MAPBIOMAS

MapBiomas General "Handbook"

Algorithm Theoretical Basis Document (ATBD)

Collection 9

Version 1

August, 2024

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Executive Summary

MapBiomas initiative was formed in 2015 by universities, NGOs, and tech companies to develop a fast, reliable, collaborative, and low-cost method to produce annual time series maps of Brazil's land cover and land use maps (LCLU) at 30 m resolution. The project is organized by biomes (the Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa, and Pantanal) and cross-cutting themes (such as Pasture, Agriculture, Forest Plantation, Coastal Zone, Mining, and Urban Area). A wide range of experts in remote sensing, geography, geology, ecology, environmental and forestry engineering, computer science, human science, journalists, and designers are involved in this project.

Since then, MapBiomas has produced eight sets of annual LCLU digital maps, named Collections. The Landsat satellite image classification methods and algorithms used in each Collection evolved over the years. Collection 1, published in 2016, consisted of the first step of the mapping process, covering the period of 2008 to 2015 and having seven LCLU classes: forest, agriculture, pasture, forest plantation, mangrove, and water. Collection 2, released in 2017, by applying empirical decision tree classification, encompassed the period of 2000 through 2016 and included 13 LCLU classes with subclasses of forest, savanna, grassland, mangrove, beach, urban infrastructure, and more.

Collection 2.3 was based on a new approach of random forest machine learning to overcome empirical calibration of the input parameters for image classification. In 2018, Collection 3 was also based on the random forest algorithm but included a more robust sampling design for training the classifier and expanded the mapping period from 1985 through 2017. In 2019, Collection 4 was produced including 2018 in the time series and other new approaches and methods, such as 1) deep learning in the aquaculture mapping, 2) a per scene-based analysis for the Amazon biome, 3) the collection of 100 thousand samples for accuracy assessment and area estimation, and 4) reduction and better selection of feature space variables.

In 2020, Collection 5 was produced by adding 2019 in the time series and other new improvements and methods; for example, 1) Wetlands were better mapped over the years in the Pantanal biome and also included in the Atlantic Forest biome; 2) The Amazon biome included the new classes Savanna and Grassland Formations in the classification; 3) In Agriculture, perennial and temporary crops were separated, adding the new classes soybean, sugar cane, other temporary crops, and perennial crops. In addition, a beta version of irrigated agriculture maps from 2000 to 2019 was released in the MapBiomas Collection 5.

Collection 6, launched in 2021, including 2020 mapping, presented new classes: Wooded Restinga (only in the Atlantic Forest), Rice, Coffee, Citrus, and Other Perennial Crops, totaling 25 mapped LCLU classes. The Wetland class expanded to the Cerrado and Amazon biomes. Until Collection 5, the classification was performed using Landsat top of atmosphere (TOA) data. In Collection 6, new Landsat mosaics were processed using surface reflectance (SR) data. Using all the images from each year, 90 spectral and temporal metrics were generated. Furthermore, since Collection 6, spatial and temporal filters were not only applied in the mappings of biomes and cross-cutting themes but also at the end on integrated maps. Besides random forests, U-Net (convolutional neural network) was applied in Aquaculture, Mining, Irrigation, Rice and Citrus classification. The classification from MapBiomas Water product was incorporated in the Water class. In the Mining module the data was divided into industrial mining and artisanal (*garimpo)* mining, as well as categorizing the main substance being exploited.

The Collection 7 presented two additional classes: Herbaceous Sandbank Vegetation (only in the Atlantic Forest, Pampa and Caatinga biomes) and Cotton (beta version). The Rocky Outcrop class was included in the Cerrado mapping. In Collection 7, new USGS Landsat surface reflectance images (Collection 2, Tier 1) were used in the classification. The accuracy assessment analysis based on the acquisition of 85,000 independent samples was updated and revised adding the years 2019, 2020, and 2021.

The Collection 8 had the same 27 LCLU classes mapped in the previous collection and included two additional classes: Floodable Forest and Palm Oil, totaling 29 classes, besides adding 2022 and other improvements in the land cover and land use classification. U-Net was expanded to mapping Palm Oil, besides Aquaculture, Irrigation, Rice, Citrus, and Mining.

In the Collection 9, 28 LCLU classes were mapped. The class Other Non Forest Formations present in Collection 8 was excluded, and its area was mapped either as Wetland or as Herbaceous Sandbank Vegetation. Shallow Coral Reef mapping is now available as a new module on the platform, separately from the LCLU data. A new module of LCLU data within different categories of environmental variables, including geomorphology, hypsometry, pedology, vegetation (all at 1:250.000 scale; IBGE 2023), slope and slope orientation (spatial resolution of 30m; NASA JPL 2020) was also made available. Finally, data featuring class transitions related to the industrial and artisanal mining were included in the mining module.

The specific procedures applied in each biome and cross-cutting theme and its improvements in Collection 9 are in the appendices (https://mapbiomas.org/en/download-of-atbds).

This Algorithm Theoretical Basis Document (ATBD) aims to provide the methodological steps of the MapBiomas Collection 9 and describe the datasets and analysis. All the MapBiomas maps and datasets are freely available on the project platform (http://mapbiomas.org), as well as all computational algorithms used in the MapBiomas classifications are available on Github (https://github.com/mapbiomas-brazil).

1. Introduction

1.1. Scope and content of the document

This document describes the theoretical basis, objectives, and methods applied to produce annual maps of land cover and land use (LCLU) in Brazil from 1985 to 2023 of the MapBiomas Collection 9.

This document covers the classification methods of Collection 9, the image processing architecture, and the approach to integrating the biomes and cross-cutting theme maps. In addition, the document presents a historical context and background information, a general description of the satellite imagery datasets, feature inputs, and the accuracy assessment method applied.

The specific procedures applied in each biome and cross-cutting theme are found in the appendices (https://mapbiomas.org/en/download-of-atbds). The classification algorithms are available on MapBiomas Github (https://github.com/mapbiomas-brazil).

1.2. Overview

The MapBiomas project was launched in July 2015, aiming at contributing towards the understanding of LCLU dynamics in Brazil. The LCLU annual maps produced in this project were based on the Landsat series archive available in the Google Earth Engine platform, encompassing the years from 1985 to the present. Since then, the MapBiomas mapping evolved year by year and was divided into Collections (more about MapBiomas' Collections comparisons in Table 5).

- Collection 1: 2008 through 2015 (launched in April 2016)
- Collection 2: 2000 through 2016 (launched in April 2017)
- Collection 2.3: a revised version of Collection 2 (launched in December 2017)
- Collection 3: 1985 through 2017 (launched in August 2018)
- Collection 4: 1985 through 2018 (launched in August 2019)
- Collection 5: 1985 through 2019 (launched in August 2020)
- Collection 6: 1985 through 2020 (launched in August 2021)
- Collection 7: 1985 through 2021 (launched in August 2022)
- Collection 8: 1985 through 2022 (launched in August 2023)
- Collection 9: 1985 through 2023 (launched in August 2024)

The MapBiomas collections aim at contributing to develop a fast, reliable, collaborative, and low-cost method to process large-scale datasets and generate historical time-series of LCLU annual maps. All data, classification maps, codes, statistics, and further analyses are openly available through the MapBiomas Platform (https://plataforma.brasil.mapbiomas.org/). All these are possible thanks to: i) Google Earth Engine platform, which provides access to data, image processing, standard algorithms, and the cloud computing facility; ii) freely available Landsat time-series datasets; iii) MapBiomas collaborative network of organizations and experts that share knowledge and mapping tools; and iv) visionary funding agencies that support the project (Souza Jr et al., 2020).

The products of the MapBiomas Brazil's LCLU Collection 9 are the following:

• Biome maps (Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa, and Pantanal) and cross-cutting theme maps (Pasture, Agriculture, Forest Plantation, Coastal Zone, Mining, and Urban Area);
• Pre-Processed feature mosaics generated from Landsat archive collections (Landsat 5, Landsat 7, Landsat 8, and Landsat 9).
• Image processing infrastructure and algorithms (scripts in Google Earth Engine and source code).
• LCLU transition statistics and spatial analysis with political territories, watersheds, protected areas, and other land tenure categorical maps.
• Quality assessment of the Landsat mosaics. Each scene may have a proportion of clouds and other interference. Thus, each pixel in a given year was qualified according to the number of available observations, varying from 0 to 23 observations per year. The quality assessment of the Landsat mosaics is available on the MapBiomas website.
• LCLU data around buffers of infrastructure (transportation, energy, mining, agribusiness and telecommunication).
• Annual and accumulated deforestation maps (from 1987 to 2023).
• Annual maps of secondary vegetation (from 1987 to 2023) and age of secondary vegetation maps.
• Irrigation maps (for center pivot irrigation systems, irrigated rice, and other irrigation systems).
• Pasture vigor condition annual maps (from 2000 to 2022).
• Industrial and artisanal (*garimpo*) mining annual maps and its main substances.
• Temporal analysis (number of classes, stable areas, and number of changes).

Besides these products, the MapBiomas network released the MapBiomas Water Collection 3 and MapBiomas Fire Collection 3 featuring annual and monthly maps of Brazil's water surface and fire scars from 1985 to 2023, respectively. Annual maps of topsoil (0 - 30 cm) organic carbon stocks from 1985 to 2021 were launched as part of the MapBiomas Soil Beta Collection, along with the open soil research data repository SoilData.

The MapBiomas initiative also expanded to other regions and countries, such as the Chaco region with its Collection 4 (https://chaco.mapbiomas.org/), the Amazon region with its Collection 5 (https://amazonia.mapbiomas.org/), Collection 2 MapBiomas Atlantic Forest (https://bosqueatlantico.mapbiomas.org/), Collection 2 South American Pampa (https://pampa.mapbiomas.org/), Collection 2 Peru (https://peru.mapbiomas.org/), Collection 2 Bolivia (https://bolivia.mapbiomas.org/), Collection 2 Indonesia (https://mapbiomas.nusantara.earth/), and most recently in Chile (https://plataforma.chile.mapbiomas.org/), Argentina (https://plataforma.argentina.mapbiomas.org/), Colombia (https://plataforma.colombia.mapbiomas.org/), Venezuela (https://plataforma.venezuela.mapbiomas.org/), Ecuador (https://plataforma.ecuador.mapbiomas.org/), Uruguay (https://plataforma.uruguay.mapbiomas.org/) and Paraguay (https://plataforma.paraguay.mapbiomas.org/) with Collection 1. These new project areas follow the mapping protocol of MapBiomas Brazil with adjustments considering the particular characteristics of their ecosystems and local teams. Detailed methodological information about these MapBiomas initiatives is found at the ATBD of these regions.

1.3. Region of Interest

MapBiomas was created to produce annual maps of LCLU for the entire Brazilian territory, thus covering all the six official biomes of the country: Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa, and Pantanal (Figure 1). A biome is a geographic region defined based on vegetation types associated with geomorphological and climatic conditions. The biomes' division helps classify distinct LCLU classes and landscape patterns across the country (Table 1). The project was also divided into cross-cutting themes: Agriculture, Pasture, Forest Plantation, Coastal Zone, Mining, and Urban Area.

For the first MapBiomas collections, a 1:1,000,000 map of the biomes was produced based on the refinement of the official map of biomes in Brazil published by IBGE (map scale of 1:5,000,000), while considering the Brazilian boundaries map (map scale of 1:250,000) and maps featuring vegetation physiognomies (map scale of 1:1,000,000), both from IBGE. Since Collection 5, the new official Brazilian biomes map (1:250,000) developed by IBGE (2019) has been used. Additionally, a 2 km buffer was used in the coastal zone beyond the biome limits in order to avoid cutting coastal areas out of the map. The buffer was intersected with the coastal and marine zone from IBGE.

Figure 1. Brazilian biomes were mapped in the MapBiomas project to generate the Collection 9 products (source: IBGE, 2019).

Table 1. Land cover and land use characteristics of the Brazilian biomes.

Biome	Area (km²) (Country %)	Land Cover	Predominant Land Use
Amazon	4,196,943 (49.29%)	Evergreen forest, with enclaves of savanna, natural grassland, and extensive wetlands and surface water, with almost 20% of the forest area of the biome cleared.	Cattle ranching, agriculture, mining, logging and non-timber forestry production.

Atlantic Forest	1,110,182 (13.04%)	Isolated forest fragments (Morellato & Haddad, 2000), mostly old secondary growth, surrounded by croplands, pasture, forest plantation, and urban area.	Agriculture, cattle ranching, urban, forest plantation, artificial water reservoir.
Caatinga	844,453 (9.92%)	Woody and deciduous forest, with at least 50% of the original converted (de Oliveira et al., 2012).	Agriculture, cattle ranching, smallholder livestock production, urbanization.
Cerrado	2,036,448 (23.92%)	Mosaic of savanna, grassland, and forest, 50% of the native vegetation cover has already been converted (PPCerrado/INPE).	Agriculture, cattle ranching.
Pampa	176,496 (2.07%)	Natural grassland, with scattered shrub and trees, rock outcrop formations (Roesch et al., 2009).	Agriculture (rice, soy, perennial crops), livestock production (in natural grasslands), forest plantation, and urbanization.
Pantanal	150,355 (1.76%)	Forest, savanna, grassland and wetland.	Agriculture and cattle ranching.

