MapBiomas General “Handbook”

Algorithm Theoretical Basis Document (ATBD)

Collection 10

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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 while featuring seven LCLU classes: forest, agriculture, pasture, forest plantation, mangrove, and water. Collection 2, released in 2017, was carried out by an empirical decision tree classification for the time-period of 2000 through 2016, which 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 that used the random forest machine learning algorithm 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 addition to including the first accuracy analysis. 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. Moreover, 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 images acquired for each year of the time series, 90 spectral and temporal metrics were generated. Furthermore, since Collection 6, spatial and temporal filters were not only applied to the biomes and cross-cutting themes maps but also to the integrated maps. Besides random forest,

U-Net (Convolutional Neural Network), a Deep Learning algorithm, was applied in the Aquaculture, Mining, Irrigation, Rice, and Citrus classification. The classification from the MapBiomas Water product was incorporated in the Water class. In the Mining module, the data were divided into industrial and artisanal (*garimpo)* mining while also categorizing the main substance being exploited based on data from the geoscience system of the Geological Service of Brazil (SGB/CPRM, 2024).

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 imagery (Collection 2, Tier 1) were used in the classification.

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. The accuracy data was updated and revised adding the years from 2019 to 2022.

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 was made 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.

In the Collection 10, the class Photovoltaic Solar Park was included as a cross-cutting theme (beta version), resulting in 30 classes. The training samples, post-classification and post-integration temporal filters were improved. Aquaculture is now being mapped throughout Brazil, not only in the Coastal Zone. The methods for mapping Rocky Outcrop, Floodable Forest, Wetland, Herbaceous Sandbank Vegetation, were revised in specific biomes. The annual wetland and water classification in Pantanal are now based on monthly data. The rice class was improved, with the inclusion of three new states to the map. The mining map was improved through extending the searching area and separating the sampling, training, and prediction for each Brazilian biome.

The specific procedures applied in each biome and cross-cutting theme and its improvements in Collection 10 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 10 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 2024 of the MapBiomas Collection 10.

This document covers the classification methods of Collection 10, the image processing architecture, and the approach that integrates 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 4).

- 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)
- Collection 10: 1985 through 2024 (launched in August 2025)

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 data; iii) MapBiomas collaborative network of organizations and experts that share knowledge and mapping tools; and iv) visionary funding agencies that support the project .

The products of the MapBiomas Brazil's LCLU Collection 10 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, Urban Area, and Photovoltaic Power Plant (beta));
• 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 within buffers of infrastructure (transportation, energy, mining, agribusiness and telecommunication).
• Annual and accumulated deforestation maps (from 1987 to 2024).
• Annual maps of secondary vegetation (from 1987 to 2024) and age of secondary vegetation maps.
• Irrigation maps (for center pivot irrigation systems, irrigated rice, and other irrigation systems).
• Annual maps of pasture vigor conditions (from 2000 to 2024).
• Annual mining maps featuring industrial and artisanal (*garimpo*) categories and its main substances.
• Temporal analysis (number of classes, stable areas, and number of changes).

Besides these products, the MapBiomas Brazil network released the MapBiomas Water Collection 4 and MapBiomas Fire Collection 4 featuring annual and monthly maps of Brazil's water surface and fire scars from 1985 to 2024, respectively. Annual maps of topsoil (0 - 30 cm) organic carbon stocks from 1985 to 2024 were launched as part of the MapBiomas Soil Beta Collection 3, including static maps of sand, silt, and clay content of the 0-10, 10-20, 20-30, 0-20 and 0-30 cm layers, and soil texture in the 0-10, 0-20 and 0-30 cm layers (beta version), 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 5 (https://chaco.mapbiomas.org/), the Amazon region with its Collection 6 (https://amazonia.mapbiomas.org/), Collection 4 MapBiomas Atlantic Forest (https://bosqueatlantico.mapbiomas.org/), Collection 4 South American Pampa (https://pampa.mapbiomas.org/), Collection 3 Peru (https://peru.mapbiomas.org/), Collection 2 Bolivia (https://bolivia.mapbiomas.org/), Collection 2 Indonesia (https://mapbiomas.nusantara.earth/), Collection 2 Colombia (https://plataforma.colombia.mapbiomas.org/), Collection 2 Venezuela (https://plataforma.venezuela.mapbiomas.org/), Collection 2 Ecuador (https://plataforma.ecuador.mapbiomas.org/), Collection 2 Uruguay (https://plataforma.uruguay.mapbiomas.org/), Collection 2 Paraguay (https://plataforma.paraguay.mapbiomas.org/), and most recently in Chile (https://plataforma.chile.mapbiomas.org/), and Argentina (https://plataforma.argentina.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. Our maps are developed per biome and then integrated into a single map of Brazil's LCLU classes in a post-processing step. Classifying LCLU classes at the biome level helps to better discriminate specific LCLU classes and landscape patterns across the country (Table 1). The project was also divided into cross-cutting themes to improve the classification accuracy and quality: Agriculture, Pasture, Forest Plantation, Coastal Zone, Mining, and Urban Area.

For the first MapBiomas collections, a 1:1,000,000 map at the biome level was produced based on the refinement of the official Brazilian biome map 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 used in the MapBiomas project to generate the Collection 10 of Land Cover and Land Use mapping products (source: IBGE, 2019).

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

Biome	Area (Mha) (Country %)	Land Cover	Predominant Land Use
Amazon	420.8 (49.5%)	Evergreen forest, with enclaves of savanna, natural grassland, and extensive wetlands and surface water.	Cattle ranching, agriculture, mining, logging and non-timber forestry production.

Atlantic Forest	110.7 (13.0%)	Evergreen forests, mangroves and sandbank vegetation along the coast. Deciduous and semi deciduous forests in the countryside and Araucaria moist forests in the South. Savanna formations and grasslands are also present. Vegetation is mostly in isolated patches.	Agriculture, cattle ranching, urban, forest plantation, artificial water reservoir.
Caatinga	86.3 (10.1%)	Dry woody and deciduous physiognomies	Agriculture, cattle ranching, smallholder livestock production, urbanization.
Cerrado	198.5 (23.3%)	Mosaic of savannas, grasslands and deciduous and semi deciduous forests	Agriculture, cattle ranching.
Pampa	19.46 (2.3%)	Mostly grasslands, but deciduous and semi deciduous forests, wetlands and herbaceous sandbank vegetation are also present	Agriculture (rice, soy, perennial crops), livestock production (in natural grasslands), forest plantation, and urbanization.
Pantanal	15.1 (1.8%)	Mostly savannas, grasslands and wetlands. Deciduous and semi deciduous forests are also present.	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 secondary vegetation
- Monitoring of water resources and their interaction with LCLU classes
- Monitoring agriculture, irrigation 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 beyond Brazil. The award is now in the seventh edition, presenting seven categories: General, Youth, Outstanding Applications in Public Policies, Outstanding Applications in Business, Applications in Schools, Actions against Deforestation, and Climate Emergencies. (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 used in the map 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)
- 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)
- Dr. Gerd Sparovek (University of São Paulo)

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 data 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 codes - these scripts 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 , 9 and 10 were written in Javascript.

• Python scripts – This code category was used to optimize 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 API, including tasks such as calibration of machine learning algorithms, data analysis, and data 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 to promote data accessibility for the general public not familiar with the 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 for general users with no-programming experience to access imagery collections, allowing data processing, management, and storage of 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. This workspace has been updated to manage the new collections.

• Mapbiomas.org (Dashboard). The web platform of the MapBiomas initiative presents the Landsat image mosaics and their quality, LCLU annual maps of Collection 10, 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 30 m data, the MapBiomas dashboard presents other products, such as deforestation, secondary vegetation, 10 m land use land cover, irrigation, urban module, degradation, coral reef, 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: Previous Mapping Initiatives

Previous LCLU mapping efforts that covered the entire extent of Brazil before MapBiomas were not frequently updated and/or featured coarse spatial resolution, resulting in significant knowledge gaps in the literature. MapBiomas datasets have several advantages and can thus be used in a complementary manner to other global and national land cover products. First, MapBiomas maps reconstruct the entire Landsat time series (>35 years), providing annual spatially-explicit information on detailed land cover and land use categories for the entire extent of Brazil. Thus, MapBiomas data allows additional monitoring analyses that are unprecedented at a national level given the lack of previous mapping efforts featuring detailed LCLU classes over a long time series and national extent. These analyses include (but are not limited to) tracking changes in primary forests (*i.e.,* deforestation), monitoring secondary vegetation, and understanding land use dynamics (changes in pasture, agriculture, forest plantation, mining, and urban area). In addition, the classification scheme used in MapBiomas products follows the official Brazilian vegetation classification legend (IBGE, 2012), thus being relevant and useful for national applications.

