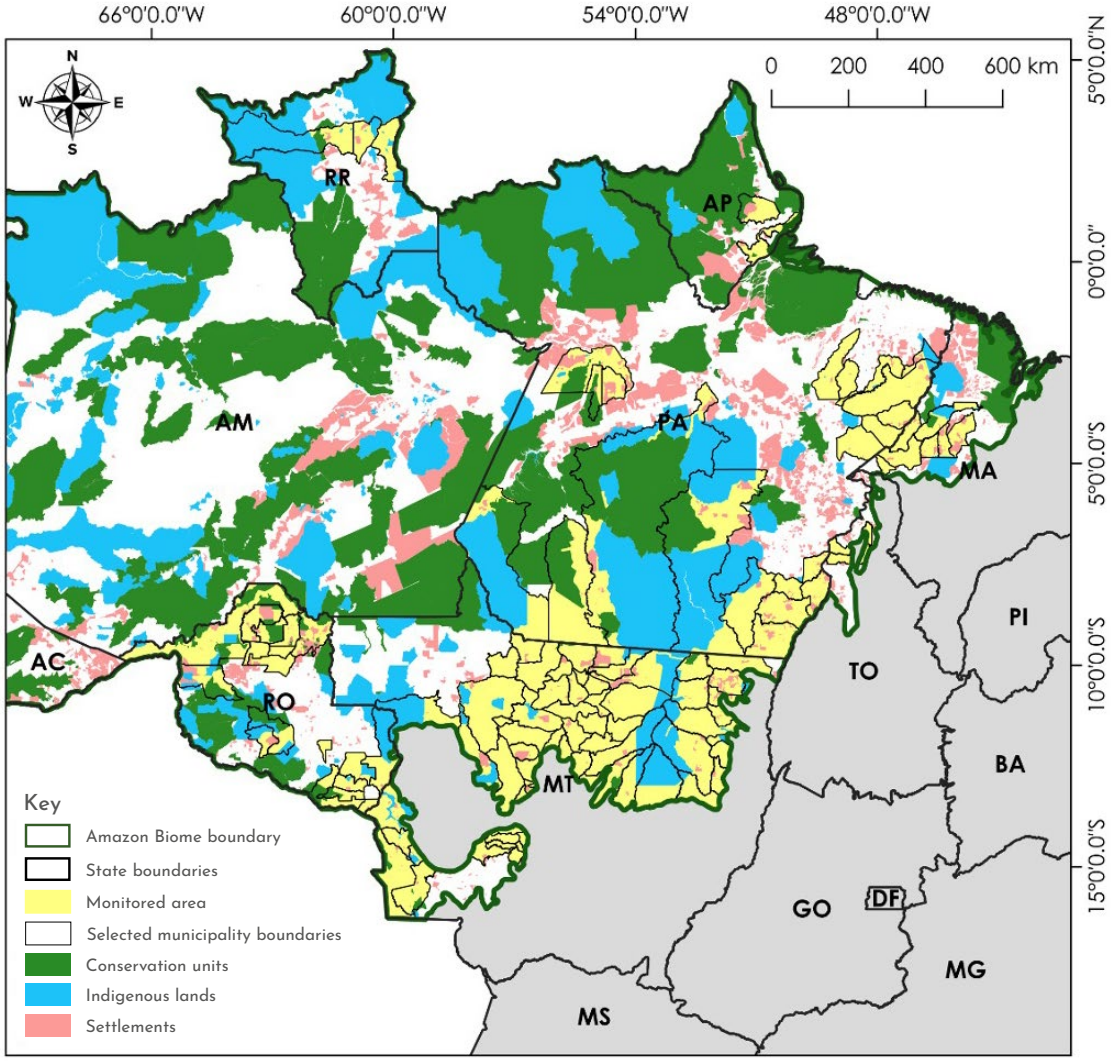


1. In the first years of the Soy Moratorium, the municipalities were selected based on the area planted with soy as informed by IBGE. Since the 2019/20 crop year, the Moratorium monitoring includes soy mapping by satellite images for the entire Amazon Biome. With the tendency for soy expansion in the Biome, the number of municipalities with over 5,000 hectares has grown every year, which is why it is important to map the soy in each new crop year.

The definition of the study area is also supported by georeferenced data from the following institutions: Agrosatélite, FUNAI (National Foundation for Native Indians), the Ministry of the Environment, IBGE (Brazilian Institute of Geography and Statistics) and INCRA (National Institute for Colonisation and Agrarian Reform). The following protected areas within the selected municipalities are excluded from the analysis: (a) Indigenous Lands and Quilombolas, (b) Settlements and (c) Conservation Units, as the Soy Moratorium is restricted to private properties. In Figure 3, the yellow areas indicate the municipalities where the deforestation that occurred during the Soy Moratorium is monitored. Any soy crops found in these deforested areas will be in non-compliance with the Moratorium.