1.4. Key Science Applications

MapBiomas was originally designed to fill knowledge gaps in Brazil's greenhouse gas emission estimates from the LCLU change sector. However, other scientific applications can be derived from an annual time-series history of LCLU maps produced, including:

- Mapping and quantifying LCLU transitions
- Quantification of gross and net forest cover loss and gain
- Monitoring of natural regeneration and secondary growth forests
- Monitoring of water resources and their interaction with LCLU classes
- Monitoring agriculture and pasture expansion
- Monitoring natural disasters
- Expansion of infrastructure and urbanization
- Identification of desertification process
- Regional planning
- Management of protected areas
- Land change modeling
- Infectious disease risk modeling
- Climate change modeling

The MapBiomas Award was created in 2019 to promote and expand technical and scientific applications that use any MapBiomas initiative and product data, including initiatives from other countries. The award is now in the sixth edition, presenting six categories: General, Youth, Outstanding Applications in Public Policies, Outstanding Applications in Business, Applications in Schools, and Actions against Deforestation. (https://mapbiomas.org/en/premio).

2. Overview and Background Information

2.1. Context and Key Information

This section addresses complementary contextual and critical information relevant to understand the MapBiomas products and methods to generate the collections.

2.1.1. MapBiomas Network

MapBiomas is a multi-institutional initiative of the Climate Observatory, a network of NGOs working on climate change in Brazil (https://www.oc.eco.br/en/). The co-creators of MapBiomas involve NGOs, universities, and technology companies (list of all organizations engaged in Annex I). These organizations play specific or multiple roles and contribute to the project's overall development. Each biome and cross-cutting theme (Agriculture, Pasture, Forest Plantation, Coastal Zone, Mining, and Urban Area) has a lead organization, as shown in the box below.

Biome coordination:

• **Amazon** – Institute of People and Environment of the Amazon (IMAZON).

• **Atlantic Forest** – SOS Atlantic Forest Foundation and ArcPlan.

• **Caatinga** – State University of Feira de Santana (UEFS), Northeast Plants Association (APNE), and Geodatin.

• **Cerrado** – Amazon Environmental Research Institute (IPAM).

• **Pampa** – Federal University of Rio Grande do Sul (UFRGS) and GeoKarten.

• **Pantanal** – SOS Pantanal Institute and ArcPlan.

Cross-cutting theme coordination:

• **Pasture** – Federal University of Goias (LAPIG/UFG).

• **Agriculture and Forest Plantation** – Agrosatelite until collection 8. Remap in collection 9

• **Coastal Zone and Mining** – Solved and Vale Technological Institute (ITV).

• **Urban Area** – University of São Paulo (USP - QUAPÁ-FAU and YBY), Federal University of Bahia (UFBA), and Federal University of São Carlos (UFSCar - NEEPC).

The geospatial tech company Ecostage is responsible for the workspace/backend and dashboard/website/frontend of MapBiomas. The Federal University of Technology - Paraná oversees the data repositories of the MapBiomas Network. Google provides the cloud computing infrastructure that allows data processing and analysis through Google Earth Engine and storage through Google Cloud Storage.

Since the beginning of MapBiomas, the funding for the initiative's implementation and operationalization comes from the Amazon Fund, Arapyaú Institute, Children's Investment Fund Foundation (CIFF), Climate and Land Use Alliance (CLUA), Good Energies Foundation, Gordon & Betty Moore Foundation, Humanize Institute, Institute for Climate and Society (iCS), Montpelier Hampshire Foundation, Mulago Foundation, Norway's International Climate and Forest Initiative (NICFI), Global Wildlife Conservation (GWC), OAK Foundation, Quadrature Climate Foundation (QCF), Sequoia Foundation, Skoll Foundation, Walmart Foundation (U.S.), and Woods & Wayside International.

Since both Climate Observatory and MapBiomas are not institutions, the initiative received generous institutional management to operational and financing tasks from partners, including Arapyaú Institute, IAMAP, Avina Foundation, and World Resources Institute (WRI).

The project also has an independent Scientific Advisory Committee (SAC), presently composed by:

- Dr. Alexandre Camargo Coutinho (Embrapa)
- Dr. Edson Eygi Sano (IBAMA)
- Dr. Gerd Sparovek (University of São Paulo)
- Dra. Leila Maria Garcia Fonseca (INPE)
- Dra. Liana Oighenstein Anderson (CEMADEN)
- Dra. Marina Hirota (Federal University of Santa Catarina)

And also former members who contributed to the project’s development on previous collections:

- Dr. Gilberto Camara Neto (INPE)
- Dr. Joberto Veloso de Freitas (Federal University of Amazonas)
- Dr. Matthew C. Hansen (Maryland University)

- Dr. Mercedes Bustamante (University of Brasília)
- Dr. Timothy Boucher (TNC)
- Dr. Robert Gilmore Pontius Jr (Clark University)

2.1.2. Remote Sensing Data

The imagery dataset used in the MapBiomas project from Collections 1 to 9 was obtained by the Landsat sensors Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and the Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS), onboard of Landsat 5, Landsat 7, Landsat 8, and Landsat 9, respectively. The Landsat imagery collections with 30 meter resolution were accessible via Google Earth Engine and produced by NASA and USGS.

In earlier collections, MapBiomas primarily used USGS Collection 1 Tier 1 top of the atmosphere (TOA) reflectance. Starting from Collection 6, new Landsat mosaics were processed using surface reflectance (SR) data. However, Collections 7, 8 and 9 used the USGS Landsat Collection 2 (Tier 1).

2.1.3. Google Earth Engine and MapBiomas Computer Applications

MapBiomas image processing is based on Google technology, which includes image processing in cloud computing infrastructure, programming with Javascript and Python via Google Earth Engine, and data storage using Google Cloud Storage. Google defines Google Earth Engine as: “a platform for petabyte-scale scientific analysis and visualization of geospatial datasets, both for public benefit and for business and government users.”

The MapBiomas project has developed the following computer applications based on Google Earth Engine:

• Javascript scripts - these computer codes were written directly in the Google Earth Engine Code Editor and were used to prototype new image processing algorithms and test large-scale image processing to be implemented in the Workspace environment for Collections 1 and 2. Most image classification and post-classification of Collections 2.3, 3, 4, 5, 6, 7, 8 and 9 were written in Javascript.

• Python scripts – This code category was used to optimize the image processing of large datasets in Google Earth Engine. In addition, the map integration, some post-classification tasks, and statistical analysis were all performed in Earth Engine Python API.

• R scripts – Used to improve the processing of large datasets in the Google Earth Engine and to perform machine learning algorithms calibration, data analysis, and visualization.

• Toolkits – User's Toolkits are collections of scripts with a friendly user interface in Google Earth Engine to download MapBiomas' data by state, biome, municipality, or any other geometry. These toolkits were developed for the general public that is not familiar with programming languages used in Google Earth Engine. They are often reviewed and improved. All the toolkits are available at https://mapbiomas.org/en/tools. Instructions are also available on GitHub (https://github.com/mapbiomas-brazil/user-toolkit).

• Github repository - All Javascript, Python, R, toolkit, and dashboard codes are available at the public GitHub repository: (https://github.com/mapbiomas-brazil).

• Workspace - a web-based application to allow general users with no-programming experience to access imagery collections, process them, manage, and store the results in databases and map assets (*i.e.*, new collections). The biome maps of Collections 1 and 2 were produced using the Workspace application before the random forest approach classification. The biome teams of analysts worked simultaneously to set the image classification parameters, pre-process, and evaluate the results and later submit tasks to large-scale image processing to generate the final products, which were the Landsat image mosaics and LCLU maps.

• Mapbiomas.org (Dashboard). The web platform of the MapBiomas initiative presents the Landsat image mosaics and their quality, LCLU annual maps of Collection 9, transitions analysis, statistics, and all the methodological information about the ATBD, tools, scripts, fact sheets, tutorial videos, and accuracy analysis. Besides the land cover and land use change data, the MapBiomas dashboard presents other products, such as deforestation, secondary vegetation, irrigation, infrastructure, pasture quality, fire scars, mining, soil organic carbon stocks, and water surface mappings. All Landsat mosaics, maps, data, and methodological documents of the MapBiomas Collections are freely available to download, and information about the MapBiomas initiative at the MapBiomas website (http://mapbiomas.org/en).

2.2. Historical Perspective: Existent Mapping Initiatives

The existing LCLU mapping efforts that covered all of Brazil before MapBiomas were neither frequent nor updated (Annex II) and sometimes had coarse resolution. MapBiomas and the available global and national land cover products can be used complementary, but there are potential advantages of MapBiomas maps. First, the MapBiomas maps reconstruct the entire Landsat annual time series (>35 years). The classification scheme is also more relevant for national applications because it follows the Brazilian vegetation classification legend (IBGE, 2012). In addition, MapBiomas has the potential to monitor primary forest changes (*i.e.,* deforestation), secondary forest regrowth, and land use classes (pasture, agriculture, forest plantation, mining, and urban area) along with this time series.

All products from MapBiomas and methods and codes to produce the maps are publicly available on the internet. This enables its reproduction in other contexts, just as it is currently taking place in all other Amazonian nations (Peru, Ecuador, Bolivia, Colombia, Venezuela, Guyanas, and Suriname - http://amazonia.mapbiomas.org/en), the Chaco region (Argentina, Bolivia, and Paraguay - http://chaco.mapbiomas.org/en), and the Pampa region (Brazil, Argentina, and Uruguay - https://pampa.mapbiomas.org/en)

2.2.1. Global Land Cover and Land Use Data

Mapping initiatives at the global level complement national mapping efforts (Annex II). In collaboration with the University of Maryland, the USGS produced global land cover and tree cover layers. USGS also has a MODIS land cover map at a 500 m pixel size. The GlobCover Portal is another initiative from the European Space Agency (ESA) which produced land cover maps with MERIS sensor at 300 m spatial resolution for two periods: December 2004 - June 2006 and January - December 2009. Later, the ESA Climate Change Initiative produced global land cover maps from 1992 to 2015 at 300 m spatial resolution and Global Sentinel 2 Land Cover for 2020 with 10 m resolution (https://viewer.esa-worldcover.org/worldcover/). Global Forest Watch (GFW) and Google Earth Engine provide the Global Forest Change (GFC) maps from 2000 to 2019 derived from the Landsat imagery at 30 m resolution produced by the University of Maryland (Global Land Cover Facility - GLCF). The National Geomatics Center of China (NGCC) had GlobeLand30 - a high-resolution (30 m) full coverage land cover map for the years 2000 and 2010 (Chen et al. 2014). Japan Aerospace Exploration Agency (JAXA) also produced a forest/non-forest map for 2007-2010 using a 25 m-resolution PALSAR mosaic. Most recently, an automated approach for global land use land cover (LCLU) classification was published using deep learning on 10 m Sentinel-2 imagery (Brown et al. 2022). Other global products were produced using coarser spatial resolution (>500 m) (e.g. Friedl et al. 2010) but are not listed here because their resolution limits applications to assess MapBiomas products, which are produced at 30 m Landsat pixel size.

2.2.2. National Land Cover and Land Use Data

The RadamBrasil project was the first national initiative to map the vegetation of the entire Brazilian territory. The project was conducted from 1975 to 1980 and was based on airborne radar imagery, visual interpretation, and extensive and detailed fieldwork involving several organizations. The RadamBrasil project produced maps at a 1:250.000 scale, which is still a solid reference for scientific and technical studies about Brazilian vegetation (Cardoso, 2009).

Only the Amazon and Atlantic Forest biomes were being monitored using other systems, so after the RadamBrasil project, the Minister of Environment launched the natural vegetation map of Brazil in 2004. This map was created as part of the Probio (Projeto de Conservação e Utilização Sustentável da Diversidade Biológica Brasileira) initiative. The Brazilian biome boundaries (IBGE, 2004a) were used as a reference for the national mapping initiative. The Probio project was based on Landsat imagery acquired in 2002, with a minimum mapping unit varying from 40 to 100 hectares and a cartographic scale of 1:250.000. The accuracy assessment was based on digital imagery products at a 1:100.000 scale, with a minimum overall accuracy of 85%. The land cover classes followed the IBGE manual for vegetation mapping (IBGE, 2004b). The Probio project updated forest change mapping for all biomes in the year 2008 and the years 2009, 2010, and 2011 depending on the biome.

In the context of the National Inventories of GHG Emissions and Removals, the Ministry of Science and Technology commissioned the production of land cover and land use maps of Brazil for the years 1994, 2002, 2010 (also 2005 for the Amazon), and 2016. Those maps were produced based on segmentation and visual interpretation of Landsat Imagery and identifying natural vegetation (forest and non-forest), agriculture, pasture, silviculture, urban area, dunes, rock outcrops, mining, and water on the 1:250.000 cartographic scale.

More recently, IBGE published a platform to monitor LCLU change in Brazil, making available maps for the years 2000, 2010, 2012, 2014, 2016, 2018 and 2022 on a 1 km resolution and covering the classes of forests, savannas, agriculture, pasture, urban areas, water, and mosaics of those classes.