All products from MapBiomas, including the methods and codes used to produce the maps, are publicly available online. 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 scale 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 produces a MODIS land cover data mapped at 500-m spatial resolution. 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 2021 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 2024 derived from the Landsat imagery at 30-m resolution (https://glad.earthengine.app/view/global-forest-change), 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, https://www.un-spider.org/links-and-resources/data-sources/land-cover-map-globeland-30-ngcc). Japan Aerospace Exploration Agency (JAXA) also produced a forest/non-forest map for 2007-2024 using a 25-m resolution PALSAR mosaic (https://www.eorc.jaxa.jp/ALOS/en/dataset/fnf_e.htm) . More 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, https://dynamicworld.app/). 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).

After the RadamBrasil project, only the Amazon and Atlantic Forest biomes were being monitored using other systems, so 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 for specific biomes in the years 2009, 2010, and 2011.

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, identifying the classes of natural vegetation (forest and non-forest), agriculture, pasture, silviculture, urban area, dunes, rock outcrops, mining, and water at 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 2020 on a 1-km resolution and featuring 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 other 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 maps are available for all biomes (https://terrabrasilis.dpi.inpe.br/app/map/deforestation?hl=pt-br) and the TerraClass maps are available for Amazonia and Cerrado (https://www.terraclass.gov.br/). These reference LCLU maps for the biomes and cross-cutting themes are presented in Annex II.

3. Methodological Description

The Collection 10 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 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, training samples were yearly 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, Citrus, and Photovoltaic Power Plant which had their areas of occurrence identified using the U-Net convolutional neural network classifier (CNN) and the Caatinga biome, which was mapped using the Gradient Tree Boosting (GTB) classifier.

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 Annex V. Spatial and temporal filters were once again applied on the integrated maps to create the final Collection 10 product.

The accuracy assessment analysis was based on acquiring 75,000 independent samples per year from 1985 to 2024. 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.

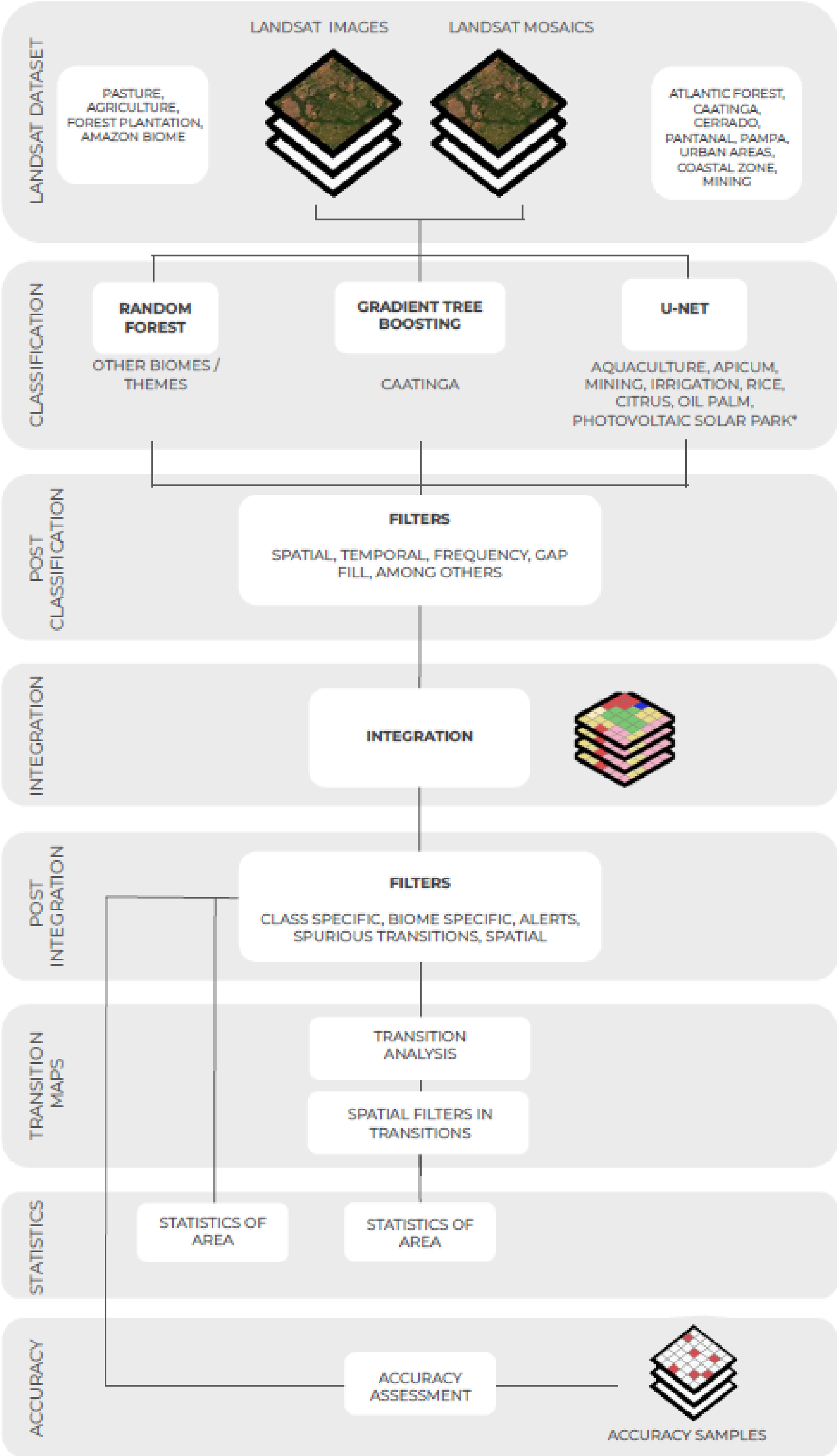


Figure 2. General methodological steps of MapBiomas Brazil Collection 10. * The class Photovoltaic Power Plant is mapped using NICFI PlanetScope imagery followed by spatial and temporal filtering, composite refinement, and resampling to a standardized 30-meter resolution grid.

3.1. Landsat Mosaics

All biomes, except the Amazon, generated cloud-free Landsat composites based on specific periods of time to optimize the spectral contrast and help with 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 Collections 7, 8, 9, and 10 the 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, Mining) and the class Photovoltaic Power Plant 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 Forest 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 21 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 10 in Brazil.

ID	COLLECTION 10 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

75	4.4. Photovoltaic Power Plant	ANTHROPIC	USE	THEMES
25	4.5. 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, Palm Oil, and Photovoltaic Power Plant classification.

In collection 10 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. 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

After the integration of maps, filters are applied to improve spatial and temporal consistency, reduce noise, and ensure coherent transitions between thematic classes. The filters were developed based on technical knowledge, change pattern analysis, visual validation, and spectral interpretation.

Process Steps

1. Forestry Filter
2. General Filter by Biome

3. Agriculture Filter
4. Pasture Filter
5. Alerts Filter
6. Spurious Transitions Filter
7. Spatial filter

3.4.3.1 Forestry Filter

This filter was developed to address spurious temporal fluctuations in class 9 (Forestry), which is often spectrally confused with natural vegetation or agricultural land use. The goal is to ensure that only consistent and sustained transitions are maintained as forestry.

Initially, the legend classes are grouped into three categories:

- **Group 1 – Natural Vegetation**: forests, savanna formations, wetlands, etc.
- **Group 2 – Agricultural Use**: pasture, crops, mosaics, alternative use
- **Group 3 – Forestry**: class 9 only

A set of temporal rules using a 7-year moving window is then applied to this remapped image. These rules detect typical transition patterns between groups. Examples:

- [2, 1, 1, 1, 1, 1, 3] → [2, 3, 3, 3, 3, 3, 3]: indicates a valid gradual transition to forestry
- [3, 3, 3, 1, 1, 1, 2] → [3, 3, 3, 3, 3, 3, 2]: corrects artificial discontinuity caused by misclassification
- [3, 3, 3, 3, 2, 2, 3] → [3, 3, 3, 3, 3, 3, 3]: removes mosaic noise within forestry
- [3, 2, 2, 2, 2, 3, 3] → [3, 3, 3, 3, 3, 3, 3]: reinforces forestry continuity after brief disturbance

Additional rules are applied for the last years of the series (2017–2023), when the analysis window is limited. These aim to maintain forestry consistency during recent legitimate transitions.

3.4.3.2 General Filter by Biome

This filter was designed to correct temporal noise in specific classes, considering the ecological and productive context of each Brazilian biome. The central idea is to smooth abrupt, unsustained transitions that do not represent real land use or cover changes but are instead due to spectral classification errors or model instability.

The filter uses two types of temporal analysis:

- **Kernel 3**: 3-year moving window to remove isolated spikes of a class (e.g., [X, Y, X] → [X, X, X])
- **Kernel 4**: 4-year moving window to correct longer or double spurious transitions (e.g., [X, Y, Y, X] → [X, X, X, X])

These filters are applied only within biome-specific regions and on select classes sensitive to noise, such as forest formations, savannas, wetlands, pastures, and agriculture. **Exception rules** are incorporated to preserve patterns recognized as valid, even if they appear as fluctuations to the algorithm.