Figure 3

Indication of the monitored area (in yellow) in the 116 soy-producing municipalities



The Amazon Biome boundary, published by IBGE and used by the Soy Moratorium, dates from 2003, on a scale of 1:5,000,000. This boundary is used in the analyses to identify soy on deforested lands in rural properties. A new boundary for the Amazon Biome was introduced by the IBGE in 2019 on a scale of 1:250,000. With this change, some rural properties are no longer in the Biome, while others now are. The implications resulting from this change need to be considered by the GTS so that the new Amazon Biome boundary can be adopted in the soy monitoring process[2].

To finalise the definition of the study area, it should be noted that the annual deforestation mapped by PRODES is the basis for identifying non-compliant soy through monitoring the deforestation that has occurred since the Soy Moratorium base date. In summary, the study area consists of the deforestation, mapped by PRODES since the Moratorium's base date, on rural properties located in municipalities with over 5,000 hectares of soy in the current crop year within the boundary of the Amazon Biome.

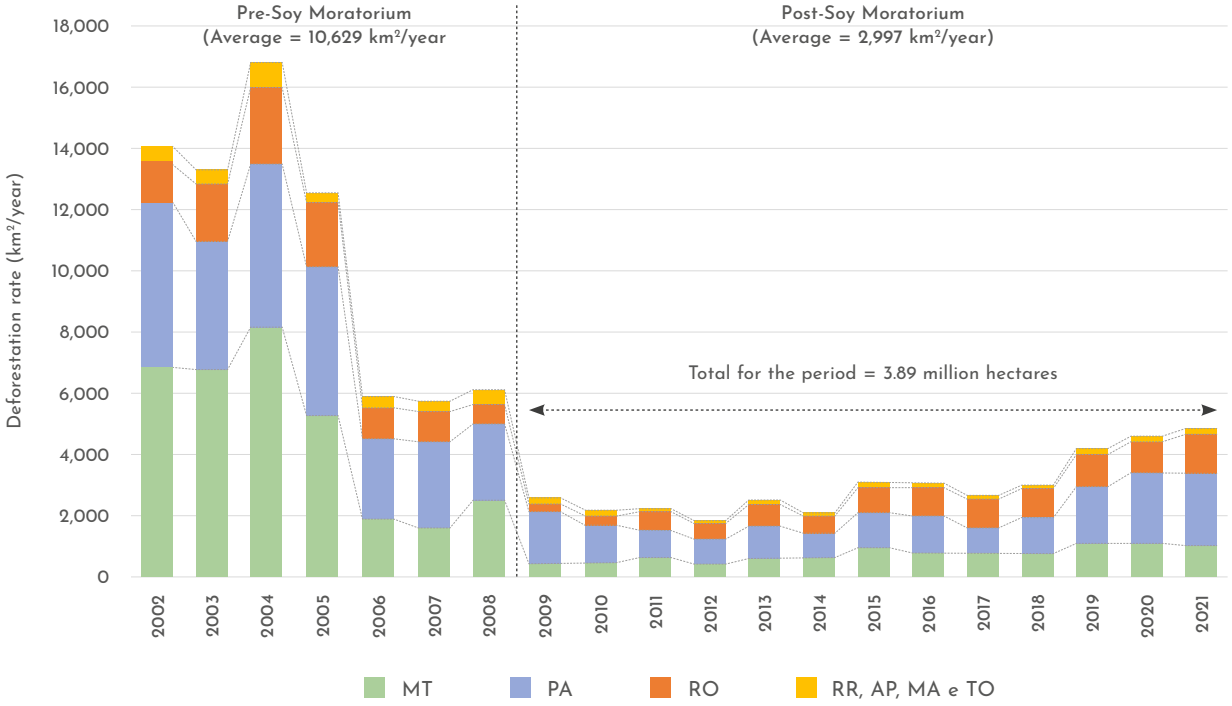
PRODES deforestation in the study area

Figure 4 shows PRODES deforestation for the period 2002 to 2021 in the 116 municipalities, wholly or partially located in the Amazon Biome, that were selected for monitoring in the 2021/22 crop year. With the creation of PPCDAm, the integrated surveillance, the entry into force of the Forest Code and the implementation of the Soy Moratorium, deforestation rates fell drastically in the Legal Amazon (Figure 1) and, consequently, in the soy-producing municipalities where the average deforestation rate fell from 10,629 km^2/year before the Moratorium (2002-2008) to 2,997 km^2/year during the Moratorium (2009-2021). However, annual deforestation in these municipalities has had a significant increase over the last three years (2019-2021), especially in the municipalities located in Pará state (Figure 4), in which period the PPCDAm was extinguished and surveillance was deficient.

2. A comparative analysis between the two Amazon Biome boundaries, made in 2020, revealed that 52,325 hectares of deforestation that occurred during the Soy Moratorium (2009-2019) are now within the Biome's new boundary, though whether there was soy in this deforested area was not analysed. On the other hand, 16 soy fields in the 2019/20 crop year, located in the municipalities of Querência, Nova Ubiratã and Diamantina, were moved to the Cerrado Biome, but they remain subject to the Moratorium rules until the GTS decides to adopt the new boundary, at least for those soy crops that are no longer part of the Amazon Biome.