2.2.3. Regional and Biomes Land Cover and Land Use Data

There are also reference LCLU maps (i.e. maps emphasizing the location of geographic features) at the biome scale and through the cross-cutting themes. For example, the PRODES and the TerraClass maps are available for all biomes. These reference LCLU maps for the biomes and cross-cutting themes are presented in Annex II.

3. Methodological Description

The Collection 9 general methodological steps are presented in Figure 2. The first step was to generate annual Landsat mosaics comprising specific temporal windows to optimize the spectral contrast and better discriminate the LCLU classes across the biomes and cross-cutting themes (see the biome and cross-cutting theme Appendices for detailed information). The second step was to derive all feature space attributes from the Landsat bands to train one random forest classifier (feature space definition) for each year (Breiman, 2001). Then, yearly training samples were acquired in each biome and cross-cutting theme according to its information availability and statistical needs. The output of the random forest classifier is one LCLU map per year for the entire territory based on the training dataset of that year. The exceptions are the classes Aquaculture, Mining, Irrigation, Rice, Palm Oil, and Citrus, which had their areas of occurrence identified using the U-Net convolutional neural network classifier (CNN).

Spatial-temporal filters were applied over the classified data for noise removal and temporal stabilization. Subsequently, the filtered LCLU maps of each biome and cross-cutting themes were hierarchically merged (integrated) based on a set of prevalence rules. The prevalence rules were set using expert knowledge and are described in Table 4. Spatial and temporal filters were once again applied on the integrated maps to create the final Collection 9 product.

The accuracy assessment analysis was based on acquiring 75,000 independent samples per year from 1985 to 2022. The acquisition of the validation samples followed the good practices proposed by Olofsson et al. (2014), Stehman et al. (2014), and Stehman & Fody (2019). The transitions and statistics of each class were derived from the annual LCLU maps. The statistical analysis covered different spatial categories, such as biome, state, municipality, watershed, and protected areas.

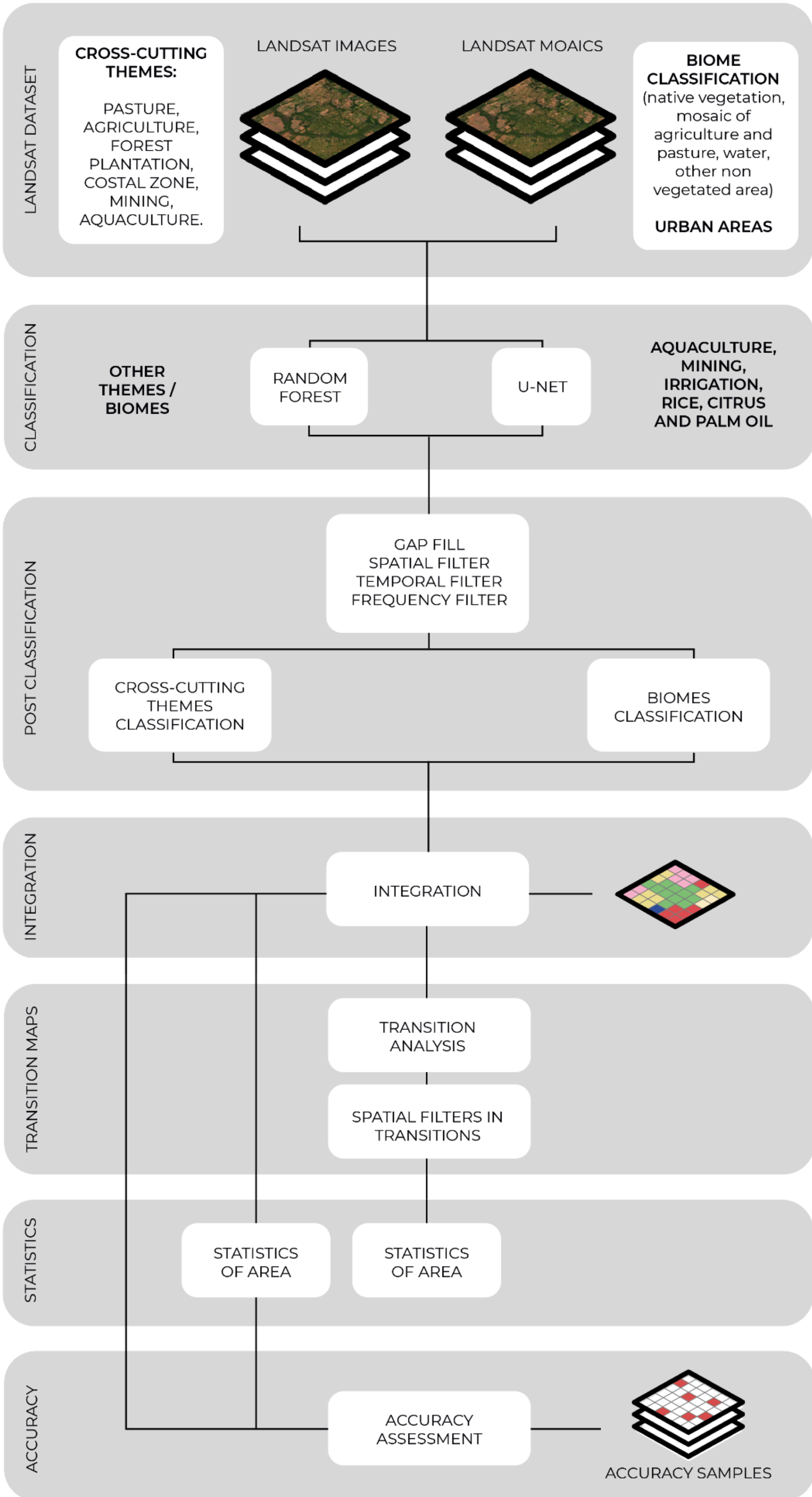

Figure 2. General methodological steps of MapBiomas Brazil Collection 9.

3.1. Landsat Mosaics

All biomes except Amazon generated Landsat cloud-free composites based on specific periods of time to optimize the spectral contrast and help within the discrimination of LCLU classes. The cloud/shadow removal script takes advantage of the quality assessment (QA) band and the GEE median reducer. The QA values can improve data integrity by indicating which pixels might be affected by artifacts or subject to cloud contamination (USGS, 2017). In conjunction, GEE can be instructed to pick the median pixel value in a stack of images. By doing so, the engine rejects values that are too bright (e.g., clouds) or too dark (e.g., shadows) and picks the median pixel value in each band over time.

In Collection 7, 8 and 9, new USGS Landsat surface reflectance images (Collection 2, Tier 1) were used in the classification. For each chart, a specific temporal mosaic of Landsat images was built based on the following selection criteria/parameters: 1. The selected Landsat data must enable an annual analysis, and 2. The period for Landsat scene selection (t0 and t1 in day/month/year) must provide enough spectral contrast to better distinguish LCLU classes.

The cross-cutting themes (Pasture, Agriculture, Forest Plantation, Urban Area, Coastal Zone, and Mining) processed Landsat mosaics per scene basis (more details available cross-cutting theme Appendices). To reduce noise and improve the mosaic quality, a tool was developed to evaluate the images individually, excluding uninformative images (excess cloud cover). The Amazon biome classified each Landsat image using Random Forests and reclassified the results to create the annual LCLU maps.

3.2. MapBiomas feature space

The feature space for LCLU classification is composed of 119 input variables per year, including the original Landsat bands and fractional and textural information derived from those bands (Table 2). Table 2 presents the formula or the description to obtain these variables, as well as highlights in green all the bands, indices, and fractions available in the feature space. In addition, statistical reducers were used to generate temporal features such as:

- Median: median of the pixel values within the defined stack of images
- Median_dry: median of the quartile of the lowest pixel NDVI values
- Median_wet: median of the quartile of the highest pixel NDVI values
- Amplitude: amplitude of variation of the index considering all the year's images
- stdDev: stdDev of the pixel values within the defined stack of images
- Min: the lower annual value of the pixels of each band
- Max: the higher annual value of the pixels of each band

Table 2. List, description, and reference of bands, fractions and indices available in the feature space.

			Reducer						
	band or index name	**formula**	**median**	**median _dry**	**median _wet**	**ampl.**	**stdDev**	**min**	**max**
bands	blue	B1 (L5 e L7); B2 (L8)							
	green	B2 (L5 e L7); B3 (L8)							
	red	B3 (L5 e L7); B4 (L8)							
	nir	B4 (L5 e L7); B5 (L8)							
	swir1	B5 (L5 e L7); B6 (L8)							
	swir2	B7 (L5); B8 (L7); B7 (L8)							
	temp	B6 (L5 e L7); B10 (L8)							
index	ndvi	(nir - red)/(nir + red)							
	evi2	(2.5 * (nir - red)/(nir + 2.4 * red + 1)							
	cai	(swir2 / swir1)							
	ndwi	(nir - swir1)/(nir + swir1)							
	gcvi	(nir / green - 1)							
	hall_cover	(-red*0.017 - nir*0.007 - swir2*0.079 + 5.22)							
	pri	(blue - green)/(blue + green)							
	savi	(1 + L) * (nir - red)/(nir + red + 0,5)							
	textG	('median_green') .entropy(ee.Kernel .square({radius: 5}))							
fraction	gv	fractional abundance of green vegetation within the pixel							
	npv	fractional abundance of non-photosynthetic vegetation within the pixel							
	soil	fractional abundance of soil within the pixel							
	cloud	fractional abundance of cloud within the							

		pixel							
	shade	100 - (gv + npv + soil + cloud)							
MEM index	gvs	gv / (gv + npv + soil + cloud)							
	ndfi	(gvs - (npv + soil))/(gvs + (npv + soil))							
	sefi	(gv+npv_s - soil)/(gv+npv_s + soil)							
	wefi	((gv+npv) - (soil+shade)) /((gv+npv) + (soil+shade))							
slope		ALOS DSM: Global 30m							

Each biome and cross-cutting theme executed a feature selection algorithm to choose the most appropriate subset of variables to train the respective random forest classifier. More details are available in the Appendices.

3.3. Classification

3.3.1. Legend

The MapBiomas classification scheme is a hierarchical system comprising four categorical levels (Table 3). At Level 1, there are six classes: 1) Forest, 2) Herbaceous and shruby vegetation, 3) Farming, 4) Non-Vegetated Area, 5) Water, and 6) Not Observed. Level 2 has 16 classes across the six classes of the first categorical level. Agriculture (3.2) is the only class with further subdivisions down to the fourth categorical level, comprising nine LCLU classes.

Annex III presents the cross-reference of the MapBiomas LCLU classes with classes from other classification systems (*i.e.*, FAO, IBGE, and National GHG Emissions Inventory). Annex IV presents the classification scheme of the previous collections of MapBiomas.

Table 3. Classes of land cover and land use of MapBiomas Collection 9 in Brazil.

ID	COLLECTION 9 CLASSES	NATURAL/ ANTHROPIC	LAND COVER/ LAND USER	BIOMES/ THEMES
1	**1. Forest**	NATURAL	COVER	-
3	1.1. Forest Formation	NATURAL	COVER	BIOMES
4	1.2. Savanna Formation	NATURAL	COVER	BIOMES
5	1.3. Mangrove	NATURAL	COVER	THEMES

6	1.4. Floodable Forest	NATURAL	COVER	
49	1.5. Wooded Sandbank Vegetation	NATURAL	COVER	BIOMES
10	**2. Herbaceous and shruby vegetation**	NATURAL	COVER	-
11	2.1. Wetland	NATURAL	COVER	BIOMES
12	2.2. Grassland Formation	NATURAL	COVER	BIOMES
32	2.3. Salt Flat	NATURAL	COVER	THEMES
29	2.4. Rocky Outcrop	NATURAL	COVER	BIOMES
50	2.5. Herbaceous Sandbank Vegetation	NATURAL	COVER	BIOMES
14	**3. Farming**	ANTHROPIC	USE	-
15	3.1. Pasture	ANTHROPIC	USE	THEMES
18	3.2. Agriculture	ANTHROPIC	USE	THEMES
19	3.2.1. Temporary Crop	ANTHROPIC	USE	THEMES
39	3.2.1.1. Soybean	ANTHROPIC	USE	THEMES
20	3.2.1.2. Sugar cane	ANTHROPIC	USE	THEMES
40	3.2.1.3. Rice	ANTHROPIC	USE	THEMES
62	3.2.1.4. Cotton	ANTHROPIC	USE	THEMES
41	3.2.1.5. Other Temporary Crops	ANTHROPIC	USE	THEMES
36	3.2.2. Perennial Crop	ANTHROPIC	USE	THEMES
46	3.2.2.1. Coffee	ANTHROPIC	USE	THEMES
47	3.2.2.2. Citrus	ANTHROPIC	USE	THEMES
35	3.2.2.3. Palm Oil	ANTHROPIC	USE	THEMES
48	3.2.2.4. Other Perennial Crops	ANTHROPIC	USE	THEMES
9	3.3. Forest Plantation	ANTHROPIC	USE	THEMES
21	3.3. Mosaic of Uses	ANTHROPIC	USE	BIOMES
22	**4. Non Vegetated Area**	NATURAL/ ANTHROPIC	COVER/USE	-
23	4.1. Beach, Dune, and Sand Spot	NATURAL	COVER	THEMES
24	4.2. Urban Area	ANTHROPIC	USE	THEMES
30	4.3. Mining	ANTHROPIC	USE	THEMES
25	4.4. Other Non Vegetated Areas	NATURAL/ ANTHROPIC	COVER/USE	BIOMES
26	**5. Water**	NATURAL/ ANTHROPIC	COVER/USE	-
33	5.1. River, Lake and Ocean	NATURAL	COVER	BIOMES
31	5.2. Aquaculture	ANTHROPIC	USE	THEMES
27	6. Not Observed	NONE	NONE	NONE

3.3.2. Training samples

Samples for training the yearly random forest classifiers were obtained using random sampling from areas with LCLU classes that did not change across all years of Collection 8 (stable classes). When necessary, additional samples were collected. The Amazon biome and cross-cutting themes used different sampling designs (see more details in the Appendices).