Exception Rules by Biome

Atlantic Forest:

- [3, 9, 9, 3] → [3, 3, 3, 3]: avoids removing forestry when inserted into a consolidated natural pattern
- [21, 3, 3, 46] → [21, 46, 46, 46]: preserves transition to perennial crops despite vegetation in the middle
- [15, 3, 3, 9] → [15, 9, 9, 9]: corrects legitimate substitution of agriculture by forestry

Amazon:

- [33, 15, 3] → [33, 3, 3]: indicates valid substitution from mosaic to vegetation after temporary use
- [33, 15, 12] → [33, 12, 12]: preserves typical pattern of light agricultural degradation over mosaic

Pampa:

- [11, 11, 49] → [11, 11, 11]: prevents incorrect transition to coastal vegetation in the last year

These exceptions are based on time series analysis, visual inspection, regional validations, and expert knowledge. They ensure that real, significant patterns are preserved during filtering.

3.4.3.3 Agriculture Filter

This filter removes temporal noise in crop classifications, especially in areas with seasonal alternation or low data quality. Agricultural classification is among the most dynamic and spectrally sensitive, often producing false changes between crops and vegetation or among crop types.

The process starts by remapping legend classes into three simplified groups:

- **Group 1 – Other Covers**: natural vegetation, pasture, mosaics, alternative use
- **Group 2 – Temporary Crops**: corn, soy, cotton, rice, similar crops
- **Group 3 – Perennial Crops**: coffee, fruit, and permanent cultivation

A 3-year window (kernel 3) is applied to detect unstable sequences. The rules correct patterns where an agricultural class appears only briefly between years of stable use — considered noise.

Applied Rules

- [1, 2, 1] → [1, 1, 1]: removes isolated temporary crop between vegetation or pasture
- [1, 3, 1] → [1, 1, 1]: removes momentary, unsupported perennial crop

These rules are applied only in the middle of the series (1986–2023) to avoid border years. Original values are preserved unless divergence is detected, preventing alteration of stable agricultural patterns.

This filter is particularly important in regions where agriculture and pasture alternate frequently, often resulting in annual variation without real land use change.

3.4.3.4 Pasture Filter

This filter corrects small temporal gaps of mosaic land use (class 21) within consolidated pasture areas (class 15). Such discontinuities typically do not indicate real changes but result from spectral variation or classification errors. The logic uses a 5-year moving window. If one to three years of class 21 interrupt a class 15 sequence, the middle years are corrected.

Recognized and Corrected Patterns
Examples include:

- [15, 21, 21, 21, 15]
- [15, 21, 21, 15, 15]
- [15, 15, 21, 21, 15]
- [15, 15, 21, 15, 15]

- [15, 21, 15, 15, 15]
- [15, 15, 15, 21, 15]

These reflect short interruptions in continuous pasture areas. Corrections are applied only to the central years (Y–1, Y, Y+1), preserving edge values (Y–2 and Y+2).

This filter helps avoid artificial fragmentation of pasture, preserving spatial continuity and improving visual interpretation and area calculation.

3.4.3.5 Alerts Filter

This filter uses MapBiomas Alerta data (https://alerta.mapbiomas.org/) to reinforce detection of real changes in natural vegetation. It acts as a cross-validation between land cover/use data and validated deforestation alert events. Alerts are provided as annual raster layers with two main attributes:

- **Deforestation driver** (e.g., urbanization, mining, extreme weather)
- **Detection Year**

The filter is applied to areas originally classified as natural vegetation and responds based on deforestation driver and year.

Deforestion drivers and reclassification rules

- **Extreme Weather (temporary alerts – type 1)**:
  Natural vegetation affected in the last 3 years is temporarily reclassified as class 25. After 3 years, original class is restored unless another filter indicates permanent change.
- **Anthropic Pressure (permanent alerts – type 2)**:
  Natural vegetation with confirmed alerts is reclassified to an anthropic class.
  The new class depends on the biome: class 15 (pasture) in Amazon and Pantanal; class 21 elsewhere.
- **Urbanization and Mining (permanent alerts – type 3)**:
  Confirmed mining or urban expansion areas are reclassified permanently as class 25.

3.4.3.6 Spurious Transitions Filter

This filter removes inconsistent or unsustained changes throughout the time series. These often involve oscillations between incompatible classes or alternating patterns that do not reflect a real land use trajectory. The core strategy is to analyze consecutive year pairs and eliminate reversible, unstable, or illogical transitions based on a thematic rule matrix that defines which combinations should be discarded.

The logic combines two complementary approaches:

- **Temporal analysis** of reversible or unsupported transitions
- **Spatial analysis** using pixel grouping to ensure changes reflect real spatial patches, not point noise

Spurious Temporal Transitions

The temporal check identifies back-and-forth patterns that last only one or two years within stable sequences. Examples:

- `[15 → 21 → 15]`: alternative use discarded, sequence filled with pasture
- `[3 → 15 → 3]`: momentary noise in forest removed
- `[4 → 12 → 4]`: isolated agriculture between savanna corrected
- `[49 → 11 → 49]`: weak transition between restinga and wetland removed

3.4.3.7 Spatial filter

A spatial consistency step is added using `connectedPixelCount`, which measures the number of contiguous pixels with the same class per year. Changes resulting in very small patches (e.g., under 5–6 pixels) are considered spectral noise and reversed. This spatial grouping distinguishes real changes from point-level fluctuations.

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 2024; (b) five years e.g. 1985-1990, 1990-1995, 1995-2000; (c) ten years e.g. 1985-1994, 1995-2004, 2005-2014; and (d) about half of the temporal extent mapped by MapBiomas, from 1985 to 2000 and from 2000 to 2024. 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 10 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

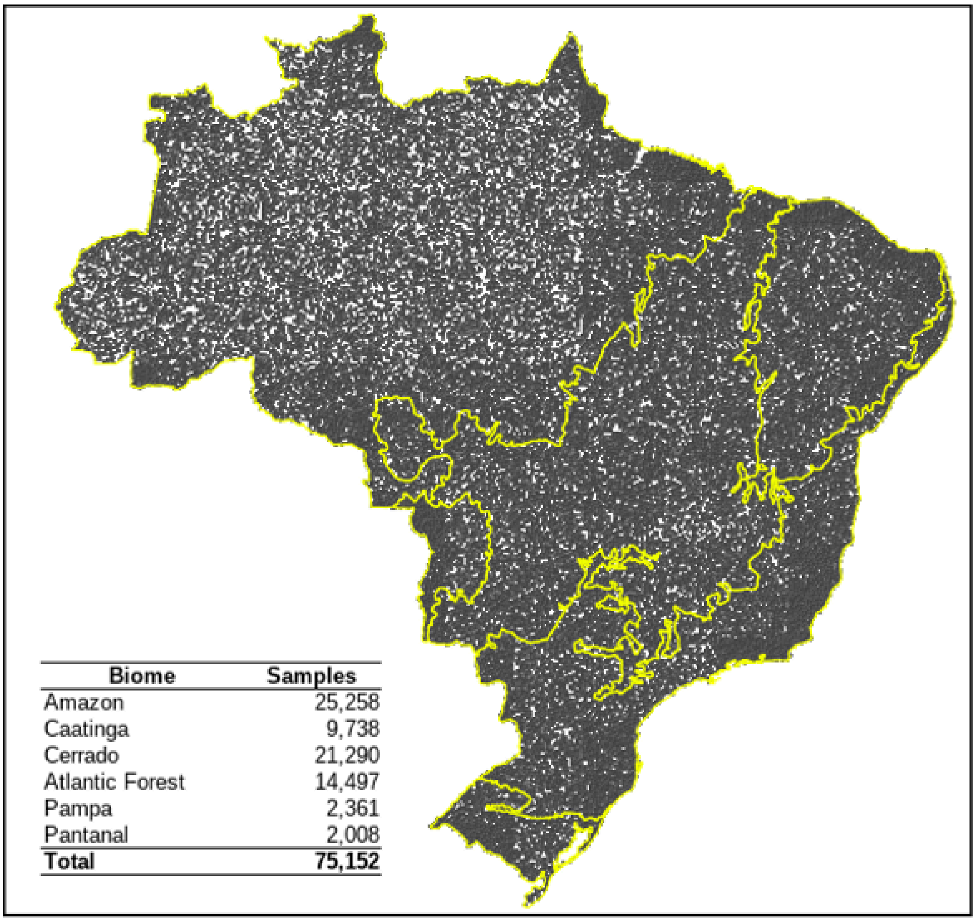
The validation strategy was based on two approaches: (i) comparative analysis with reference maps of specific biomes/regions and years, and (ii) accuracy analysis based on statistical techniques using independent sample points covering the entirety of Brazil throughout the time series.

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 85,152 spatially independent samples, replicated for each of the 40 years between 1985 and 2024, 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).