Figure 4

PRODES deforestation rates (km²/year) in the 116 monitored municipalities in the 2021/22 crop year, within the Amazon Biome, highlighting the years before and after the Soy Moratorium[3].



Source: Adapted from INPE from georeferenced databases

Although the PRODES deforestation mapping complies with the methodological procedure defined by the GTS, in practice some care must be taken in the use of these databases, such as: adjustment of any spatial shifts resulting from the analysis at different scales, or elimination of the deforestation identified as occurring outside the period of the Moratorium.

Considering the nature of the Soy Moratorium, which deals with large-scale agriculture, the GTS established 25 hectares as the minimum area for the PRODES deforestation polygons, even though the minimum area mapped by PRODES is 6.25 hectares. However, polygons of less than 25 hectares become monitored when, in subsequent years, the deforestation in surrounding areas reaches an area of 25 hectares or more. For example, Figure 5 illustrates the aggregation procedure for adjacent polygons, deforested in different years, forming polygons of 25 hectares or more.

3. The annual mapping carried out by PRODES goes from 1st August to 31st July of the given year. As the Soy Moratorium base date is 22nd July 2008, the first year of PRODES deforestation is 2009, which covers the deforestation observed from 1st August 2008 to 31st July 2009 (PRODES-2009)..

Figure 5

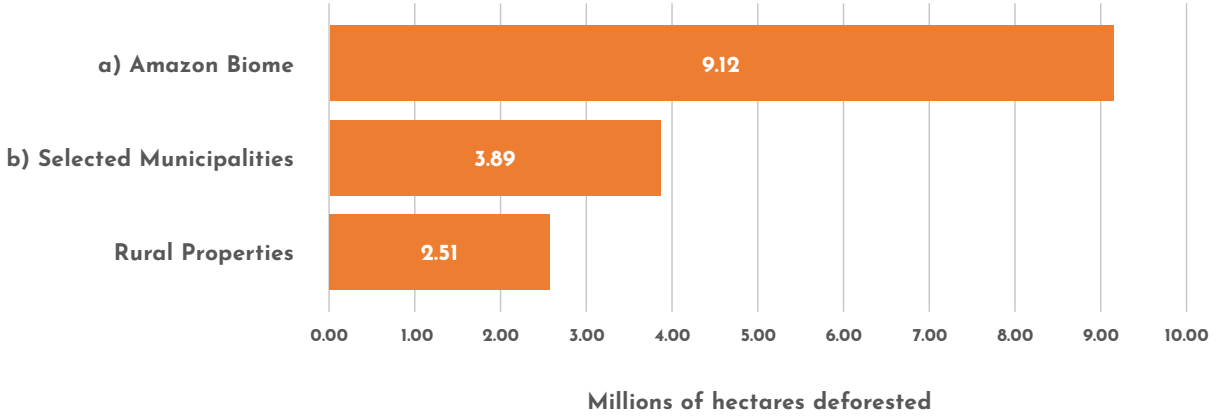
Example of aggregation of adjacent PRODES polygons mapped between 2009 and 2021, forming polygons of ≥25 hectares (dark grey with red outline) that are monitored. Polygons in light grey are not monitored as they are smaller than 25 hectares.

Figure 6 summarises the deforestation (PRODES 2009-2021) that occurred during the Soy Moratorium: (a) in the Amazon Biome, (b) in the 116 selected municipalities that grow at least 5,000 hectares of soy, and (c) in rural properties with deforestation of 25 hectares or more.

Based on the analysis of the images acquired during the 2021/22 crop year, soy crops in non-compliance with the Soy Moratorium were identified on 2.51 million hectares of deforestation observed in polygons with 25 or more hectares in rural properties. This optimises the monitoring activity by concentrating the efforts to identify non-compliant soy just to the 27.5% of the Amazon Biome's deforestation that has some possibility of having been converted to soy, since the other 72.5% shows no evidence of a link to soy crops.

Figure 6

Area deforested during the Soy Moratorium (PRODES 2009-2021): (a) in the Amazon Biome, (b) in the 116 selected municipalities in the 2021/22 crop year, and (c) in rural properties.



Identification of non-compliant soy on satellite images

Selection of satellite images

Over the last few years, the launching of several satellites has provided very favourable conditions in terms of getting, during key periods, cloud-free images to identify soy in the Amazon region (Figure 7, Table 1).

Figure 7

Remote-sensing satellites used to acquire images to identify soy crops that are not in compliance with the Soy Moratorium.