3.3.3. Classification

Random forest demands the definition of a few parameters, such as the number of trees, a list of variables, and training samples. The appendices of the biomes and cross-cutting themes detail these parameters, variables, and the number of training samples. Besides random forest, deep learning algorithms were used, such as U-Net (convolutional neural network) in Aquaculture, Mining, Irrigation, Rice, Citrus, and Palm Oil classification.

In collection 9 all classifications used either the MULTIPROBILITY output mode, when more than two classes were mapped, or the PROBABILITY output mode, in the case of binary classifications (such as pasture and urban areas).

3.4. Post-classification

3.4.1. Spatial and temporal filters

Due to the pixel-based classification method and the long time series, post-classification filters were applied to remove classification noises. Each biome and cross-cutting theme map was produced using a particular set and sequence of filters, which are detailed in the respective appendices. The applied filters in each case may include:

- Time-wise gap fill: a temporal filter used to fill no-data values.

- Spatial filter: removes isolated pixels.

- Temporal filter: backward moving windows of three and four (all classes) and five (forest) years that identify temporally unrealistic transitions between LCLU classes.

- Frequency filter: considers the frequency with which a LCLU class occurs throughout the entire time series, reducing the temporal oscillation associated with a given natural class, decreasing the number of false positives and preserving consolidated trajectories.

- Incident filter: changes the value of pixels that had changed too many times along the 39 years period.

These post-classification procedures were implemented in the Google Earth Engine platform.

3.4.2 Integration

The maps of each biome and of cross-cutting themes were integrated on a pixel-by-pixel basis through the hierarchical overlap of each mapped class, following prevalence rules defined by experts. Certain prevalence rules may show exceptions for one or more classes. Some classes present specific prevalence rules or exceptions in certain biomes or regions. The Lagoa dos Peixes, for instance, is a region in the Pampa biome with very particular characteristics where many exceptions to the prevalence rules were necessary. From 2019 onwards, if the MapBiomas Alerta accumulated mask overlaps with any natural class, the class 21 is applied. The prevalence rules and its exceptions are listed in the Annex V and details about biome-wise prevalence rules are described in the respective Appendices.

3.4.3. Filters on Integrated Maps

A spatial filter similar to the one described in 3.4.1 was applied on the integrated maps to remove isolated classes with less than half a hectare as well as noise resulting from integration. A temporal filter was applied on isolated pixels over the time series. After the application of the spatial filter a temporal filter was applied on integrated maps.

3.4.4. Transition Maps

The pixel-by-pixel class differences between any two maps were computed for the following periods: (A) any consecutive years (e.g. 2001-2002); (B) five-year periods (e.g. 2000-2005); (C) Forest Code period (2008-2023); (D) Forest Code approval (2012-2023); (E) National GHG Inventory (1994-2002; 2002-2010; 2010-2016); (F) all the years (1985-2023). The class transitions represent LCLU changes such as: Transitions from classes of agriculture or non-vegetated areas to forest cover or natural non-forest areas; Transitions that add water surface; Transitions that reduce water surface; Transitions with gain in forest plantation areas; Transitions from forest cover or natural non-forest areas to agriculture or non-vegetated areas; and Areas without transition or transitions that involve not observed areas or transitions between classes within level 1 of legend.

3.4.5. Spatial Filter on Transition Maps

A spatial filter similar to the one described in 3.4.1 was applied in the transition maps. The target is to eliminate single pixels or streams of pixels in the border of different classes derived from the creation of transition maps. The general rules for this filter were: (i) pixels with only one neighbor pixel in the same transition class; (ii) streams of up to five pixels with two or one neighbor pixel in the same transition class.

3.4.6. Temporal Analysis

Since Collection 7, new temporal analyses besides the transition maps are present in the MapBiomas platform: stable areas, number of classes and number of changes. The stable area tool shows areas that stayed in the same LCLU class throughout the years in the temporal extent selected by the user. The number of classes tool shows the number of LCLU classes a pixel was classified as during the temporal extent selected by the user, while the number of changes shows the number of changes between LCLU classes a pixel went through during the temporal extent selected. Both tools consider a temporal resolution of one year and allows the user to choose the following temporal extents: (a) The whole temporal extent mapped by MapBiomas, from 1985 to 2023; (b) five years e.g. 1985-1990, 1990-1995, 1995-2000; (c) ten years e.g. 1985-1995, 1995-2005, 2005-2015; and (d) about half of the temporal extent mapped by MapBiomas, from 1985 to 2000 and from 2000 to 2023. Results can also be obtained for an individual class and for various legend levels.

3.4.7. Statistics

Zonal statistics of the mapped classes were calculated for different spatial units, such as the biomes, states, and municipalities, watersheds, protected areas (including indigenous lands and conservation units), forest concessions, non-designated public forests, priority areas for biodiversity conservation (MMA, 2018). A toolkit in the Google Earth Engine is available to upload user-defined polygons and download the LCLU maps (https://code.earthengine.google.com/?scriptPath=users%2Fmapbiomas%2Fuser-toolkit%3Amapbiomas-user-toolkit-lulc.js).

Additionally, the Collection 9 LCLU data was calculated for different categories of environmental variables, including geomorphology, hypsometry, pedology, vegetation (all at 1:250.000 scale; IBGE 2023), slope and slope orientation (spatial resolution of 30m; NASA JPL 2020).

3.5. Validation Strategies

The validation strategy was based on two approaches: (i) comparative analysis with reference maps of specific biomes/regions and years, and (ii) accuracy analysis based on statistical techniques using independent sample points covering the entirety of Brazil throughout the time series.

3.5.1. Validation with Reference Maps

Each biome and cross-cutting theme conducted the spatial agreement analysis with reference maps where available. More details are available in the Appendices and on the reference maps webpage (https://mapbiomas.org/en/mapas-de-referencia?cama_set_language=en).

3.5.2. Validation with Independent Points

The 85,000 spatially independent samples, replicated for each of the 38 years between 1985 and 2022, were labeled according to MapBiomas LULC classes by experts after the visual interpretation of Landsat data, MODIS-NDVI times series, and high-resolution imagery from Google Earth (when available). Out of these , 10,000 samples were used as training samples for the Amazon biome. Thus, the error assessment analysis was conducted using ~75,000 samples per year (Figure 3).

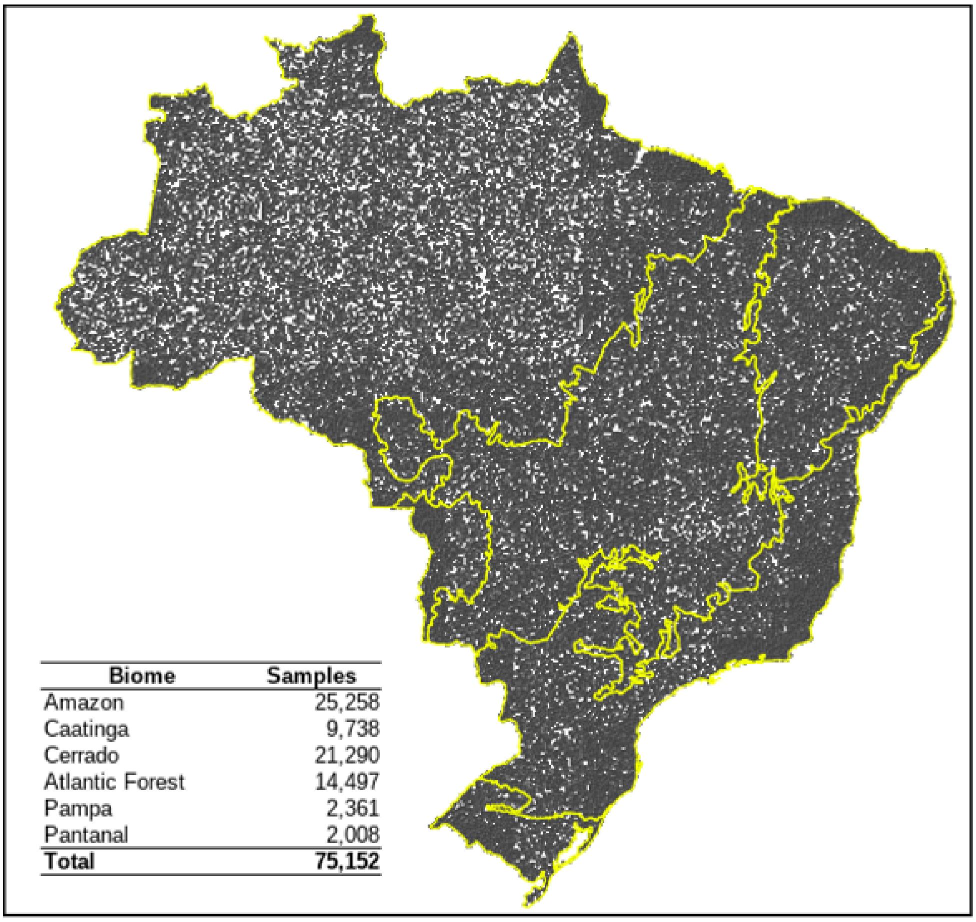

Figure 3. Independent random samples used in the Brazilian biomes for the error assessment analysis of MapBiomas Collections.

The accuracy analysis was based on Stehman et al. (2014) and Stehman & Fody (2019) using the population error matrix and the global, user, and producer accuracies. A detailed description of the accuracy assessment data and methods are available in the Appendix 15.

The global accuracy for each level of LCLU classes in the Collection 9 legend was calculated for each year, class, and biome (more details can be explored in the MapBiomas web platform (brasil.mapbiomas.org/en/analise-de-acuracia/). In Level 1 classes, the LCLU mapping product in the Collection 9 presented 93.1% mean global accuracy and 6.1 % allocation disagreement with 0.8% area disagreement. At Level 2, the global accuracy was 89.8%, with 7.2% allocation disagreement and 2.9% area disagreement. Finally, at Level 3, the global accuracy was 89.8%, with 7.1% allocation disagreement and 3.0% area disagreement. The global accuracy was stable over the mapped period, varying across biomes from 84.6% to 97.7% in Level 1.

4. Map Collections and Analysis

The MapBiomas Collections produced so far are listed and summarized below (Table 5):

• Collection 1 - comprised the period of 2008 to 2016 and was based on empirical decision trees for the biomes and Coastal Zone. Before launching Collection 1, a Beta Collection was produced to test the methodology used in Collection 1.

• Collection 2 - comprised the period of 2000 to 2016 and was based on empirical decision trees for the biomes and Coastal Zone.

• Collection 2.3 - comprised the period of 2000 to 2016 and was based on random forest decision trees for all biomes and the Coastal Zone, Pasture, and Agriculture themes.

• Collection 3 - comprised the period of 1985 to 2017 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Area, Mining, Pasture, and Agriculture themes. Collection 3.1 was published in Remote Sensing (Souza Jr. et al. 2020).

• Collection 4 - comprised the period of 1985 to 2018 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Area, Mining, Pasture, and Agriculture themes, except the Aquaculture that had its classification based on the U-Net convolutional neural network classifier.

• Collection 5 - comprised the period of 1985 to 2019 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Area, Mining, Pasture, and Agriculture themes, except the Aquaculture and Irrigated Agriculture (central pivot) that the classification was based on the U-Net convolutional neural network classifier.

• Collection 6 - comprised the period of 1985 to 2020 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Area, Pasture, and Agriculture themes, except the Aquaculture, Mining, Irrigation, Rice, and Citrus that applied U-Net convolutional neural networks in the classification.

• Collection 7 - comprised the period of 1985 to 2021 and was based on random forest classification for all biomes and the Coastal Zone, Urban Area, Pasture, and Agriculture themes, except the Aquaculture, Mining, Irrigation, Rice, and Citrus that applied U-Net convolutional neural networks in the classification.

• Collection 8 - comprised the period of 1985 to 2022 and was based on random forest classification for all biomes and the Coastal Zone, Urban Area, Pasture, and Agriculture themes, except the Aquaculture, Mining, Irrigation, Rice, Citrus, and Palm Oil that applied U-Net convolutional neural networks in the classification.