Biome	Samples
Amazon	25,258
Caatinga	9,738
Cerrado	21,290
Atlantic Forest	14,497
Pampa	2,361
Pantanal	2,008
Total	**75,152**

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 10 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 10 presented 93.3% mean global accuracy and 5.3 % allocation disagreement with 1.3% area disagreement. At Level 2, the global accuracy was 90.2%, with 6.8% allocation disagreement and 3.0% area disagreement. Finally, at Level 3, the global accuracy was 90.2%, with 6.7% allocation disagreement and 3.1% area disagreement. The global accuracy was stable over the mapped period, varying across biomes from 86.9% to 97.5% in Level 1.

4. Map Collections and Analysis

The MapBiomas Collections produced so far are listed and summarized below (Table 4):

- 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 Amazon, Atlantic Forest, Cerrado, Pampa, and Pantanal biomes, Coastal Zone, Urban Area, Pasture, Agriculture and Shallow Coral Reef themes. For Caatinga the GTB classifier was used. The Aquaculture, Hypersaline tidal flats, Mining, Irrigation, Rice, Citrus, Palm Oil themes applied U-Net convolutional neural networks in the classification.

• Collection 10 - comprised the period of 1985 to 2024 and was based on random forest classification for Amazon, Atlantic Forest, Cerrado, Pampa, and Pantanal biomes, Coastal Zone, Urban Area, Pasture, Agriculture and Shallow Coral Reef themes. For Caatinga the GTB classifier was used. For the Aquaculture, Hypersaline tidal flats, Mining, Irrigation, Rice, Citrus, Palm Oil and Photovoltaic Power Plant, U-Net convolutional neural networks were applied in the classification.

Table 4. 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,	L1 - Gb **91%** Ar 2% All: 7% L2 - Gb **87%** Ar 3% All: 9%

			Irrigation, Mining, Rice, and Citrus)	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 + GTB (Caatinga)+ U-Net (Aquaculture, Hypersaline tidal flats, 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%
10.0	40 years 1985-2024	4 levels / 30 classes	Random Forest + GTB (Caatinga)+ U-Net (Aquaculture, Hypersaline tidal flats, Irrigation, Mining, Rice, Citrus, Palm Oil and Photovoltaic Solar Park)	L1 - Gb **93%** Ar 1% All: 5% L2 - Gb **90%** Ar 3% All: 7% L3 - Gb **90%** Ar 3% All: 7%

Collection 10 resulted not only in a long time series, adding the year 2023 and 2024, but more spatially and temporally consistent annual LCLU maps of Brazil. The class Photovoltaic Solar Plants was included as a cross-cutting theme. . The training samples, post-classification and post-integration temporal filters were improved. Rocky Outcrop, Floodable Forest and Wetland mapping was improved, and the Herbaceous Sandbank Vegetation class began to be mapped in the coastal region of the Cerrado biome. In the Atlantic Forest, this class began to follow the full classification workflow, instead of being defined in the post-processing steps, as in Collection 9. Aquaculture is now being mapped throughout Brazil, not only in the Coastal Zone. The annual wetland and water classification in Pantanal are now based on monthly data. The rice class was improved, with the inclusion of Pará, Mato Grosso do Sul and Goiás states to the map. The mining map was improved through extending the searching area and separating the sampling, training, and prediction for each Brazilian biome. 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 and is in the implementation phase in other tropical countries. 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.

6. References

Breiman, L. Random forests. **Machine learning**, v. 45, n. 1, p. 5-32. 2001.

Brown, C. F. *et al.* Dynamic World, Near real-time global 10 m land use land cover mapping. **Scientific Data** v. 9, 251. 2022. https://doi.org/10.1038/s41597-022-01307-4.

Chen, J. *et al.* Global land cover mapping at 30 m resolution: A POK-based operational approach. **ISPRS Journal of Photogrammetry and Remote Sensing** v. 103, p. 7–27. 2014.

Friedl, M. A. *et al.* MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. **Remote Sensing of Environment**, v. 114, p. 168–182. 2010.

FAO. **Manual for integrated field data collection.** Rome: FAO, 2012.

Hasenack, H.; Cordeiro, J. L. P; Weber, E. J. (Org.). **Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2002.** Porto Alegre: UFRGS IB Centro de Ecologia, 2015. Available at http://www.ecologia.ufrgs.br/labgeo

Hoffmann, G. S.; Weber, E. J.; Hasenack, H. (Org.). **Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2015.** Porto Alegre: UFRGS IB Centro de Ecologia, 2018. Available at http://www.ecologia.ufrgs.br/labgeo

IBGE. **Mapa de biomas do Brasil (escala 1:5.000.000).** Rio de Janeiro: IBGE. Mapa e nota técnica, 2004a.

IBGE. **Mapa de biomas do Brasil (escala 1:5.000.000).** Rio de Janeiro: IBGE, 2004b.

IBGE. **Uso da terra no Estado do Rio Grande do Sul: relatório técnico.** Rio de Janeiro: IBGE, 2010.

IBGE. **Manual técnico de uso da terra.** Rio de Janeiro: IBGE, 1999.

IBGE. **Manual técnico da vegetação brasileira.** 2ed. Rio de Janeiro: IBGE, 2012.

IBGE. **Biomas e Sistema Costeiro-Marinho do Brasil 1:250.000**, 2019. Available at https://www.ibge.gov.br/geociencias/informacoes-ambientais/vegetacao/15842-biomas.html .

IBGE. **Banco de Dados e Informações Ambientais (BDiA) - Mapeamento de Recursos Naturais (MRN) Escala 1:250 000**, 2023 Available at https://bdiaweb.ibge.gov.br/#/home .

Lima, M. I. C. 2009. **Projeto Radam: uma saga na Amazônia**. Belém: Paka-tatu, 2009.

Morellato L. P. C.; Haddad C. F. B. . Introduction: The Brazilian Atlantic Forest. **Biotropica** 32: 786–792, 2000. doi:10.1111/j.1744-7429.2000.tb00618.x.

NASA JPL. NASADEM Merged DEM Global 1 arc second V001. NASA EOSDIS Land Processes DAAC, 2020. Available at doi:10.5067/MEaSUREs/NASADEM/NASADEM_HGT.001

de Oliveira G. *et al*. Conserving the Brazilian semiarid (Caatinga) biome under climate change. **Biodiversity and Conservation,** v. 21, p. 2913–2926, 2012. doi:10.1007/s10531-012-0346-7.

Olofsson P. *et al.*. Good practices for estimating area and assessing accuracy of land change. **Remote Sensing of Environment**, v. 148, p.42-57, 2014.

Roesch L. F. W. *et al.* The Brazilian Pampa: A fragile biome. **Diversity,** v.1, p. 182–198, 2009. doi:10.3390/d1020182.

SGB/CPRM. Dados, informações e produtos do Serviço Geológico do Brasil , 2024. Available at https://geosgb.sgb.gov.br/.

Souza, C.M., Jr.; Z. Shimbo, J.; Rosa, M. R.; Parente, L. L.; A. Alencar, A.; Rudorff, B. F. T.; Hasenack, H.; Matsumoto, M.; G. Ferreira, L.; Souza-Filho, P. W. M.; de Oliveira, S. W.; Rocha, W. F.; Fonseca, A. V.; Marques, C. B.; Diniz, C. G.; Costa, D.; Monteiro, D.; Rosa, E. R.; Vélez-Martin, E.; Weber, E. J.; Lenti, F. E. B.; Paternost, F. F.; Pareyn, F. G. C.; Siqueira, J. V.; Viera, J. L.; Neto, L. C. F.; Saraiva, M. M.; Sales, M. H.; Salgado, M. P. G.; Vasconcelos, R.; Galano, S.; Mesquita, V. V.; Azevedo, T. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. **Remote Sensing**, v. 12, 2735, 2020. https://doi.org/10.3390/rs12172735.

Stehman, S. V. Sampling designs for accuracy assessment of land cover. **International Journal of Remote Sensing**, v. 30, p. 5243-5272, 2019. doi:10.1080/01431160903131000.

Stehman, S. V. Estimating area and map accuracy for stratified random sampling when the strata are different from the map classes. **International Journal of Remote Sensing**, v. 34, p. 4923-4939, 2014. doi:10.1080/01431161.2014.930207

USGS. Landsat Collection 1 Level 1 Product Definition. 2017. Available online: https://landsat.usgs.gov/sites/default/files/documents/LSDS-1656_Landsat_Level-1_Product_Collection_Definition.pdf.

Weber, E. J.; Hoffmann, G .S.; Oliveira, C. V.; Hasenack, H. (Orgs.). **Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2009**. Porto Alegre: UFRGS IB Centro de Ecologia, 2016. 1a ed. ISBN 978-85-63843-20-3. Available at http://www.ecologia.ufrgs.br/labgeo.