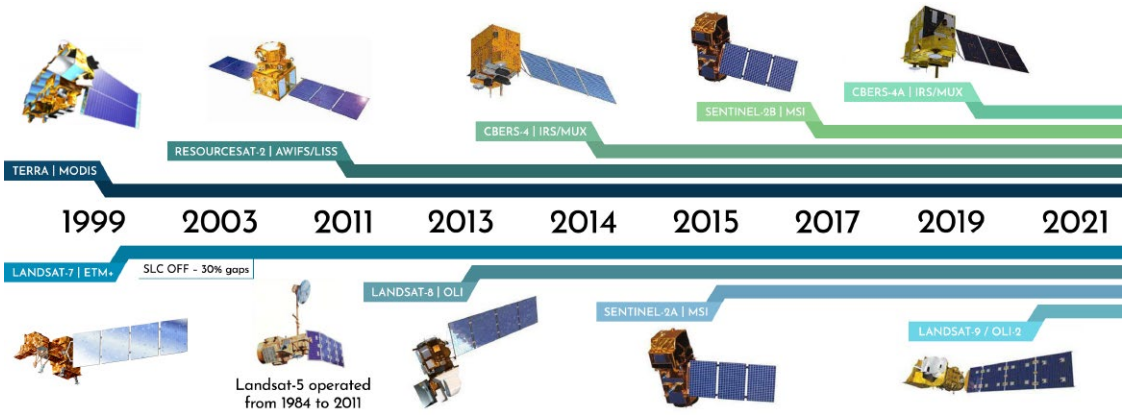


Table 1

Characteristics of the images used in the Soy Moratorium monitoring process.

SATELLITE | SENSOR	RESOLUTION			
	TEMPORAL (days)			Spatial (m)
Sentinel-2A | MSI	10	5	1 to 5	10 and 20
Sentinel-2B | MSI	10			10 and 20
Landsat-8 | OLI-1	16	8		15 and 30
Landsat-7 | ETM+	16			30
Landsat-9 | OLI-2	16			15 and 30
CBERS-4 and 4A | MUX and IRS	26			20 and 40
ResourceSat-2 | LISS3 and AWIFS	24 and 5			23.5 and 56
TERRA | MODIS	~1			250

The images acquired by the Sentinel and Landsat satellites are given priority because they have the same georeferenced base and are available operationally and without cost to the users. Images from CBERS can be used when cloud-free images are not available from the Landsat and Sentinel satellites, though in such cases the CBERS images generally present the same unavailability.

Since the third year of soy monitoring (2009/10 crop year), the high temporal resolution images from the MODIS sensor have been used to help identify non-compliant soy crops. Appendix 1 details the methodology adopted between the 2014/15 and 2018/19 crop years for identifying soy crops. As previously mentioned, since the 2019/20 crop year, soy mapping for the entire Amazon Biome is carried out through visual interpretation of Sentinel and Landsat images on a scale of around 1:75,000. To identify non-compliant soy, this mapping is refined by increasing the scale of analysis to 1:25,000. In this mapping refinement, MODIS images continue to be an important support tool in the form of temporal series, accessed through EMBRAPA's SATVeg tool, as exemplified in Figure 8, which confirms that, starting in the 2020/21 crop year, soy started to be grown on an area that was deforested during the Soy Moratorium.

Figure 8

Example of using the temporal series of MODIS images to confirm the presence of soy on land deforested during the Soy Moratorium.