• Collection 9 - comprised the period of 1985 to 2023 and was based on random forest classification for all biomes and the Coastal Zone, Urban Area, Pasture, Agriculture and Shallow Coral Reef themes, except the Aquaculture, Mining, Irrigation, Rice, Citrus, and Palm Oil that applied U-Net convolutional neural networks in the classification.

Table 5. MapBiomas' Collection evolution and its period, number of levels, and land cover and land use classes, methods, and global accuracy (Gb) . Ar = area disagreement and All = allocation disagreement.

Collection	Time interval	Classes	Method	Global Accuracy
Beta & 1	8 years 2008-2015	1 level / 7 classes	Empirical Decision Tree + Random Forest (Farming)	n.a.
2.0 2.3	16 years 2000-2016	3 levels / 13 classes	Empirical Decision Tree + Random Forest (Farming) All Random Forest (C2.3)	[C2.3] L1 - Gb **79%** Ar 7% All: 14% L2 - Gb **80%** Ar 11% All: 10% L3 - Gb **74%** Ar 12% All: 14%
3.0 & 3.1	33 years 1985-2017	3 levels / 19 classes	Random Forest	L1 - Gb **89%** Ar 2% All: 9% L2 - Gb **88%** Ar 4% All: 8% L3 - Gb **85%** Ar 5% All: 9%
4.0 & 4.1	34 years 1985-2018	3 levels / 19 classes	Random Forest + U-Net (Aquaculture)	L1 - Gb **90%** Ar 1% All: 8% L2 - Gb **89%** Ar 2% All: 9% L3 - Gb **86%** Ar 2% All: 11%
5.0	35 years 1985-2019	4 levels / 21 classes	Random Forest + U-Net (Aquaculture & Irrigation)	L1 - Gb **91%** Ar 2% All: 7% L2 - Gb **90%** Ar 3% All: 7% L3 - Gb **88%** Ar 4% All: 9%
6.0	36 years 1985-2020	4 levels / 25 classes	Random Forest + U-Net (Aquaculture, Irrigation, Mining, Rice, and Citrus)	L1 - Gb **91%** Ar 2% All: 7% L2 - Gb **87%** Ar 3% All: 9% L3 - Gb **87%** Ar 3% All: 9%
7.0 & 7.1	37 years 1985-2021	4 levels / 27 classes	Random Forest + U-Net (Aquaculture, Irrigation, Mining, Rice, and Citrus)	L1 - Gb **91%** Ar 2% All: 7% L2 - Gb **88%** Ar 3% All: 8% L3 - Gb **88%** Ar 4% All: 8%

8.0	38 years 1985-2022	4 levels / 29 classes	Random Forest + U-Net (Aquaculture, Irrigation, Mining, Rice, Citrus, and Palm Oil)	L1 - Gb **90%** Ar 1% All: 9% L2 - Gb **86%** Ar 5% All: 9% L3 - Gb **86%** Ar 5% All: 9%
9.0	39 years 1985-2023	4 levels / 29 classes	Random Forest + U-Net (Aquaculture, Irrigation, Mining, Rice, Citrus, and Palm Oil)	L1 - Gb **93%** Ar 1% All: 6% L2 - Gb **90%** Ar 3% All: 7% L3 - Gb **90%** Ar 3% All: 7%

Collection 9 resulted not only in a long time series, adding the year 2023, but more spatially and temporally consistent annual LCLU maps of Brazil. The shallow coral reef theme was included as a new module. The post-classification temporal filters were improved. Floodable Forest classification was improved, moving from beta to version 1 and resulting in a larger mapped area. Pantanal improved the differentiation between Forest Formation and Savana Formation and between Grassland and Wetland. The use of PRODES Pantanal as one of the references in the mapping of Pantanal allowed better identification of pasture areas. Rice mapping was improved in Mato Grosso do Sul, Pará and Goiás States. Atlantic Forest reclassified "Other non-forest natural formations" in either Wetland or Herbaceous Sandbank Vegetation. Caatinga introduced the use of Gradient Tree Bost (GTB) as a new classifier, improved the mapping of grasslands and rocky outcrop and in the beginning of the time series. A 2 km buffer was used in the coastal zone beyond the biome limits in order to avoid cutting coastal areas.

All the programming codes for running the MapBiomas classifications are publicly available and accessible through https://github.com/mapbiomas-brazil. All documents and data are available and referenced with a unique digital identifier DOI through the MapBiomas Network Data Repository (https://data.mapbiomas.org/).

5. Concluding Remarks and Perspectives

The algorithms developed for pre-processing and classifying Landsat imagery hold promise for revolutionizing the production of LCLU maps on a large scale. Thanks to Google Earth Engine and open source technology, it is possible to access and process large-scale satellite imagery datasets such as the one generated by the MapBiomas project. The replication of this type of project is viable for other areas of the planet. The MapBiomas initiative has expanded to all South American countries and Indonesia. In addition, the MapBiomas team will keep improving the following collections in subsequent years. The open-access MapBiomas LCLU dataset allowed several scientific publications in Brazil and abroad. Policymakers and stakeholders also use the dataset for public policies and decision-makers in the country.

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APPENDICES

Appendix 1 - Amazon biome

Appendix 2 - Atlantic Forest biome

Appendix 3 - Caatinga biome

Appendix 4 - Cerrado biome

Appendix 5 - Pampa biome

Appendix 6 - Pantanal biome

Appendix 7 - Agriculture and Forest Plantation

Appendix 8 - Pasture

Appendix 9 - Coastal Zone

Appendix 10 - Mining

Appendix 11 - Urban Area

Appendix 12 - Irrigation

Appendix 13 - Infrastructure layers (Transportation, Energy and Mining)

Appendix 14 - Deforestation and Secondary Vegetation

Appendix 15 - Accuracy Assessment

ANNEXES

Annex I: MapBiomas Network

MapBiomas is an initiative of the Climate Observatory, involving a collaborative network of NGOs, universities and technology companies organized by biomes and cross-cutting themes.

Biomes Coordination:

- Amazon – Institute of People and Environment of the Amazon (IMAZON)

- Caatinga – State University of Feira de Santana (UEFS), Northeast Plants Association (APNE), and Geodatin
- Cerrado – Amazon Environmental Research Institute (IPAM)
- Atlantic Forest – Foundation SOS Atlantic Forest and ArcPlan
- Pampa – Federal University of Rio Grande do Sul (UFRGS) and GeoKarten
- Pantanal – Institute SOS Pantanal and ArcPlan

Cross-cutting Themes Coordination:

- Pasture – Federal University of Goias (LAPIG/UFG)
- Agriculture – Agrosatelite until collection 8. Remap in collection 9.
- Coastal Zone and Mining – Vale Technological Institute (ITV) and Solved
- Urban Area – University of São Paulo (USP - QUAPÁ-FAU and YBY), Federal University of Bahia (UFBA) and Federal University of São Carlos (UFSCar - NEEPC)

Technology Partners:

- Google
- EcoStage
- Terras App

Financing:

- Amazon Fund
- Arapyaú Institute
- Children's Investment Fund Foundation (CIFF)
- Climate and Land Use Alliance (CLUA)
- Good Energies Foundation
- Gordon & Betty Moore Foundation
- Humanize Institute
- Institute for Climate and Society (iCS)
- Montpelier Foundation
- Mulago Foundation
- Norway's International Climate and Forest Initiative (NICFI)
- Global Wildlife Conservation (GWC)
- OAK Foundation
- Quadrature Climate Foundation (QCF)
- Sequoia Foundation
- Skoll Foundation
- Walmart Foundation
- Woods & Wayside International

Institutional Partners:

- Arapyaú Institute
- MapBiomas Support Institute (IAMap)
- WRI Brasil
- AVINA Foundation

General Coordination: Tasso Azevedo (SEEG/OC)

Technical Coordination: Marcos Rosa (ArcPlan)

Scientific Coordination: Julia Shimbo (IPAM)

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- Dra. Liana Oighenstein Anderson (CEMADEN)
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- Dr. Gilberto Camara Neto (INPE)
- Dr. Joberto Veloso de Freitas (Federal University of Amazonas)
- Dr. Matthew C. Hansen (Maryland University)
- Dr. Mercedes Bustamante (University of Brasília)
- Dr. Timothy Boucher (TNC)
- Dr. Robert Gilmore Pontius Jr (Clark University)

Technical Partners:

- Institute of Agricultural and Forest Management and Certification - Imaflora (IMAFLORA)
- Energy and Environment Institute (IEMA)
- Socioambiental Institute (ISA)
- Institute for Democracy and Sustainability (IDS)
- The Nature Conservancy (TNC)
- Life Center Institute (ICV)
- WWF Brasil
- Brasil I.O

Annex II: Mapping initiatives at global scale, in Brazil, biomes and cross-cutting themes, and respectively references/sources in Collection 9.

MAP	SOURCE	DESCRIPTION	DOWNLOAD
Agricultura Irrigada por Pivôs Centrais no Brasil	ANA / Embrapa	Mapeamento da área e do número de equipamentos de irrigação por pivô central no Brasil entre 1985 e 2017. Estudo realizado por meio de parceria entre a Agência Nacional de Águas - ANA e a Embrapa Milho e Sorgo.	https://metadados.snirh.gov.br/geonetwork/srv/api/records/e2d38e3f-5e62-41ad-87ab-990490841073
Aglomerados Subnormais 2019	IBGE	Esta versão preliminar incorpora atualizações até dezembro de 2019 e é formada por 13 152 Aglomerados Subnormais. Esses aglomerados estão localizados em 734 Municípios, em todos os Estados e no Distrito Federal, e totalizam 5 127 747 domicílio	https://www.ibge.gov.br/geociencias/organizacao-do-territorio/tipologias-do-territorio/15788-favelas-e-comunidades-urbanas.html?edicao=27720
Atlas da Mata Atlântica	SOS Mata Atlântica/INPE	Mapeamento das formações florestais e ecossistemas associados, ano de referência 2018/2019	http://mapas.sosma.org.br/dados/
Atlas dos Manguezais do Brasil	MMA / ICMBio	Parceria entre o Instituto Chico Mendes de Conservação da Biodiversidade e o Projeto "Conservação e Uso Sustentável Efetivos de Ecossistemas Manguezais no Brasil", implementado pelo Programa das Nações Unidas para o desenvolvimento – Brasil (PNUD), com o apoio do Fundo Global para o Meio Ambiente (GEF).	https://www.gov.br/icmbio/pt-br/centrais-de-conteudo/atlas-dos-manguezais-do-brasil-pdf
Base Vetorial Digital Temática do CAR - Estado do Tocantins	Secretaria do Meio Ambiente e Recursos Hidrícos do Estado do Tocantins	Elaborada a partir de imagens de satélite (Plêiades Ano 2015), e se constitui em uma base vetorial, digital, compatível com a escala 1:25.000, composta por feições da malha hidrográfica, limites municipais, malha do sistema viário, linhas de transmissão e áreas especiais do Estado do Tocantins, recortadas e articuladas conforme folhas 1:25.000	https://www.to.gov.br/semarh/base-vetorial-digital-tematica-do-car/1knojozyng4n

		do Sistema Cartográfico Nacional – SCN.	
Global Distribution of Mangroves USGS	USGS	Este conjunto de dados mostra a distribuição global das florestas de mangue, derivada de imagens de satélite de observação da Terra	http://sedac.ciesin.columbia.edu/data/set/lulc-global-mangrove-forests-distribution-2000/data-download
Global Forest Change 2000–2015	University of Maryland	Resultados da análise de série temporal de imagens Landsat na caracterização da extensão e mudança florestal global de 2000 a 2015.	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.7.html
Global Human Settlement Layer (GHS-BUILT e GHS_BUILT_S2)	European Commission Joint Research Centre (JRC)	Uma camada de informação multitemporal sobre a presença de área construída derivada de coleções de imagens Landsat (GLS1975, GLS1990, GLS2000 e coleção Landsat 8 ad-hoc 2013/2014).	https://ghsl.jrc.ec.europa.eu/download.php
Global Land Analysis Discovery - Commodity Crop Mapping and Monitoring in South America	University of Maryland	Mapas anuais da cobertura da soja na América do Sul, Cobertura da soja de 2000 em diante para permitir rastrear os efeitos indiretos da expansão da soja no desmatamento e informar as negociações de múltiplas partes interessadas sobre a sustentabilidade da soja, Mapas da cobertura do milho na América do Sul, atualizado semestralmente.	https://glad.umd.edu/projects/commodity-crop-mapping-and-monitoring-south-america
Índice de Vias e Estruturas (IVE)	Justiniano et. al	Apresenta uma nova metodologia facilmente reprodutível para a cartografia urbana. A metodologia permite o processamento combinado de dados OpenStreeMap e de Sensoriamento Remoto, onde é proposta uma métrica denominada índice de vias e estruturas (IVE) para cartografar áreas urbanas. O IVE é utilizado com NDVI e MNDWI para cartografar a superfície urbana com alta precisão, com o ano de referencia de 2020.	https://www.sciencedirect.com/science/article/pii/S0303243422001179?via%3Dihub
IV Comunicação Nacional de Emissões de Gases de Efeito Estufa (setor LULUCF)	MCTIC	Mapa das áreas de agricultura (anual, semi-perene e perene)	https://www.gov.br/mcti/pt-br/centrais-de-conteudo/publicacoes-mcti/quarta-comunicacao-nacional-do-brasil-a-unfccc/sumario_executivo_4cn_brasil_