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 - Infrastructure layers (Transportation, Energy and Mining)

Appendix 13 - Deforestation and Secondary Vegetation

Appendix 14 - Accuracy Assessment

Appendix 15 - Photovoltaic Power Plant

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)

The project counts on an Independent Committee of Scientific Advice composed by renowned specialists:

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

Former members:

- Dr. Gerd Sparovek (University of São Paulo)
- 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
Agriculture Irrigated by Center Pivots in Brazil	ANA / Embrapa	Mapping of the area and number of central pivot irrigation equipment in Brazil between 1985 and 2017. Study carried out through a partnership between the National Water Agency - ANA and Embrapa Milho e Sorgo.	https://metadados.ana.gov.br/geonetwork/srv/pt/main.home?uuid=e2d38e3f-5e62-41ad-87ab-990490841073
Favelas and Urban Communities 2019	IBGE	This preliminary version incorporates updates through December 2019 and is comprised of 13 152 Subnormal Agglomerations. These agglomerations are located in 734 Municipalities, in all States and in the Federal District, and total 5 127 747 household	https://www.ibge.gov.br/geociencias/organizacao-do-territorio/tipologias-do-territorio/15788-aglomerados-subnormais.html?=&t=saiba-mais-edicao
Atlas of the Atlantic Forest	SOS Atlantic Forest/INPE	Mapping of forest formations and associated ecosystems, reference year 2023/2024	https://www.sosma.org.br/iniciativas/atlas-da-mata-atlantica
Atlas of the Mangroves of Brazil	MMA / ICMBio	Partnership between the Chico Mendes Institute for Biodiversity Conservation and the Project "Effective Conservation and Sustainable Use of Mangrove Ecosystems in Brazil", implemented by the United Nations Development Program - Brazil (UNDP), with the support of the Global Fund for the Environment Environment (GEF).	https://www.gov.br/icmbio/pt-br/centrais-de-conteudo/atlas-dos-manguezais-do-brasil-pdf
CAR Thematic Digital Vector Base - State of Tocantins	Tocantins State Secretariat for the Environment and Water Resources	Prepared from satellite images (Plêiades Year 2015), and constitutes a vectorial, digital base, compatible with a 1:25,000 scale, consisting of features of the hydrographic grid, municipal boundaries, road system grid, transmission lines and special areas of the State of	https://www.to.gov.br/semarh/base-vetorial-digital-tematica-do-car/1knojozyng4n

		Tocantins, cut and articulated according to sheets 1:25,000 of the National Cartographic System – SCN.	
Global Distribution of Mangroves USGS	USGS	This dataset shows the global distribution of mangrove forests, derived from earth observation satellite imagery	http://sedac.ciesin.columbia.edu/data/set/lulc-global-mangrove-forests-distribution-2000/data-download
Global Human Settlement Layer (GHS-BUILT e GHS_BUILT_S2)	European Commission Joint Research Centre (JRC)	A layer of multitemporal information on the presence of built-up area derived from Landsat image collections (GLS1975, GLS1990, GLS2000 and Landsat 8 ad-hoc 2013/2014 collection).	https://ghsl.jrc.ec.europa.eu/download.php
Global Land Analysis Discovery - Commodity Crop Mapping and Monitoring in South America	University of Maryland	Annual Soy Coverage Maps in South America, Soy Coverage 2000 onwards to enable tracking of indirect effects of soy expansion on deforestation and inform multi-stakeholder negotiations on soy sustainability, Corn Coverage Maps in South America South America, updated semi-annually.	https://glad.umd.edu/projects/commodity-crop-mapping-and-monitoring-south-america
Index of Roads and Structures (IRS)	Justiniano et. al	Presents a new easily reproducible methodology for urban mapping. The methodology allows the combined processing of OpenStreeMap and Remote Sensing data, where a metric called the road and structure index (LVI) is proposed for mapping urban areas. The IVE is used with NDVI and MNDWI to map the urban surface with high accuracy, with a reference year of 2020.	https://www.sciencedirect.com/science/article/pii/S0303243422001179?via%3Dihub
IV National Inventory of Greenhouse Gas Emissions (LULUCF sector)	MCTIC	Map of agricultural areas (annual, semi-perennial and perennial)	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
Census Tracts 2021	Instituto Brasileiro de geografia e Estatística (IBGE)	The 2021 Sectoral Mesh was updated for the collection stage of the 2022 Demographic Census, taking into account the updated situation of the Brazilian Political-Administrative Division – DPA, in force on	https://www.ibge.gov.br/geociencias/downloads-geociencias.html?caminho=organizacao_do_territorio/malhas_territoriais/malhas_de_set

		04/30/2021.	ores_censitarios__divisoes_intramunicipais/2021/Malha_de_setores_(shp)_Brasil
Brazilian Mining Map	Brazil-Germany Chamber of Commerce and Industry / GeoAnsata Projects	Portraits of the mining industry and intermediation of interested parties in the area, experts and producers in the sector with mining companies.	https://www.google.com/maps/d/viewer?mid=19ps2n5FI62X-ib2V2teFhaqcUCbS2BZJ&ll=-14.64391762573763%2C-58.49807411843837&z=4
Deforestation Alert Map - Mining Class - DETER Project	INPE	Mining Class of the Near Real Time Alert System (DETER), maintained by the National Institute for Space Research (INPE)	http://terrabrasilis.dpi.inpe.br/
Amazon Mining Watch Network Mining Map	AMW	Amazon Mining Watch Mining Activity Data	https://amazonminingwatch.org/
Planted forests map	GFW/WRI	Map of planted forests for Brazil	http://data.globalforestwatch.org/datasets/baae47df61ed4a73a6f54f00cb4207e0_5
Biomes Boundary Map 1:250,000	IBGE	Together with the methodological report that brings new limits between the six Brazilian biomes, Amazon, Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampa, compatible with the 1:250 000 scale.	https://www.ibge.gov.br/geociencias/informacoes-ambientais/estudos-ambientais/15842-biomas.html?=&t=acesso-ao-produto
Amazon Mining Map	Social and Environmental Institute - ISA	Mining data in the Brazilian Amazon compiled by Instituto Socioambiental - ISA	https://www.amazoniasocioambiental.org/es/mapas/#descargas

Brazil Mineral Resources Map	Geological Survey of Brazil (CPRM) - GeoSGB	The spatial representation of Brazil's mineral resources is maintained by the Geological Service of Brazil (CPRM) through its geoportal called GeoSGB.	https://geoportal.cprm.gov.br/geosgb/
Map of mangroves in northeastern Brazil	Pereira, E.A., Souza-Filho, P.W.M., et al.	Map of mangrove areas from Ponta de Tubarão-MA to the south of the State of Bahia from the classification of Landsat and ALOS PALSAR images from 2008	
Map of mangroves in the northern region of Brazil	Nascimento Jr, W.R; Souza-Filho, P.W.M., et al.	Map of mangrove areas from Oiapoque-AP to Ponta de Tubarão-MA generated from the classification of Landsat and ALOS PALSAR images from 2008	http://dx.doi.org/10.1016/j.ecss.2012.10.005
Synthesis Map of Pastures of Brazil - v8	LAPIG/UFG	Mapping of pasture areas, from TerraClass Amazon data compilation; Funcate; PROBIO; Canasat and TNC.	http://maps.lapig.iesa.ufg.br/?layers=pa_br_areas_pastagens_250_2016_lapig
Vegetal Coverage Maps of Brazilian Biomes - ProBio	UEFS/APNE/EMBRAPA-Solos/UFCE/UFRN/UFRPE/UFPB/CRA/SEMARH-MMA	Survey of vegetable coverage and land use of the Caatinga Bioma	http://mapas.mma.gov.br/geodados/brasil/vegetacao/vegetacao2002/mosaicos_vegetacao/caatinga.zip
Mapping of the Upper Paraguay Basin	SOS Pantanal/WWF Brasil	Monitoring the use and vegetation cover of the Upper Paraguay Basin, which includes the Pantanal and its headwaters. Data available for 2002, 2008, 2010, 2012, 2014 and 2016	https://www.sospantanal.org.br/atlas/
Mapping of the Vegetal Coverage of the Atlantic Forest of Minas Gerais	State Forest Institute (IEF)	Mapping carried out a sweep of 30,673,854.99 hectares, which included the legal limit of the biome established by Federal Law 11,428/2006, plus a five-kilometer buffer, considering the transition areas for the other biomes.	https://geoportal.meioambiente.mg.gov.br/
Mapping of Native Vegetal Coverage and Land Use 1/25,000 in the State of Espírito Santo	State Institute for the Environment and Water Resources (IEMA)	Mapping carried out through orthophotos with 25cm and photointerpretation and manual vectorization of limits between use and coverage classes with a minimum area of 0.5ha.	https://geobases.es.gov.br/downloads