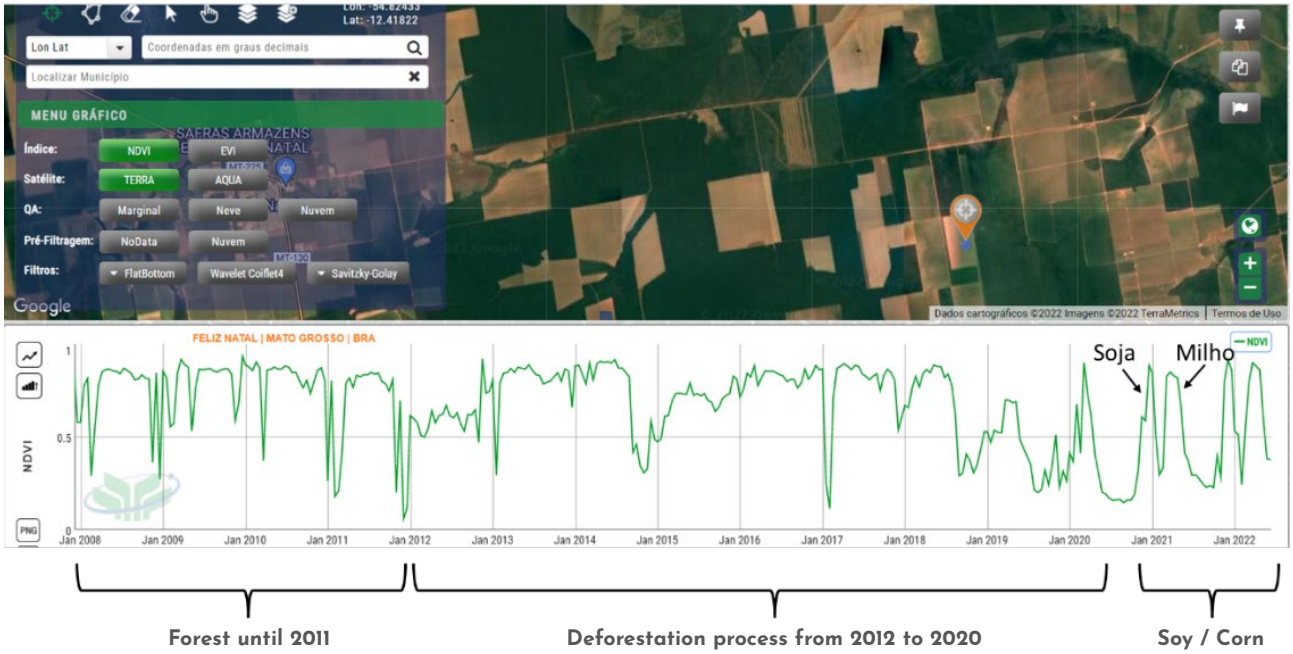


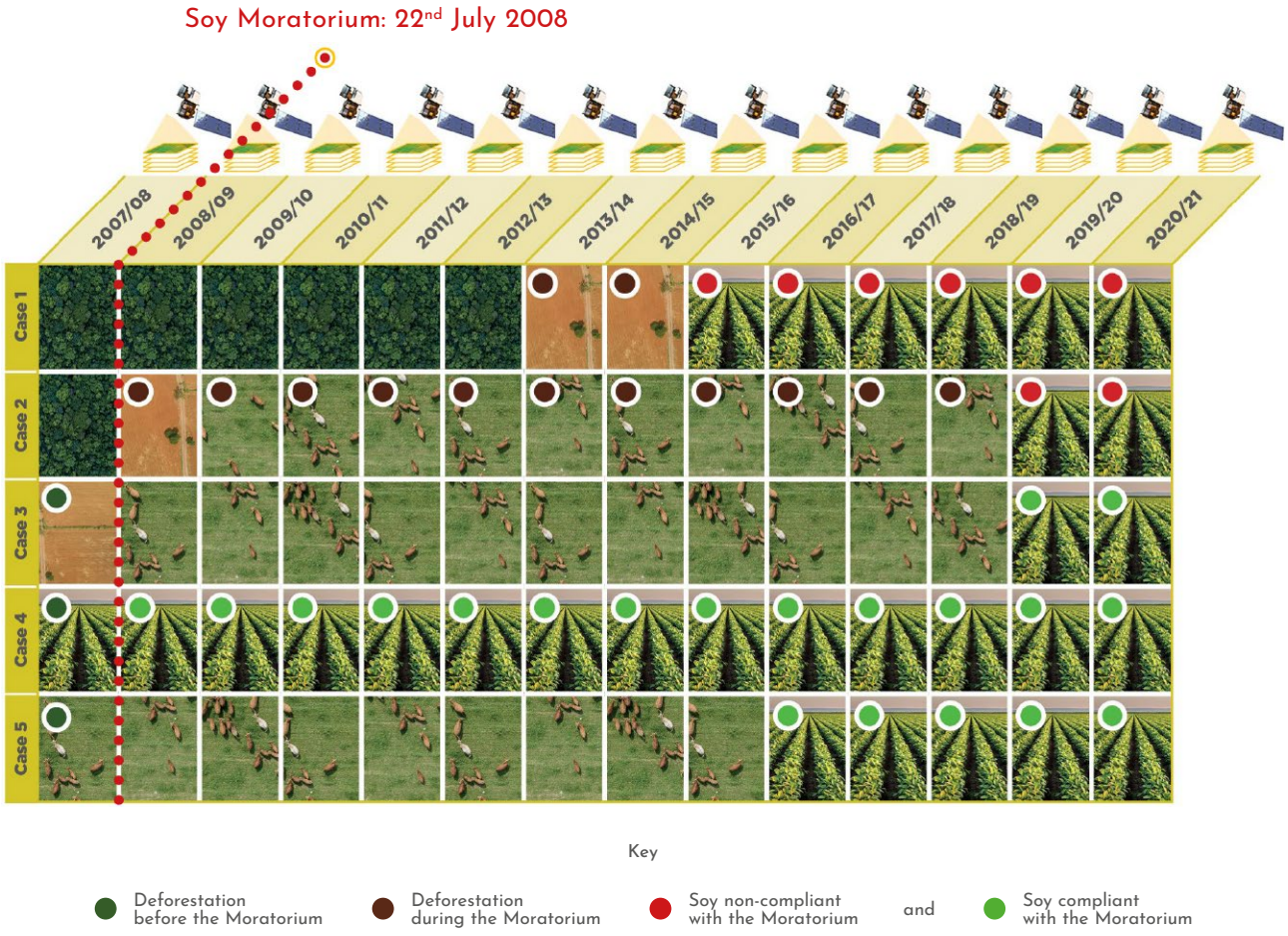
Image analysis

Figure 9 schematically illustrates the rule that defines whether the soy crop is or is not compliant with the Soy Moratorium. Cases 1 and 2 shows examples where soy is in non-compliance as it was grown in an area that was deforested during the Moratorium. In Cases 3, 4 and 5, the soy is compliant as it was grown in an area deforested before the Moratorium's base date of 22nd July 2008.