			web.pdf
Malha de Setores Censitários 2021	Instituto Brasileiro de geografia e Estatística (IBGE)	A Malha Setorial de 2021 foi atualizada com vistas à etapa de coleta do Censo Demográfico 2022, contenplando a situação atualizada da Divisão Político-Administrativa Brasileira – DPA, vigente em 30/04/2021.	https://www.ibge.gov.br/geociencias/downloads-geociencias.html?caminho=organizacao_do_territorio/malhas_territoriais/malhas_de_setores_censitarios__divisoes_intramunicipais/2021/Malha_de_setores_(shp)_Brasil
Mapa da Mineração Brasileira	Camara de Comercio e Industria Brasil-Alemanha/ GeoAnsata Projetosa	Retratos da indústria mineradora e intermediações dos interessados da área, especialistas e produtores do setor com empresas mineradoras.	https://www.google.com/maps/d/viewer?mid=19ps2n5FI62X-ib2V2teFhaqcUCbS2BZJ&ll=-14.64391762573763%2C-58.49807411843837&z=4
Alertas de Desmatamento - Classe de Mineração - Projeto DETER	INPE	Classe de Mineração do Sistema de Alerta em Tempo Quase Real (DETER)	http://terrabrasilis.dpi.inpe.br/
Base de Mineração Ilegal da RAISG	RAISG	Dado de minereção ilegal da Red Amazónica de Información Socioambiental Georreferenciada	http://www.amazoniasocioambiental.org
Atividade Garimpeira da Rede Amazon Mining Watch	AMW	Dados de atividade garimpeira da Amazon Mining Watch	https://amazonminingwatch.org/
Mapa de florestas plantadas	GFW/WRI	Mapa de florestas plantadas para o Brasil	http://data.globalforestwatch.org/datasets/baae47df61ed4a73a6f54f00cb4207e0_5
Mapa de Limite dos Biomas	IBGE	Conjunto com o relatório metodológico que traz novos	https://www.ibge.gov.br/geociencias/i

1:250.000		limites entre os seis Biomas brasileiros, Amazônia, Mata Atlântica, Caatinga, Cerrado, Pantanal e Pampa, compatíveis com a escala 1:250 000.	nformacoes-ambientais/estudos-ambientais/15842-biomas.html?=&t=acesso-ao-produto
Base de Mineração na Amazônia Brasileira - ISA	Insitituto Socioambiental - ISA	Dado de mineração na Amazonia Brasileiro compilado pelo Instituto Socioambiental - ISA	https://www.amazoniasocioambiental.org/es/mapas/#descargas
Base de Recursos Minerais do Brasil	Serviço Geológico do Brasil (CPRM) - GeoSGB	O representação espacial dos recursos minerais do Brasil é mantida pelo Serviço Geológico do Brasil (CPRM) atraves de seu geoportal denomindado de GeoSGB.	https://geoportal.cprm.gov.br/geosgb/
Mapa dos manguezais da região nordeste do Brasil	Pereira, E.A., Souza-Filho, P.W.M., et al.	Mapa das áreas de manguezal da Ponta de Tubarão-MA até o sul do Estado da Bahia a partir da classificação de imagens Landsat e ALOS PALSAR do ano de 2008	
Mapa dos manguezais da região norte do Brasil	Nascimento Jr, W.R; Souza-Filho, P.W.M., et al.	Mapa das áreas de manguezal do Oiapoque-AP até a Ponta de Tubarão-MA gerado a partir da classificação de imagens Landsat e ALOS PALSAR do ano de 2008	http://dx.doi.org/10.1016/j.ecss.2012.10.005
Mapa Síntese de Pastagens do Brasil - v8	LAPIG/UFG	Mapeamento de áreas de pastagem, a partir de compilação de dados TerraClass Amazon; Funcate; PROBIO; Canasat e TNC.	https://atlasdaspastagens.ufg.br
Mapas de Cobertura Vegetal dos Biomas Brasileiros - ProBio	UEFS/APNE/EMBRAPA-Solos/UFCE/UFRN/UFRPE/UFPB/CRA/SEMARH-MMA	Levantamento da cobertura vegetal e do uso do solo do Bioma Caatinga	http://mapas.mma.gov.br/geodados/brasil/vegetacao/vegetacao2002/mosaicos_vegetacao/caatinga.zip
Mapeamento da Bacia do Alto Paraguai	SOS Pantanal/WWF Brasil	Monitoramento do uso e cobertura vegetal da Bacia do Alto Paraguai, que inclui o Pantanal e suas cabeceiras. Dados disponíveis para 2002, 2008, 2010, 2012, 2014 e 2016	https://www.sospantanal.org.br/atlas/
Mapeamento da Cobertura Vegetal da Mata Atlântica de Minas Gerais	Instituto Estadual de Floresta (IEF)	Mapeamento fez uma varredura em 30.673.854,99 hectares, que incluiu o limite legal do bioma estabelecido pela Lei Federal 11.428/2006, acrescido de um buffer de cinco quilômetros, considerando as áreas de transição para os outros biomas.	https://www.ief.mg.gov.br/geoprocessamento/mapas-da-cobertura-vegetal
Mapeamento da Cobertura Vegetal	Instituto Estadual de Meio	Mapeamento realizado por meio de ortofotos com 25cm e	https://geobases.es.gov.br/downloads

Nativa e do Uso das Terras 1/25.000 do Estado do Espírito Santo	Ambiente e Recursos Hídricos (IEMA)	fotointerpretação e vetorização manual de limites entre classes de uso e cobertura com área mínima de 0,5ha.	
Mapeamento de uso da terra para o Cerrado e Mata Atlântica	FBDS	Mapeamento de uso da terra para o Cerrado e Mata Atlântica. Baseado em imagens de alta resolução RapidEye com resolução de 5m.	http://geo.fbds.org.br/
Mapeamento de Uso e Cobertura da Terra do Estado do Paraná	Secretaria de Estado do Planejamento e Projetos Estruturantes	Mapeamento realizado por meio de imagens orbitais de satélites de alta resolução espacial (2 metro), referentes ao período de 2011 a 2016 - WorldView2 e Pleiades 1A e 1B). Classificação automática supervisionado (GEOBIA).	https://geopr.iat.pr.gov.br/portal/apps/dashboards/1eca83bf72e44193ae62f282574da52f
Mapeamento do Arroz Irrigado no Brasil	Agência Nacional de Águas (ANA) / Companhia Nacional de Abastecimento (Conab)	Mapeamento do Arroz Irrigado no Brasil	https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/metadata/1ac9b37f-0745-44f9-a60b-6a2bd366bbe1
Mapeamento do Inventário Florestal do Estado de São Paulo	Secretária de Infraestrutura e Meio Ambiente do Estado de São Paulo - Instituto Florestal	Mapeamento realizado por meio de imagens orbitais de satélites de alta resolução espacial (0,5 metro), referentes ao período de 2017 a 2019, pertencentes ao acervo da Secretaria de Infraestrutura e Meio Ambiente.	
OpenStreetMap	OpenStreetMap Foundation	OpenStreetMap é uma iniciativa para criar e fornecer dados geográficos gratuitos, como mapas de ruas, para qualquer pessoa.	https://www.openstreetmap.org/
Prodes	INPE	Monitoramento por satélites do desmatamento por corte raso na Amazônia Legal e produz, desde 1988, as taxas anuais de desmatamento na região, que são usadas pelo governo brasileiro para o estabelecimento de políticas públicas.	http://www.dpi.inpe.br/prodesdigital/dadosn/
Terra Class Cerrado	MMA, IBAMA, EMBRAPA, INPE, UFG e UFU	Mapeamento do Uso e Cobertura da Terra do Cerrado	https://www.terraclass.gov.br/download-de-dados
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2002.	Hasenack, H.; Cordeiro, J.L.P; Weber, E.J. (Org.). Porto Alegre: UFRGS IB Centro de	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2002, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	https://www.ufrgs.br/labgeo/index.php/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2002/

	Ecologia, 2015. 1a ed. ISBN 978-85-63843-15-9.		
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2009.	Weber, E.J.; Hofmann, G.S.; Oliveira, C.V.; Hasenack, H. (Org.). Porto Alegre: UFRGS IB Centro de Ecologia, 2016. 1a ed. ISBN 978-85-63843-20-3.	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2009, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	https://www.ufrgs.br/labgeo/index.php/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2009/
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2015.	Hofmann, G.S.; Weber, E.J.; Hasenack, H. (Org.). Porto Alegre: UFRGS IB Centro de Ecologia, 2018. 1a ed. ISBN 978-85-63843-22-7.	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2015, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	https://www.ufrgs.br/labgeo/index.php/downloads/dados-geoespaciais/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2015/
Mapeamento da Evolução da Cobertura Vegetal.	Forum Florestal da Bahia	O monitoramento independente da cobertura vegetal e uso do solo dos territórios de identidade Costa do Descobrimento, Extremo Sul e Parcela do Litoral Sul (áreas de atuação das empresas Suzano e Veracel), tem como objetivo a realização do mapeamento da evolução da cobertura vegetal.	https://forumflorestalbahia-worldresources.hub.arcgis.com/
Mapa de Café	CONAB	O mapeamento dos cultivos agrícolas é realizado por meio de sensoriamento remoto. Ele tem por objetivo contribuir com a estimativa de área e de produtividade, oferecendo informações precisas sobre a distribuição geográfica em cada estado. Na estimativa de área, o resultado do mapeamento auxilia na análise da informação declarada, como um dado passível de verificação em campo. Na estimativa de produtividade, o conhecimento da localização das áreas de cultivo possibilita o monitoramento das áreas produtivas através de parâmetros agrometeorológicos, oferecendo	https://www.conab.gov.br/info-agro/safras/mapeamentos-agricolas

		indicativos sobre a previsão de rendimento das lavouras. Os mapeamentos estão disponíveis para download no formato shapefile.	
VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1	NASA	Os mapeamentos estão disponíveis para download no formato shapefile.	https://eogdata.mines.edu/download_dnb_composites.html
Mapa de Áreas Úmidas na Bacia Amazônica	Hess, L.L., J.M. Melack, A.G. Affonso, C.C.F. Barbosa, M. Gastil-Buhl, and E.M.L.M. Novo. 2015. LBA-ECO LC-07 Wetland Extent, Vegetation, and Inundation: Lowland Amazon Basin. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1284	Mapa da extensão das zonas úmidas, do tipo de vegetação e do estado de inundação em duas estações de toda a bacia do baixo Amazonas	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1284
Mapa Global de Áreas Úmidas	Gumbricht, T., Román-Cuesta, R.M., Verchot, L.V., Herold, M., Wittmann, F., Householder, E., Herold, N., Murdiyarso, D.. 2017. An expert system model for mapping tropical wetlands and peatlands reveals South America as the largest contributor. Global Change Biology 23(9):3581-3599 doi: http://www.cifor.org/pid/6419	Modelo hidro-geomorfológico baseado numa abordagem de sistema especializado para estimar as áreas de zonas úmidas.	https://www2.cifor.org/global-wetlands/
Mapa Global de Áreas Úmidas	Tootchi, Ardalan; Jost, Anne; Ducharne, Agnès (2018):	mapas de zonas húmidas compostas que combinam duas classes de zonas húmidas: (1) zonas úmidas regularmente	https://doi.pangaea.de/10.1594/PANGAEA.892657?format=html#downloa

	Multi-source global wetland maps combining surface water imagery and groundwater constraints. Sorbonne Université, Paris, France, PANGAEA, https://doi.org/10.1594/PANGAEA.892657	inundadas e (2) zonas úmidas conduzidas por águas subterrâneas.	d
Mapa de Pedologia do Brasil	IBGE	mapa de solos do Brasil na escala 1:250.000	https://geoftp.ibge.gov.br/informacoes_ambientais/pedologia/vetores/escala_250_mil/versao_2023/
Prodes	INPE	Projeto PRODES Cerrado que inclui o mapeamento da supressão vegetação nativa no bioma no período de 2000 a 2023	https://terrabrasilis.dpi.inpe.br/downloads/
SAD Cerrado	IPAM	Sistema de Alertas de Desmatamento (SAD Cerrado) inclui alertas mensai de desmatamento em todo bioma Cerrado desde 2020.	https://sadcerrado.ipam.org.br/#Download
MapBiomas Alerta	Tootchi, Ardalan; Jost, Anne; Ducharne, Agnès (2018): Multi-source global wetland maps combining surface water imagery and groundwater constraints. Sorbonne Université, Paris, France, PANGAEA, https://doi.org/10.1594/PANGAEA.892657	Sistema de validação e refinamento de alertas de desmatamento provenientes de diversos sistemas de detecção desde 2019	https://plataforma.alerta.mapbiomas.org/downloads