Land use mapping for the Cerrado and Atlantic Forest	FBDS	Land use mapping for the Cerrado and Atlantic Forest. Based on RapidEye high resolution images with 5m resolution.	http://geo.fbds.org.br/
Land Use and Coverage Mapping of the State of Paraná	State Secretariat for Planning and Structuring Projects	Mapping carried out through orbital images of high spatial resolution (2 meter) satellites for the period 2011 to 2016 - WorldView2 and Pleiades 1A and 1B). Supervised automatic classification (GEOBIA).	https://geopr.iat.pr.gov.br/portal/apps/dashboards/1eca83bf72e44193ae62f282574da52f
Mapping of Irrigated Rice in Brazil	National Water Agency (ANA) / National Supply Company (Conab)	Mapping of Irrigated Rice in Brazil	https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/metadata/1ac9b37f-0745-44f9-a60b-6a2bd366bbe1
Mapping of the Forest Inventory of the State of São Paulo	Infrastructure and Environment Secretariat of the State of São Paulo - Forestry Institute	Mapping carried out using orbital satellite images of high spatial resolution (0.5 meter), for the period 2017 to 2019, belonging to the collection of the Infrastructure and Environment Department.	
OpenStreetMap	OpenStreetMap Foundation	OpenStreetMap is an initiative to create and provide free geographic data, such as street maps, to anyone.	https://www.openstreetmap.org/
Prodes	INPE	Satellite monitoring of clear-cut deforestation in the Legal Amazon which provides, since 1988, the annual deforestation rates in the region used by the Brazilian government to establish public policies.	http://www.dpi.inpe.br/prodesdigital/dadosn/
Terra Class Cerrado	MMA, IBAMA, EMBRAPA, INPE, UFG e UFU	Cerrado Land Use and Coverage Mapping	https://www.terraclass.gov.br/download-de-dados
Use and vegetation cover in the State of Rio Grande do Sul – situation in 2002.	Hasenack, H.; Cordeiro, J.L.P; Weber, E.J. (Org.). Porto Alegre: UFRGS IB Centro de Ecologia, 2015. 1a ed. ISBN 978-85-63843-15-9.	Vegetation Cover Map of Rio Grande do Sul - 2002 base year, obtained by visual interpretation of Landsat images. Level of detail compatible with 1:250,000 scale	https://www.ufrgs.br/labgeo/index.php/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2002/

Use and vegetation cover in the State of Rio Grande do Sul – situation in 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.	Vegetation Cover Map of Rio Grande do Sul - base year 2009, obtained by visual interpretation of Landsat images. Level of detail compatible with 1:250,000 scale	https://www.ufrgs.br/labgeo/index.php/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2009/
Use and vegetation cover in the State of Rio Grande do Sul – situation in 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.	Vegetation cover map of Rio Grande do Sul - base year 2015, obtained by visual interpretation of Landsat images. Level of detail compatible with 1:250,000 scale	https://www.ufrgs.br/labgeo/index.php/downloads/dados-geoespaciais/uso-e-cobertura-vegetal-do-rio-grande-do-sul-situacao-em-2015/
Mapping of the Evolution of Vegetation Cover.	Bahia Forestry Forum	The objective of the independent monitoring of the vegetation cover and soil use of the Discovery Coast, Extremo Sul, and South Coast Parcel (areas where Suzano and Veracel operate), is to map the evolution of the vegetation cover.	https://forumflorestalbahia-worldresources.hub.arcgis.com/
Cofee Map	CONAB	The mapping of agricultural crops is carried out by means of remote sensing. It aims to contribute to the estimation of area and productivity, offering precise information about the geographic distribution in each state. In area estimation, the mapping result helps in the analysis of the declared information, as a verifiable data in the field. In the productivity estimation, the knowledge of the location of the cultivation areas enables the monitoring of the productive areas through agrometeorological parameters, offering indicatives on the forecast of the yield of the crops. The mappings are available for download in shapefile format.	https://www.conab.gov.br/info-agro/safras/mapeamentos-agricolas

Urban Areas 2019	IBGE	Spatial representation of the urban phenomenon, obtained through visual interpretation of satellite imagery, based on the year 2019.	https://www.ibge.gov.br/geociencias/organizacao-do-territorio/tipologias-do-territorio/15789-areas-urbanizadas.html?edicao=35569&t=acesso-ao-produto
Google Open Buildings v3	Sirko et al.	Large-scale open dataset contains the outlines of buildings derived from high-resolution satellite imagery.	https://sites.research.google/gr/open-buildings/
VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1	NASA		https://eogdata.mines.edu/download_dnb_composites.html
Map of Wetlands in the Amazon Basin	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	Map of the extent of wetlands, vegetation type and flooding status in two seasons throughout the lower Amazon basin	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1284
Global Wetlands Map	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	Hydro-geomorphological model based on an expert system approach to estimate wetland areas.	https://www2.cifor.org/global-wetlands/

	the largest contributor. Global Change Biology 23(9):3581-3599 doi: http://www.cifor.org/pid/6419		
Global Wetlands Map	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	Composite wetland maps that combine two classes of wetlands: (1) regularly flooded wetlands and (2) groundwater-driven wetlands.	https://doi.pangaea.de/10.1594/PANGAEA.892657?format=html#download
Pedology Map of Brazil	IBGE	Soil map of Brazil at scale 1:250,000	https://geoftp.ibge.gov.br/informacoes_ambientais/pedologia/vetores/escala_250_mil/versao_2023/
Prodes Cerrado	INPE	PRODES Cerrado project that includes mapping the suppression of native vegetation in the biome from 2000 to 2023	https://terrabrasilis.dpi.inpe.br/downloads/
MapBiomas Alerta	MapBiomas	System for validating and refining deforestation alerts from various detection systems since 2019	https://plataforma.alerta.mapbiomas.org/downloads
Remnants of Murundus Fields or Covais in the State of Goiás	SEMAD - GO	Map of murundus fields at cartographic scale 1:50,000 in the state of Goiás in 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	Global canopy top height for the year 2020 at 10 m sampling distance from the ground.	https://nlang.users.earthengine.app/view/global-canopy-height-2020

Land Use and Cover Map of the Federal District	SISDIA - DF	Mapping the land cover of the Federal District on a 1:100,000 regional scale in 2019	https://sisdia.df.gov.br/portal/home/item.html?id=609c066c72a94111ab843c76b4074ea2
Rocky outcrop map	SGB/CPRM	Mapping of rock outcrops contained in the GeoSGB database.	https://geoportal.sgb.gov.br/server/rest/services/geologia/afloramentos/MapServer
Map of non-forest areas	INPE	Mask of non-forest areas in the Amazon	https://terrabrasilis.dpi.inpe.br/downloads/
Map of the distribution of mapped municipalities (G75) that make up the study area and the location of Sentinel–2A and 2B images obtained on the Earth Explorer platform	EMBRAPA	Mapping of excavated ponds for aquaculture in Brazil using remote sensing - Map of the distribution of municipalities that concentrate 75% of the aquaculture production of each Federal Unit	https://ainfo.cnptia.embrapa.br/digital/bitstream/doc/1152279/1/6105.pdf
Global Distribution of Coral Reefs	UNEP-WCMC	Global Distribution of Coral Reefs	https://data.unep-wcmc.org/datasets/1
Allen Coral Atlas	The Allen Coral Atlas	Global Coral Reef Mapping and Monitoring Coastal Ecosystem Threats	https://allencoralatlas.org/
Atlas of Coral Reefs in Brazilian Conservation Units	PRATES, A. P. L. 2003	Mapping of coral reefs in different Brazilian regions, priority areas, maps of biological importance	http://mtc-m12.sid.inpe.br/rep/sid.inpe.br/sergio/2005/01.31.11.00
Panorama Database for the conservation of coastal and marine ecosystems in Brazil	MMA. Management of Aquatic Biodiversity and Fisheries Resources.	Overview of the Conservation of Coastal and Marine Ecosystems in Brazil - MMA	https://www.marinha.mil.br/secirm/sites/www.marinha.mil.br.secirm/files/mma-205_publicacao27072011042233.pdf
Map of priority areas of the coastal and marine zone	MMA	PRIORITY AREAS OF THE COASTAL AND MARINE ZONE	https://www.gov.br/mma/pt-br/assuntos/biodiversidade-e-biomas/ecossistemas/conservacao-1/areas-prioritarias/zona_costeira.jpg
Cartographic Base of Southeast Tocantins (Wetlands)	SEPLAN/TO	These are thematic data in shapefile format at 50,000 and 100,000 scales, referring to the data generated from the Delimitation and Cartographic Characterization	https://geoportal.to.gov.br/gvsigonline/servicios/