Based on the Soy Moratorium rule, the procedure for identifying non-compliant soy crops consists of superimposing the PRODES (2009-2021) map of deforested polygons on the Amazon Biome soy map produced by Agrosatélite for the 2021/22 crop year. Each PRODES deforested polygon is individually inspected through visual analysis of a set of up to twenty images acquired from the Sentinel and Landsat satellites. The acquisition dates for the images take into account the broad soy planting calendar adopted in the different soy-producing regions of the Amazon Biome.

Figure 9

Illustrative diagram of the Soy Moratorium rule



It should be noted that the soy map produced for the entire Amazon Biome is prepared on a scale with less detail (1:75,000 to 1:50,000) that sometimes is not accurate enough to show the specifics of the boundaries of deforested polygons or of rural properties. Therefore, each deforested polygon goes through a thorough analysis, on a scale of greater detail (about 1:25,000), to ensure the correct identification of the soy crop and its delimitation within the polygons, as well as possible shifts of PRODES polygon registrations in order to avoid false positives[4]. Similarly, the other PRODES polygons, where no soy crops were identified, also undergo a thorough inspection to avoid false negatives[5].

4. "False positives" are areas mapped with soy at the landscape level mapping phase, but which need to be adjusted or have parts removed in a more detailed analysis that occurs during the individual inspection of the polygons.

5. "False negatives" correspond to possible errors of omission. In other words, small areas of soy that were not identified in the landscape level mapping phase and which should be added during the individual inspection of the polygons. This also could occur in some first-year soy expansion areas, when they don't show up in typical format on the images and need to pass through a more refined analysis or even possible redefinitions of the soy area boundaries.

The deforested polygons identified with soy crops not in compliance with the Soy Moratorium go through a review process because the deforestation date indicated by PRODES may not coincide with the date specified in the Moratorium. The date review is based on Landsat images obtained from the year 2000 up to the period closest to the Moratorium base date (22nd July 2008), assisted by images from the MODIS sensor for the same period (Figure 8). In this revision process, soy crops on deforestation that occurred before the Moratorium base date are removed. It should be noted that the polygons removed in the date review, in years prior to the current crop year, are excluded beforehand to avoid an unnecessary re-analysis. Deforestation identified with soy in polygons partially located in Conservation Units, Indigenous Lands and Settlements is also subjected to a review. The few soy fields fully contained within these protected areas are eliminated. In other words, they are not inconsistent with the Soy Moratorium and would have been wrongly assigned as the non-compliant soy fields without this review procedure.

Ao final do processo de identificação da soja em desacordo com a Moratória, o INPE realiza, de forma independente, uma rigorosa auditoria dos resultados, atestando a qualidade e a acurácia do trabalho desenvolvido pela Agrosatélite.

Preparation of the list of rural properties with non-compliant soy

From the results obtained in the identification phase of soy crops on land deforested after the Soy Moratorium base date, a list is prepared of the farms, and their respective owners, who are not in compliance with the Moratorium for the signatory companies so they do not acquire or finance soy originating on rural properties included in that list. The penalty in the Soy Moratorium does not cover just the soy crop grown on deforested land, but all the soy grown on that property. Therefore, the Moratorium's impact is very significant in favour of a sustainable soy production in the Amazon Biome.

Contestation by producers

Although the procedure for identifying soy crops on deforestation mapped by PRODES during the Soy Moratorium is carried out stringently, it is possible for an area to be mistakenly identified, whether because it is not a soy crop or because it is on land deforested before the Moratorium. For example, during the process of converting forest to soy, some producers opt to plant rice for a year or two until the area is suitable for planting soy, and this may cause an incorrect classification of the area in some instances. Another example of contestation is when the deforestation occurred before the Moratorium, but was not mapped by PRODES, and went through a regeneration process, followed by new deforestation that is

identified by PRODES within the period of the Moratorium, with subsequent soy planting. However, the great majority of contestation cases are unfounded and are returned with reports prepared on a case-by-case basis. Both the soy mapping and the deforestation date are carefully reviewed beforehand to avoid any contestation as much as possible, since producers are greatly inconvenienced if they are incorrectly included in the list of non-compliant producers as they then cannot sell their production or receive financing, as are the signatory companies who are prevented from buying their soy.

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Appendix 1

Methodology for identifying soy crops using MODIS images from the crop years 2013/14 to 2018/19

The combined analysis of remote-sensing satellite images acquired from sensors with different spatial and temporal resolutions has ensured the identification of soy crops on the deforestation monitored by the Soy Moratorium. Since the 2013/14 crop year, only satellite images have been used for monitoring in the context of the Moratorium. Until the 2018/19 crop year, the MODIS sensor images were used to obtain a map of the temporal crops throughout the study area – which are mostly soy crops – for further refinement using the Landsat and Sentinel satellite images.