Remanescentes de Campos de Murundus ou Covais no Estado de Goiás	SEMAD - GO	Mapa de campos de murundus na escala cartográfica 1:50.000 do estado de Goiás em 2020	https://siga.meioambiente.go.gov.br/catalogue/uuid/a8764228-277f-11ec-b499-005056829b53
Global Canopy Height 2020	EcoVision Lab, Photogrammetry and Remote Sensing, ETH Zürich	Altura global do topo do dossel para o ano de 2020 a 10 m de distância de amostragem do solo.	https://nlang.users.earthengine.app/view/global-canopy-height-2020
Mapa de Uso e Cobertura do Solo do Distrito Federal	SISDIA - DF	O mapeamento da cobertura da terra do Distrito Federal em escala regional 1:100.000 do ano de 2019	https://sisdia.df.gov.br/portal/home/item.html?id=609c066c72a94111ab843c76b4074ea2
Afloramento Rochoso	SGB/CPRM	Mapeamento dos afloramentos rochosos contidos no banco de dados GeoSGB.	https://geoportal.sgb.gov.br/portal/home/item.html?id=674d3e4be428441fb046bd0251d744fb
Mapa de áreas não florestais	INPE	Máscara de áreas não florestais na Amazônia	https://terrabrasilis.dpi.inpe.br/downloads/
Mapa da distribuição dos municípios mapeados (G75) que compõem a área de estudo e a localização das imagens Sentinel–2A e 2B obtidas na plataforma Earth Explorer	EMBRAPA	Mapeamento de viveiros escavados para aquicultura no Brasil por sensoriamento remoto - Mapa da distribuição dos municípios que concentram 75% da produção aquícola de cada UF	https://ainfo.cnptia.embrapa.br/digital/bitstream/doc/1152279/1/6105.pdf
Global Distribution of Coral Reefs	UNEP-WCMC	Distribuição Global de Recifes de Coral	https://data.unep-wcmc.org/datasets/1
Allen Coral Atlas	The Allen Coral Atlas	Mapeamento global de recifes de corais e monitoramento de ameaças de ecosistemas costeiros	https://allencoralatlas.org/
Atlas de Recifes de Coral nas Unidades de Conservação Brasileiras	PRATES, A. P. L. 2003	Mapeamento de recifes de coral em diferentes regiões brasileiras, áreas prioritárias, mapas de importância biológica	http://mtc-m12.sid.inpe.br/rep/sid.inpe.br/sergio/2005/01.31.11.00

Base de Dados do Panorama da conservação dos ecossistemas costeiros e marinhos no Brasil	MMA. Gerência de Biodiversidade Aquática e Recursos Pesqueiros.	Panorama da Conservação dos Ecossistemas Costeiros e Marinhos no Brasil - MMA	https://www.marinha.mil.br/secirm/sites/www.marinha.mil.br.secirm/files/mma-205_publicacao27072011042233.pdf
Mapa das áreas prioritárias da Zona Costeira e Marinha	MMA	Áreas prioritárias da Zona Costeira e Marinha	https://www.gov.br/mma/pt-br/assuntos/biodiversidade-e-biomas/ecossistemas/conservacao-1/areas-prioritarias/zona_costeira.jpg

Annex III: Cross-reference of MapBiomas land use/land cover classes in the Collection 9 with FAO, IBGE and National GHG Emissions Inventory classes.

Level 1	Level 2	Level 3	Level 4	Biome	Brief description	IBGE (1999; 2012) Classification	FAO (2012) Classification	National Inventory of GHG Emissions (2015) Classification
Forest	Forest Formation			Amazon	Dense Ombrophilous Forest, Evergreen Seasonal Forest, Open Ombrophilous Forest, Semi-deciduous Seasonal Forest, Deciduous Seasonal Forest, Wooded Savannah, Areas that had fire or logging, Forest resulting from natural successional processes, after total or partial primary vegetation suppression by anthropogenic actions or natural causes, which may have remaining trees of primary vegetation. Bamboo forest (Acre).	Da, Db, Ds, Dm, Ha, Hb, Hs, Ld, La, Aa, Ab, As, Am, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, Vsp	FDP, FEP, FSP, FEM, FDM, FSM	FMN, FM, FSec
				Caatinga	Vegetation types with predominance of continuous canopy - Wooded Steppe Savanna, Semi-deciduous and Deciduous Seasonal Forest.	Td, Cs, Cm, Fm, Fs, Pa, As, Fb, Pf, Pm, Fa, Cb, Ds, Am, Ab, Sd	FEP, FSP	FMN, FM
				Cerrado	Vegetation types with predominance of tree species, with continuous canopy formation (Riparian Forest, Gallery Forest, Dry Forest and Forested Savanna) (Ribeiro & Walter, 2008), as well as Semi-deciduous Seasonal Forests.	Aa, Ab, As, Cb, Cm, Cs, Da, Dm, Ds, F, Ml, Mm, P, Sd, Td	FEP, FDP, FSP	FMN, FM

		Atlantic Forest	Dense, Open and Mixed Ombrophilous Forest, Semi-deciduous and Deciduous Seasonal Forest, and Pioneer Formation.	D, A, M, F, C, Pma	FEP, FSP	FMN, FM
		Pampa	Vegetation with predominance of tree species and continuous canopy. It includes forest typologies: Ombrophilous, Semi-deciduous and Deciduous and part of the pioneer formations.	Da, Db, Ds, Dm, Ma, Ms, Mm, Ml, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, P, Pa, Pm	FEP, FDP, FSP	FMN, FM, FSec, CS
		Pantanal	Tall trees and shrubs in the lower stratum: Deciduous and Semi-deciduous Seasonal Forest, Wooded Savanna, Wooded Steppe Savanna, and Fluvial and/or Lacustre Influenced Pioneer Formations.	Ca, Cb, Cs, Fa, Fb, Fs, SN, Sd, Td, Pa	FEP, FSP	FMN, FM
	Savanna Formation	Amazon	Open plant formation with a more or less developed shrub and/or arboreal layer, herbaceous layer always present.	Sa, Ta	WS	FMN, FM
		Caatinga	Vegetation types with predominance of semi-continuous canopy species - Wooded Steppe Savanna and Wooded Savanna.	Ta, Sa,	FDP	FMN, FM
		Cerrado	Savanna formations with defined tree and shrub-herbaceous stratum (Cerrado Stricto Sensu: Dense, Typical, Sparse and Rupestrian Savanna).	Sa, Ta	FDP, FSP, WS	FMN, FM
		Atlantic Forest	Steppe, Forested and Wooded Savannas.	Sd, Td, Sa, Ta	FDP, FSP, WS	FMN, FM
		Pantanal	Small tree species, sparsely arranged in the shrub and herbaceous continuous vegetation. The herbaceous vegetation mixes with erect and decumbent shrubs.	Sa, Sp, Sg, Td, Ta, Tp	FDP, FSP, WS	FMN, FM

	Mangrove		Dense and Evergreen Forest formations, often flooded by tide and associated with the mangrove coastal ecosystem.	Pf	FEP, FEM	FMN, FM
	Floodable Forest (beta)	Amazon	Alluvial Open Ombrophilous Forest established along the watercourses, occurring in periodically or permanently flooded plains and terraces, where in the Amazon represent the physiognomies of igapó and lowland forests, respectively.	Da, Db, Ds, Dm, Ha, Hb, Hs, Ld, La, Aa, Ab, As, Am, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, Vsp	FDP, FEP, FSP, FEM, FDM, FSM	FMN, FM, FSec
	Wooded Sandbank Vegetation	Atlantic Forest	Forest formations on sandy soils in the coastal region.	Pma	FEP, FEM	FMN, FM
		Pampa	Forest formations on sandy soils in the coastal region.	Pma	FEP, FEM	FMN, FM
		Caatinga	Forest formations on sandy soils in the coastal region.	Pma	FEP, FEM	FMN, FM
Non-Forest Natural Formation	Wetland	Amazon	Lowland or grassland vegetation that suffers fluvial and/or lacustrine influence.	Pa	OM	GNM, GM, GSec
		Cerrado	Vegetation with a predominance of herbaceous strata subject to seasonal flooding (e.g. Campo Umido) or under fluvial/lacustrine influence (e.g. Brejo). In some regions, the herbaceous matrix is associated with arboreal species of savanna formation (e.g. Parque de Cerrado) or palm trees (Vereda, Palmeiral).	Pa, Sp	OM	GNM, GM, GSec
		Atlantic Forest	Wetlands with fluvial influence.	Pa	OM	GNM, GM, GSec

		Pampa	Wetland areas, regionally called banhados or marshes (saline influence). Vegetation typically hygrophilous, with aquatic plants emerging, submerged or floating. They occupy plains and depressions of the terrain with waterlogged soil and also the shallow edges of ponds or water reservoirs.	P, Pa, Pm	OM	A, Res
		Pantanal	Herbaceous vegetation with a predominance of grasses subject to permanent or temporary flooding (at least once a year) according to the natural flood pulses. The woody element can be present on the country matrix forming a mosaic with shrub or tree plants (e.g.: cambarazal, paratudal and carandazal). Swampy areas generally occur on the banks of temporary or permanent lagoons occupied by emergent, submerged or floating aquatic plants (eg swamps and barns). Areas with a water surface, but difficult to classify due to the amount of macrophytes, eutrophication or sediments, were also included in this category.	Tg, Sp, Pa, Tp	OM	GNM, GM, GSec
	Grassland Formation	Amazon	Savanna, Park Savana (Marajó), Steppe-Savana (Roraima), Grassland Savanna, Campinarana, for regions outside the Amazon/Cerrado Ecotone. And for regions within the Amazon/Cerrado Ecotone, predominance of herbaceous strata.	Sa, Sp, Sg, Ta, Tp, Tg	WG, OG, WS	GNM, GM, GSec
		Caatinga	Vegetation type with predominance of herbaceous species (Park Steppe Savanna, Herbaceous-Woody Steppe Savanna, Park Savanna, Herbaceous-Woody Savanna) + (Flooded areas with an interconnected pond net, located along waterways and in lowlands	Tp, Sg, Rm, Sp, Tg, Rl	WG, OG, WS	GNM, GM, GSec

			areas that accumulate water, vegetation predominantly herbaceous to shrub).			
		Cerrado	Grassland formations with a predominance of herbaceous strata (dirty, clean and rupestrian fields) and some areas of savanna formations such as the rupestrian cerrado.	Sg, Tp, Tg	WG, OG	GNM, GM, GSec
		Atlantic Forest	Park and Grassland Steppe Savannas, Steppe and Shrub and Herbaceous Pioneers.	Sp, Sg, Tp, Tg, E, Pa	WS,OG	GNM, GM, GSec
		Pampa	Vegetation with a predominance of grassy strata, with the presence of herbaceous and sub-shrub dicots. The botanical composition is influenced by edaphic and topographic gradients and by pasture management (livestock). They occur in deep to shallow soils, including rocky (rupestrian fields) and sandy (sandy or psamophilic fields). Occupy well-drained soil (mesic fields) to soils with higher moisture content (wet fields - with a strong presence of sedges). In most cases, it corresponds to native vegetation, but patches of exotic invasive vegetation or exotic forage use (planted pasture) may be present.	E, Ea, Ep, Eg, T, Ta, Tp, P, Pa, Pm	WG, OG	GNM, GM, GSec
		Pantanal	Vegetation with a predominance of grassy stratum, with the presence of isolated and stunted woody shrubs. The botanical composition is influenced by the edaphic and topographical gradients and pasture management (livestock). Patches of invasive exotic vegetation or forage use (planted pasture) may be present forming mosaics with native vegetation.	Sg, Sp, Ta, Tg	WG, OG	GNM, GM, GSec

	Hypersaline Tidal Flat		"Apicuns" or hypersaline tidal flats are formations often without tree vegetation, associated to a higher, hypersaline and less flooded area in the mangrove, generally in the transition between this area and the continent.	Pf, Pfh	OM, OX	O
	Rocky Outcrop	Amazon	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM
		Caatinga	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM
		Cerrado	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM
		Atlantic Forest	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM
		Pampa	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM
	Herbaceous Sandbank Vegetation	Atlantic Forest	Herbaceous vegetation that is established on sandy soils or on dunes in the coastal zone.	Pmb, Pmh	WG, OG	GNM, GM
		Caatinga	Herbaceous vegetation that is established on sandy soils or on dunes in the coastal zone.	Pmb, Pmh	WG, OG	GNM, GM

				Pampa	Herbaceous vegetation that is established on sandy soils or on dunes in the coastal zone.	Pmb, Pmh	WG, OG	GNM, GM
	Other Non-Forest Formations			Atlantic Forest	Marshes (with fluvio-marine influence).	Pfh, Pmb, Pmh	WG, OG	GNM, GM, GSec
Farming	Pasture			Amazon	Pasture area, predominantly planted, linked to livestock production activities. Areas of natural pasture are predominantly classified as grassland or wetland, that may or may not be grazed.	AP, PE, PS	OP, OG	Ap
	Agriculture	Temporary Crop	Soybean		Areas cultivated with soybean.	AMc (s)	OCA	AC
			Sugar cane		Cultivated areas with sugar cane.	AMc (c)	OCA	AC
			Rice		Areas cultivated with rice, exclusively under irrigation, in the states of Rio Grande do Sul, Tocantins, Santa Catarina and Coast of Paraná. This map is the same one presented in the irrigation module in the "Irrigated Rice" class.	AMc	OCA	AC
			Cotton (beta)		Areas cultivated with cotton cultivation.	AMc (s)	OCA	AC
			Other Temporary Crops		Areas occupied with short or medium-term agricultural crops, generally with a vegetative cycle of less than one year, which after harvesting need to be planted again to produce.	AMc	OCA	AC
		Perennial Crop	Coffee		Areas cultivated with coffee plantation.	AMp (c)	OCP	PER
			Citrus		Areas cultivated with citrus cultivation.	AMp	OCP	PER
			Palm Oil (beta)		Areas cultivated with palm oil plantation.	AMp	OCP	PER