		of Areas Vulnerable to Water Scarcity in the Southeast Region of the State of Tocantins. Work carried out by the then Secretariat of Finance and Planning in 2019.	
Cartographic Base of Southeast Tocantins (Land Cover and Land Use)	SEPLAN/TO	These are thematic data in shapefile format at 50,000 and 100,000 scales, referring to the data generated from the Delimitation and Cartographic Characterization of Areas Vulnerable to Water Scarcity in the Southeast Region of the State of Tocantins. Work carried out by the then Secretariat of Finance and Planning in 2019.	https://geoportal.to.gov.br/gvsigonline/servicios/
MERIT Hydro: Global Hydrography Datasets	Yamazaki D., D. Ikeshima, J. Sosa, P.D. Bates, G.H. Allen, T.M. Pavelsky. MERIT Hydro: um mapa global de hidrografia de alta resolução com base nos mais recentes conjuntos de dados de topografia. Water Resources Research, vol.55, pp.5053-5073, 2019	MERIT Hydro is a new global flow direction map with 3 arc-second resolution (~90 m at the equator) derived from version 1.0.3 of the MERIT DEM elevation data and water body datasets (G1WBM, GSWO and OpenStreetMap). Access to publication: doi:10.1029/2019WR024873	https://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/
MERIT DEM: Multi-Error-Removed Improved-Terrain DEM	Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanae & P.D. Bates. Um mapa de alta precisão das elevações do terreno global. Geophysical Research Letters, vol.44, pp.5844-5853, 2017.	A high-precision global DEM with 3 arc-second resolution (~90 m at the equator) produced by eliminating major error components from current DEMs (NASA SRTM3 DEM, JAXA AW3D DEM, Viewfinder Panoramas DEM). Access to publication: doi:10.1002/2017GL072874	https://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/
Overview of Fish Farming in the State of Rio Grande do Sul,	DA ROCHA, Andrea Ferretto; ROTTA, Marco	Mapping of confirmed fish farming in Rio Grande do Sul, Brazil.	https://revistapag.agricultura.rs.gov.br/ojs/index.php/revistapag/article/

Brazil	Aurélio; SAMPAIO, João Alfredo de Oliveira; TORRES, Pietra Fialho; CAVALLI, Lissandra Souto; DE BRITO, Kelly Cristina Tagliari; DE BRITO, Benito Guimarães. Panorama da Piscicultura no Estado do Rio Grande do Sul, Brasil. Pesquisa Agropecuária Gaúcha, [S. l.], v. 30, n. 1, p. 15–37, 2024.		view/788

Annex III: Cross-reference of MapBiomas land use/land cover classes in the Collection 10 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	IUCN Global Ecosystem Typology 2.0
Forest	Forest Formation			Amazon	Dense Ombrophilous Forest, Evergreen Seasonal Forest, Open Ombrophilous Forest, Semi-deciduous Seasonal Forest, Deciduous Seasonal Forest, Wooded Savannah, areas under impacts of 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 from primary vegetation. Bamboo forest (Acre State).	Da, Db, Ds, Dm, Ha, Hb, Hs, Aa, Ab, As, Am, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, Ld, La, Vs	FDP, FEP, FSP, FEM, FDM, FSM	FNM, FM, FSec	T1

		Caatinga	Vegetation types with continuous canopy predominance - Wooded Steppe Savannah, Semi-deciduous and Deciduous Seasonal Forest.	Td, Fa, Fb, Fm, Fs, Cb, Cm, Cs	FEP, FSP	FNM, FM	T1, T4.1
		Cerrado	Vegetation types characterized by the predominance of tree species forming a continuous canopy. This includes Riparian Forests, Gallery Forests, Dry Forests, and Forested Savannas (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	FNM, FM	T1.2, TF1.1
		Atlantic Forest	Vegetation types characterized by the predominance of tree species, with high tree density, closed canopy, and vertical stratification. It includes forest typologies: Dense, Open and Mixed Ombrophilous Forest, Semi-deciduous and Deciduous Seasonal Forest, and Pioneer Formation.	D, A, M, F, C, Pma	FEP, FSP	FNM, FM	T1
		Pampa	Vegetation with tree species predominance 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	FNM, FM, FSec, CS	T2.4

		Pantanal	Tall trees and shrubs on lower stratum: Deciduous and Semi-deciduous Seasonal Forest, Wooded Savannah, Wooded Steppe Savannah, and Fluvial and/or Lacustre Influenced Pioneer Formations.	Ca, Cb, Cs, Fa, Fb, Fs, SN, Sd, Td, Pa	FEP, FSP	FNM, FM	T2.2, T1.2
	Savanna Formation	Amazon	Open plant formation with a more or less developed shrub and/or arboreal layer, herbaceous layer always present.	Sa, Ta	WS	FNM, FM	T3.1, T4.1
		Caatinga	Vegetation types with predominance of semi-continuous canopy species - Wooded Steppe Savannah and Wooded Savannah.	Sa, Ta	FDP	FNM, FM	T4.1
		Cerrado	Vegetation types with a distinct stratification of tree, shrub, and herbaceous stratum. This includes different physiognomies of Cerrado sensu stricto (Dense, Typical, Sparse, and Rupestrian Savanna) (Ribeiro & Walter, 2008).	Sa, Ta	FDP, FSP, WS	FNM, FM	T3.1, T4.2

		Atlantic Forest	Vegetation type characterized by the presence of sparse tree and shrub species, with a semi-continuous canopy. It includes: Steppe, Forested and Wooded Savannah.	Sd, Td, Sa, Ta	FDP, FSP, WS	FNM, FM	T4.1
		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	FNM, FM	T4.1
	Mangrove		Dense and Evergreen Forest formations, often flooded by tide and associated with the mangrove coastal ecosystem.	Pf	FEP, FEM	FNM, FM	MFT1.2
	Floodable Forest	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, Vs	FDP, FEP, FSP, FEM, FDM, FSM	FNM, FM, FSec	TF1.1
	Wooded Sandbank Vegetation	Atlantic Forest	Forest formations on sandy soils in the coastal region.	Pma	FEP, FEM	FNM, FM	MT2

		Pampa	Forest formations on sandy soils in the coastal region.	Pma	FEP, FEM	FNM, FM	T2.4
Herbaceous and Shrubby Vegetation	Wetland	Amazon	Lowland or grassland vegetation that suffers fluvial and/or lacustrine influence.	Pa	OM	GNM, GM, GSec	TF1.2, TF1.3
		Cerrado	Ecosystems dominated by herbaceous vegetation subject to seasonal flooding or constant fluvial/lacustrine influence. Examples include Campo Úmido and Brejo. In some areas, the herbaceous matrix is interspersed with savanna tree species (e.g., Parque de Cerrado) or palm species, such as in Veredas and Palmeirais (Ribeiro & Walter, 2008).	Pa, Sp	OM	GNM, GM, GSec	TF1.3, TF1.4
		Atlantic Forest	Floodplain or grassland vegetation influenced by fluvial and/or lacustrine dynamics, characterized by the predominance of hygrophilous vegetation, including emergent, submerged, or floating aquatic plants.	Pa	OM	GNM, GM, GSec	TF1.2

		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	TF1.3, MFT1.3
		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 grasslands 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 (e.g.: 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	TF1.4

	Grassland Formation	Amazon	Savannah, Park Savannah (Marajó), Steppe Savannah (Roraima), Grassland Savannah, 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	T4.5
		Caatinga	Vegetation type with predominance of herbaceous species (Park Steppe Savannah, Herbaceous-Woody Steppe Savannah, Park Savannah, Herbaceous-Woody Savannah) + (Flooded areas with an interconnected pond net, located along waterways and in lowlands areas that accumulate water, vegetation predominantly herbaceous to shrub).	Tp, Sg, Rm, Sp, Tg, Rl	WG, OG, WS	GNM, GM, GSec	T3.1
		Cerrado	Open vegetation dominated by herbaceous species, with minimal or no tree cover. Includes Dirty, Clean, and Rupestrian Grasslands, as well as some savanna formations such as Rupestrian Cerrado (Ribeiro & Walter, 2008).	Sg, Tp, Tg	WG, OG	GNM, GM, GSec	T4.5, T3.4

		Atlantic Forest	Vegetation dominated by herbaceous species and grasses, with few scattered trees and shrubs, generally featuring an open or absent canopy. It occurs on soils ranging from deep to shallow, including rocky terrains (rupestrian grasslands). Included: Park and Grassland Steppe Savannas, Steppe and Shrub and Herbaceous Pioneers.	Sp, Sg, Tp, Tg, E, Pa	WS,OG	GNM, GM, GSec	T4.5
		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 grasslands) and sandy (sandy or psamophile grasslands). Ocurs at well-drained soil (mesic grasslands) to soils with higher moisture content (wet grasslands - with a strong presence of sedges). In most cases, it corresponds to native vegetation, though spots 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	T4.5

		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). Invasive exotic vegetation or forage use (planted pasture) spots may be present forming mosaics with native vegetation.	Sg, Sp, Ta, Tg	WG, OG	GNM, GM, GSec	T4.5
	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	NA	NA
	Rocky Outcrop	Amazon	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM	T3.4
		Caatinga	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM	T3.4