Starting in the 2019/20 crop year, soy mapping began to be carried out for the entire Amazon Biome, based on Landsat and Sentinel images using visual interpretation techniques. Thus, MODIS images started to play a secondary role; the procedure adopted in the 2018/19 crop year is described here for information purposes. In this year, about 100 images from the MODIS sensor on board the Terra satellite were used, in addition to 783 images from Landsat-7 and Landsat-8 satellites, and 600 images from the Sentinel-2A and Sentinel-2B satellites.

The acquisition dates of MODIS images take into account the soy calendar adopted in the different regions analysed. To monitor soy grown in the states of Mato Grosso, Rondônia and Tocantins, images from the MODIS sensor obtained from July 2018 to April 2019 were selected. In the states of Maranhão, Pará, Roraima and Amapá, because of the different soy planting calendar, acquisition of the images was extended to the end of August 2019.

The method used to detect the presence of soy and other seasonal crops was based on an index called Crop Enhancement Index (CEI), which highlights the difference in the values of the Enhanced Vegetation Index (EVI) at two specific moments: (a) in the off-season, before the start of the soy growing season, when the EVI values for soy are relatively lower than those for regenerating forest or pasture (MinEVI, Figure A.1), and (b) when the soy is well developed and has EVI values that are higher than those for regenerating forest, cerrado or pasture (MaxEVI, Figure A.1).

High CEI values indicate the presence of seasonal crops, which in the case of the study area are mostly soy. Forest regeneration and pasture have low CEI values due to the lesser extent of their EVI seasonal variation when compared to seasonal crops (Figure A.1). In this way, CEI allows seasonal crops to be differentiated from other land uses and cover, such as regenerating forest and pasture.

Figure A1

Example of temporal variation in EVI values for: early soy; late soy

According to the Mato Grosso calendar; forest; regenerating forest; and cerrado/pasture. Also indicated are the periods where the minimum (MinEVI) and maximum (MaxEVI) EVI values are obtained to calculate the CEI. Furthermore, the approximate CEI values for the targets presented in the graph are shown.