			Other Perennial Crops	Areas occupied with agricultural crops with a long vegetative cycle (more than one year), which allow successive harvests, without the need for new planting. In this version, the map covers mostly cashew areas on the northeast coast and oil palm in the northeast region of Pará, but without distinction between them.	AMp	OCP	PER
	Forest Plantation			Tree species planted for commercial purposes (e.g. pinus, eucalyptus, araucaria).	R	FPB, FPC, FPM	Ref
	Mosaic of Uses		Caatinga	Farming areas where it was not possible to distinguish between pasture and agriculture.	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG	AC, PER, Ap, APD
			Cerrado	Areas of agricultural use where it was not possible to distinguish between pasture and agriculture.	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG	AC, PER
			Atlantic Forest	Farming areas where it was not possible to distinguish between pasture and agriculture.	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG	AC, PER
			Pampa	Areas of agricultural use, where it was not possible to distinguish between pasture and agriculture. It may include cropland, winter or summer pasture and horticulture. Includes rest areas between agricultural crops (fallow).	AP, AS, AT, AM, PE, PS, Ag, Ap, Ac, Acc, Acp, AA	OCA, OCM, OP, OG, OF	AC, PER, Ap, APD
			Urban Areas	Areas of urban vegetation, including cultivated vegetation and natural forest and non-forest vegetation.		OB	S
Non Vegetated Area	Beach, Dune and Sand Spot			Sandy areas, with bright white color, where there is no vegetation predominance of any kind.	Dn	OX	DnM,DnNM

	Urban Area		Urban areas with predominance of non-vegetated surfaces, including roads, highways and constructions.		OB	S
	Mining		Areas where clear signs of extensive mineral extractions are present, shows clear exposure of the soil by the action of heavy machinery. Only regions surrounding the AhkBrasilien (AHK) and the CPRM digital reference data were considered.	MCA	OQ	Min
	Other Non Vegetated Areas	Amazon	Non-permeable surface areas (infrastructure, urban expansion or mining) not mapped into their classes	AU, MCA	OB, OQ	S, Min
		Caatinga	Non-permeable surface areas (infrastructure, urban expansion or mining) not mapped into their classes	AU,MCA	OB, OQ	S, Min
		Cerrado	Non-permeable surface areas (infrastructure, urban expansion or mining) not mapped into their classes	AU, MCA	OB, OQ	S, Min
		Atlantic Forest	Non-permeable surface areas (infrastructure, urban expansion or mining) not mapped into their classes and regions of exposed soil in natural or crop areas	AU, MCA	OB, OQ	S, Min
		Pampa	Mixed class that includes natural and anthropic areas. Natural areas include exposed sandy surfaces including mainly river and sandy beaches. Anthropic areas include non-permeable surfaces (roads and infrastructure for rural developments).	AU, MCA, Dn, Iu	OB, OQ, OX	S, SE, DnM, DnNM, Min
		Pantanal	Exposed soil areas (mainly sandy soil) not classified as Grassland Formation or Pasture.	PE, Sg	OX	Ap, GNM, GSec

Water	River, Lake and Ocean	Rivers, lakes, dams, reservoir and other water bodies		IRP, IRS, IL, ID	A, Res
	Aquaculture	Artificial lakes, where aquaculture and/or salt production activities predominate			
Not Observed		Areas blocked by clouds or atmospheric noise, or with absence of ground observation masked out from analysis.			NO
References: Instituto Brasileiro de Geografia e Estatística - IBGE. Manual técnico de uso da terra, IBGE: Rio de Janeiro, Brazil, 1999, 58p.; Instituto Brasileiro de Geografia e Estatistica - IBGE. Manual técnico da vegetação brasileira, 2nd ed., IBGE: Rio de Janeiro, Brazil, 2012. pp.157-160; Food and Agriculture Organization of the United Nations - FAO. Manual for integrated field data collection. FAO: Rome, Italy, 2012, 175p.; Ministério da Ciência, Tecnologia e Inovações. Secretaria de Pesquisa e Formação Científica. Quarta Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança do Clima, Brasília, 2020, 620p.					

Annex IV: Classes of land cover and land use of Collections 1, 2, 2.3, 3, 4, 5, 6 and 7 of MapBiomas.

Collection 1

Forest
Forest in Costal Zone
Planted Forest
Agriculture
Pasture
Water
Other
Non-Observed

7 Classes

Collection 2

1. Forest
1.1. Natural Forest
1.1.1. Natural Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantations
2. Non-Forest Natural Formations
2.1. Non-forest Natural Wetlands
2.2. Grasslands
3. Farming
3.1. Pasture
3.2. Agriculture
3.3 Agriculture or Pasture
4. Non-Vegetated areas
4.1. Beach and dune
4.3. Other non-vegetated areas
4.2. Urban Infrastructure
5. Water
6. Non-Observed

13 Classes

Collection 3

1. Forest
1.1. Natural Forest
1.1.1. Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantation
2. Non Forest Natural Formation
2.1. Wetland
2.2. Grassland
2.3. Salt flat
2.3. Other non forest natural formation
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Annual and Perennial Crop
3.2.2. Semi-perennial Crop
3.3. Mosaic of Agriculture and Pasture
4. Non vegetated area
4.1. Beach and Dune
4.2. Urban Infrastructure
4.3. Rocky outcrop
4.4. Mining
4.5. Other non vegetated area
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture
6. Non Observed

19 Classes

Collection 4

1. Forest
1.1. Natural Forest
1.1.1. Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantation
2. Non Forest Natural Formation
2.1. Wetland
2.2. Grassland
2.3. Salt flat
2.4. Rocky outcrop
2.5. Other non forest natural formation
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Annual and Perennial Crop
3.2.2. Semi-perennial Crop
3.3. Mosaic of Agriculture and Pasture
4. Non vegetated area
4.1. Beach and Dune
4.2. Urban Infrastructure
4.3. Mining
4.4. Other non vegetated area
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture
6. Non Observed

19 Classes

Collection 5

1. Forest
1.1. Natural Forest
1.1.1. Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantation
2. Non Forest Natural Formation
2.1. Flooded Grassland and Swamped Area
2.2. Grassland
2.3. Salt flat
2.4. Rocky outcrop
2.5. Other non forest natural formation
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Annual Crop
3.2.1.1. Soy bean
3.2.1.2. Sugar Cane
3.2.1.3. Other annual crops
3.2.2. Perennial Crop
3.3. Mosaic of Agriculture and Pasture
4. Non vegetated area
4.1. Beach and Dune
4.2. Urban Infrastructure
4.3. Mining
4.4. Other non vegetated area
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture
6. Non Observed

21 Classes

Collection 6

1. Forest
1.1. Forest Formation
1.2. Savanna Formation
1.3. Mangrove
1.5. Wooded Restinga
2. Non Forest Natural Formation
2.1. Flooded Grassland and Swamped Area
2.2. Grassland
2.3. Salt Flat
2.4. Rocky Outcrop
2.6. Other non Forest Formations
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Temporary Crop
3.2.1.1. Soybean
3.2.1.2. Sugar cane
3.2.1.3. Rice
3.2.1.4. Other Temporary Crops
3.2.2. Perennial Crop
3.2.1.1. Coffee
3.2.1.2. Citrus
3.2.1.3. Other Perennial Crops
3.3. Forest Plantation
3.4. Mosaic of Agriculture and Pasture
4. Non vegetated area
4.1. Beach, Dune and Sand Spot
4.2. Urban Area
4.3. Mining
4.4. Other non Vegetated Areas
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture

25 Classes

Collection 7

1. Forest
1.1. Forest Formation
1.2. Savanna Formation
1.3. Mangrove
1.4. Wooded Sandbank Vegetation
2. Non Forest Natural Formation
2.1. Wetland
2.2. Grassland
2.3. Salt Flat
2.4. Rocky Outcrop
2.5. Herbaceous Sandbank Vegetation
2.5. Other non Forest Formations
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Temporary Crop
3.2.1.1. Soybean
3.2.1.2. Sugar cane
3.2.1.3. Rice
3.2.1.4. Cotton (beta)
3.2.1.5. Other Temporary Crops
3.2.2. Perennial Crop
3.2.1.1. Coffee
3.2.1.2. Citrus
3.2.1.3. Other Perennial Crops
3.3. Forest Plantation
3.4. Mosaic of Uses
4. Non vegetated area
4.1. Beach, Dune and Sand Spot
4.2. Urban Area
4.3. Mining
4.4. Other non Vegetated Areas
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture
6. Non Observed

27 Classes

MAPBIOMAS

Annex V: Collection 9 prevalence rules, given by the "Prevalence ID" (from the most to the less prevalent class), used for integrating biomes and cross-cutting themes maps. Since some classes are mapped both as cross-cutting themes and in the biomes, the "Source" column indicates the source of information for that specific rule. "Exceptions" are classes that are prevalent over the listed one in that region.

CLASS ID	CLASS NAME	SOURCE	PREVALENCE ID	EXCEPTION
30	4.3. Mining	Mining	1	In São Paulo and Mato Grosso states, the cross-cutting class 24 is prevalent
23	4.1. Beach, Dune, and Sand Spot	Coastal Zone and Biomes	2	
5	1.3. Mangrove	Coastal Zone	3	
31	5.2. Aquaculture	Aquaculture	4	
32	2.3. Salt Flat	Coastal Zone	5	
24	4.2. Urban Area	Urban Area	6	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent

9	3.3. Forest Plantation	Forest Plantation	7	At Lagoa dos Peixes (Pampa), the classes 3, 11, 12, 29, 33, 49, 50 are prevalent
29	2.4. Rocky Outcrop	Biomes	8	
20	3.2.1.2. Sugar Cane	Agriculture	9	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent
39	3.2.1.1. Soybean	Agriculture	10	At Lagoa dos Peixes (Pampa), the classes 3, 11, 12, 29, 33, 49, 50 are prevalent. In Pampa, classes 11 and 33 are prevalent
40	3.2.1.3. Rice	Agriculture	11	At Lagoa dos Peixes (Pampa), the classes 3, 11, 12, 29, 33, 49, 50 are prevalent. In Pampa, classes 11 and 33 are prevalent. In the Amazon, Caatinga, Cerrado and Pantanal, class 33 is prevalent. In the Atlantic Forest, classes 3, 12 and 33 are prevalent
62	3.2.1.4. Cotton	Agriculture	12	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
41	3.2.1.5 Other Temporary Crops	Agriculture	13	At Lagoa dos Peixes (Pampa), the classes 3, 11, 12, 29, 33, 49, 50 are prevalent. In the Amazon, Caatinga, Cerrado and Atlantic Forest, class 33 is prevalent. In Pampa, classes 11 and 33 are prevalent and

				if the pixel was never classified as soybean throughout the time series the classes 3 and 12 are prevalent.
46	3.2.2.1. Coffee	Agriculture	14	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
47	3.2.2.2. Citrus	Agriculture	15	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
35	3.2.2.3. Palm Oil	Agriculture	16	
48	3.2.2.4. Other Perennial Crops	Agriculture	17	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent
18	3.2. Agriculture	Agriculture	18	Remaining agriculture is classified as class 41, unless in the Amazon and Atlantic Forest, where class 15 is prevalent
50	2.5. Herbaceous Sandbank Vegetation	Biomes	19	
25	4.4. Other Non Vegetated Areas	Biomes	20	

33	5.1. River, Lake and Ocean	MapBiomas Water	21	Not used in Pantanal
33	5.1. River, Lake and Ocean	Biomes	22	
3	1.1. Forest Formation	Biomes	23	In the Amazon, cross-cutting class 15 is prevalent
4	1.2. Savanna Formation	Biomes	24	Outside protected areas in Cerrado the class 15 is prevalent
49	1.5. Wooded Sandbank Vegetation	Biomes	25	
6	1.4. Floodable Forest	Biomes	26	
11	2.1. Wetland	Biomes	27	Outside protected areas in Cerrado the class 15 is prevalent
12	2.2. Grassland Formation	Biomes	28	Outside protected areas in Cerrado the class 15 is prevalent
15	3.1. Pasture	Pasture	29	Not used in Pantanal. In Pampa, class 21 is prevalent. Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
15	3.1. Pasture	Biomes	30	Amazon, Cerrado and Pantanal map class 15

21	3.4. Mosaic of Uses	Biomes	31	In Cerrado, 21 is converted to 15 within Conservation Units