		Cerrado	Naturally exposed rocky surfaces, including monoliths, bedrock, and slabs with little or no soil cover and minimal vegetation. These features are typically associated with stable geological formations of sedimentary, igneous, or metamorphic origin	Ar	OX	ARM, ArNM	T3.4
		Atlantic Forest	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ARM, ArNM	T3.4
		Pampa	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM	T3.4
		Pantanal	Naturally exposed rocks without soil cover, often with the partial presence of rupicolous vegetation and high slope.	Ar	OX	ArM, ArNM	T3.4
	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	MT2.1
		Caatinga	Herbaceous vegetation that is established on sandy soils or on dunes in the coastal zone.	Pmb, Pmh	WG, OG	GNM, GM	MT2.1

			Cerrado	Coastal sandy plain ecosystems characterized by predominantly herbaceous and shrubby vegetation, with sparse shrub distribution.	Pmb, Pmh	WG, OG	GNM, GM	MT2.1
			Pampa	Herbaceous vegetation that is established on sandy soils or on dunes in the coastal zone.	Pmb, Pmh	WG, OG	GNM, GM	MT2.1
Farming	Pasture			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. In Amazon, this class may occur on recently deforestated areas, even if farming activities haven't started yet.	AP, PE, PS	OP, OG	Ap	T7.2, T7.5
	Agricultur e	Temporary Crop	Soybean	Cultivated areas with soybean.	AMc (s)	OCA	AC	T7.1
			Sugar cane	Cultivated areas with sugar cane.	AMc (c)	OCA	AC	T7.1

			Rice	Cultivated areas with rice, exclusively under irrigation, in the states of Rio Grande do Sul, Tocantins, Santa Catarina and Coast of Paraná. It's the same map shown on irrigation module, at "Irrigated Rice" class.	AMc	OCA	AC	T7.1
			Cotton (beta)	Cultivated areas with cotton.	AMc (s)	OCA	AC	T7.1
			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	T7.1
		Perennial Crop	Coffee	Cultivated areas with coffee plantation.	AMp (c)	OCP	PER	T7.3
			Citrus	Cultivated areas with citrus plantation.	AMp	OCP	PER	T7.3
			Palm Oil	Cultivated areas with palm oil plantation.	AMp	OCP	PER	T7.3

			Other Perennial Crops	Areas occupied with agricultural crops which has a long vegetative cycle (more than one year) and allows 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 state, but without distinction between them.	AMp	OCP	PER	T7.3
	Forest Plantation			Tree species planted for commercial purposes (e.g. pinus, eucalyptus, araucaria).	R	FPB, FPC, FPM	Ref	T7.3
	Mosaic of Uses		Caatinga	Not distinguishable between pasture and agriculture farm areas . It may include peri-urban occupation areas, such as small farms, rural properties, and housing estates.	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG, OB	AC, PER, Ap, APD, S	T7.5

		Cerrado	Farming landscapes where it is not possible to clearly distinguish between pasture and cropland. This class may include abandoned pastures in early stages of natural regeneration, anthropized zones within protected areas (excluding APAs and Indigenous Lands), and peri-urban areas such as small farms, rural properties, and housing estates	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG, OB	AC, PER, S	T7.5
		Atlantic Forest	Areas intended for agricultural and livestock use where it was not possible to distinguish between pastures and croplands, including fallow lands. These areas may also include peri-urban zones such as small farms, rural properties, and residential estates. Transitional areas are also included, where secondary vegetation is developing in abandoned pastures or in ecological restoration processes, prior to reaching forest size and structure.	AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG, OB	AC, PER, S	T7.5

		Pampa	Not distinguishable between pasture and agriculture farming areas. It may include cropland, winter or summer pasture and horticulture. Includes rest areas between agricultural crops (pousio). It may include peri-urban occupation areas, such as small farms, rural properties, and housing estates.	AP, AS, AT, AM, PE, PS, Ag, Ap, Ac, Acc, Acp, AA	OCA, OCM, OP, OG, OF, OB	AC, PER, Ap, APD, S	T7.5
Non Vegetated Area	Beach, Dune and Sand Spot		Sandy areas, with bright white color, with no vegetation predominance of any kind.	Dn	OX	DnM,DnNM	MT1.3
	Urban Area		Urban areas with high density of roads, edifications and predominance of non-vegetated surfaces, including infrastructure and open spaces.	Iu	OB	S	T7.4
	Mining		Areas of industrial or artisanal mineral extraction (garimpos), with clear exposure of the soil due to anthropogenic action. Only areas close to CPRM (GeoSGB), AhkBrasilien (AHK), DETER (INPE) and Instituto Socioambiental (ISA) mining resource spatial references are considered.	MCA	OQ	Min	NA

	Other Non Vegetated Areas	Amazon	In terms of land use, these plants occupy significant areas: it's estimated that an installation in tropical regions requires about 1 ha per MW using fixed modules, potentially varying to 2–3 ha/MW depending on technology (trackers) and panel arrangement. National examples confirm this range: the Nova Olinda Solar Park (292 MW across 690 ha ≈ 2.4 ha/MW), and the Pirapora Solar Complex (321 MW across ≈ 1,500 ha, about 4.7 ha/MW).	AU, MCA	OB, OQ	S, Min	NA
		Caatinga	Non-permeable surface areas (infrastructure, urban expansion or mining) not mapped into their classes	AU,MCA	OB, OQ	S, Min	NA
		Cerrado	Includes impermeable surfaces (e.g., roads, buildings, mining infrastructure), exposed soil in natural settings (e.g., erosion features, gullies, landslides), and croplands in the off-season.	AU, MCA	OB, OQ	S, Min	NA
		Atlantic Forest	Natural areas with exposed soil resulting from climatic events (landslides, flooding) and areas with non-permeable surfaces (infrastructure, urban expansion, or mining) not mapped within their respective classes.	AU, MCA	OB, OQ	S, Min	NA

		Pampa	Mixed class that includes natural and anthropic areas. Natural areas include sandy surfaces including mainly river and sandy beaches. Anthropic areas include exposed soil and non-permeable surfaces (infrastructure, urban expansion or mining).	AU, MCA, Dn, Iu	OB, OQ, OX	S, SE, DnM, DnNM, Min	NA
		Pantanal	Exposed soil areas (mainly sandy soil) not classified as Grassland Formation or Pasture.	PE, Sg	OX	Ap, GNM, GSec	NA
	Photovoltaic Power Plant		A "photovoltaic power plant" is a medium to large-scale installation designed to generate electricity directly from sunlight, primarily focused on commercializing the energy, Atlas Brasileiro de Energia Solar, 2017. In Brazil, plants with a capacity greater than 5 MW are considered large-scale, while those up to 5 MW are classified as mini-generation, according to regulations (Law 14.182/2021; Law 10.438/2002; Decree 5.025/2004; ANEEL Resolution 127/2004). The electricity generated is connected to the National Interconnected System (SIN), which distributes power throughout the country.	NA	NA	NA	NA

Water	River, Lake and Ocean	Rivers, lakes, dams, reservoir and other water bodies.	NA	IRP, IRS, IL, ID	A, Res	F1.1, F1.2, F2.1, F2.2, F3.1, F3.2, F3.5, FM1.2, FM1.3
	Aquaculture	Artificial lakes, with a predominance of aquaculture and/or salt production activities.	NA	NA	NA	NA
Not Observed		Blocked areas by clouds or atmospheric noise, or with absence of ground observation masked out from analysis.	NA	NA	NO	NA
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. ; Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. and Kingsford, R.T. (eds.). The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. Gland, Switzerland: IUCN, 2020, 192 p.						

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
75	4.4 Photovoltaic Solar Park	Photovoltaic Solar Park	1	
30	4.3. Mining	Mining	2	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	3	
5	1.3. Mangrove	Coastal Zone	4	
31	5.2. Aquaculture	Aquaculture	5	
32	2.3. Salt Flat	Coastal Zone	6	

24	4.2. Urban Area	Urban Area	7	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent
9	3.3. Forest Plantation	Forest Plantation	8	At Lagoa dos Peixes (Pampa), the classes 3, 11, 12, 29, 33, 49, 50 are prevalent
29	2.4. Rocky Outcrop	Biomes	9	
20	3.2.1.2. Sugar Cane	Agriculture	10	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent
39	3.2.1.1. Soybean	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
40	3.2.1.3. Rice	Agriculture	12	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	13	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent

41	3.2.1.5 Other Temporary Crops	Agriculture	14	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.
46	3.2.2.1. Coffee	Agriculture	15	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
47	3.2.2.2. Citrus	Agriculture	16	Within protected areas in Cerrado, classes 3, 4, 11 and 12 are prevalent
35	3.2.2.3. Palm Oil	Agriculture	17	
48	3.2.2.4. Other Perennial Crops	Agriculture	18	Where both biomes and MapBiomas Water indicates class 33, class 33 is prevalent
18	3.2. Agriculture	Agriculture	19	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	20	
25	4.4. Other Non Vegetated Areas	Biomes	21	In the Cerrado biome, class 15 is prevalent

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

15	3.1. Pasture	Biomes	31	Amazon, Cerrado and Pantanal map class 15
21	3.4. Mosaic of Uses	Biomes	32	In Cerrado, 21 is converted to 15 within Conservation Units