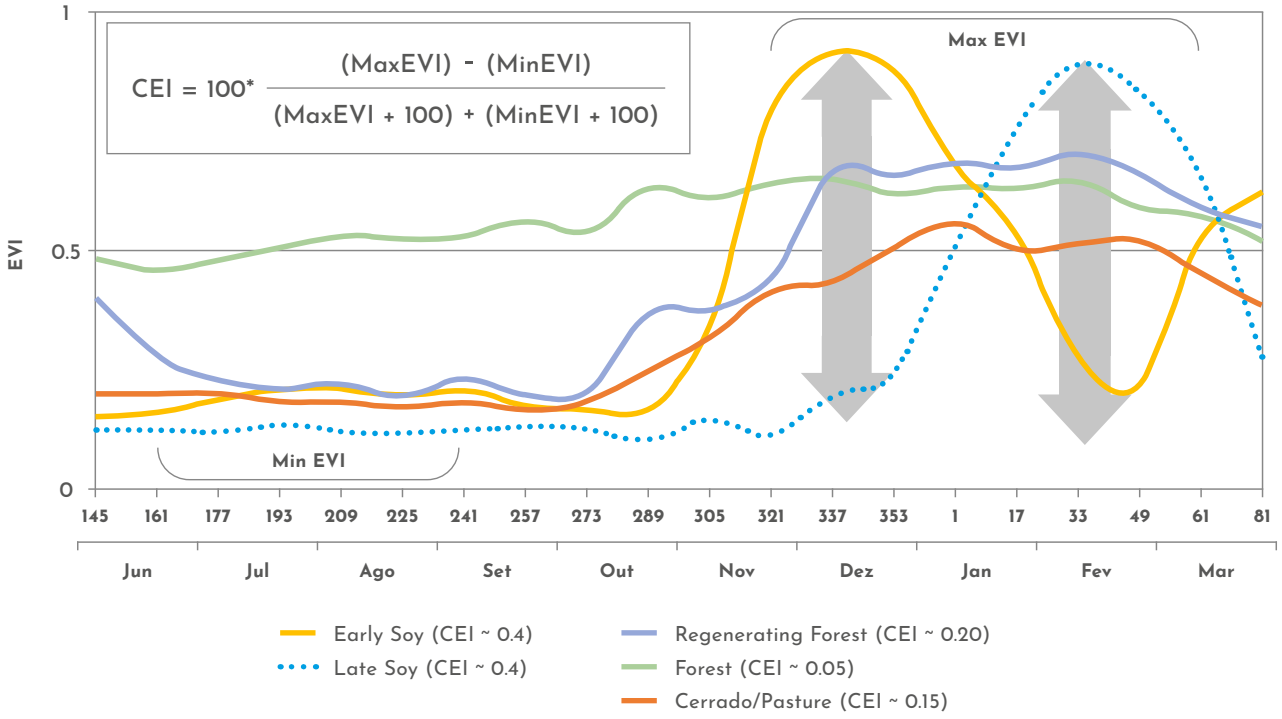


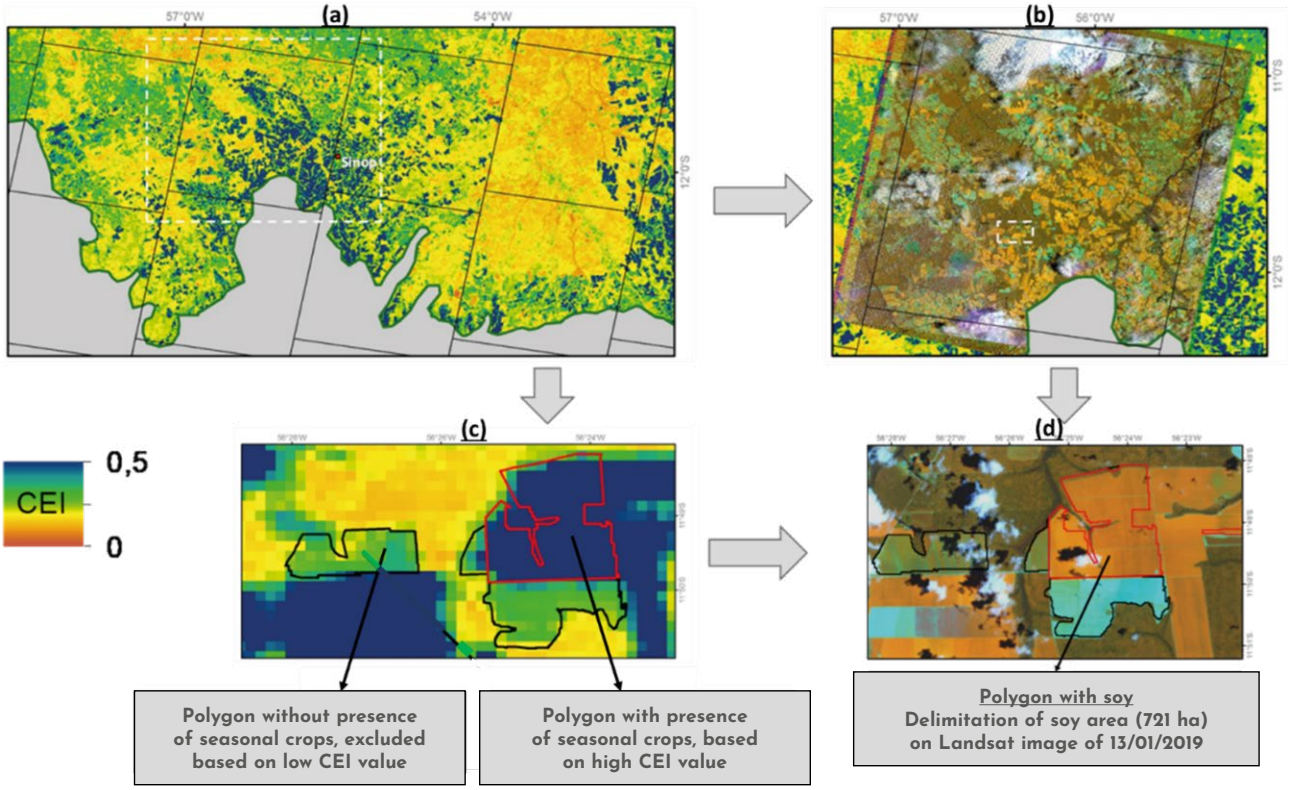
Figure A.2. illustrates the sequence of analysis and identification of the soy crops in the satellite images. Figure A.2a. shows a CEI image where soy and other seasonal crops with similar agricultural calendars are highlighted in dark blue, distinguishing them from the other targets in the image that do not have the characteristic behaviour of seasonal crops. Figure A.2b. shows a Landsat-8 image used in the delineation of soy crops on deforested land. Figure A.2c. shows a detail of the CEI image where two deforested polygons can be seen: one with a low CEI value

(light green) and, therefore, without the presence of a seasonal crop, and the second with a high CEI value typical of a soy or other seasonal crop (dark blue). The presence of soy was confirmed, in this case, with an OLI/Landsat-8 image acquired on 13th January 2019, when 721 hectares of soy were identified and mapped in this deforested polygon, as highlighted Figure A.2d.

Figure A2

Sequence of the identification and mapping of soy crops in satellite images in deforested polygons:

(a) CEI image obtained from EVI/MODIS images, (b) OLI/Landsat-8 image dated 13th January 2019, (c) detail of CEI image identifying areas with and without the presence of seasonal crops, (d) detail of the OLI/Landsat-8 image confirming the presence of 721 hectares of soy in the deforested polygon.



Monitoring of the Soy Moratorium through satellite images:

Supplementary Material

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