MAPBIOMAS VENEZUELA

Algorithm Theoretical Basis Document (ATBD)

MapBiomas Venezuela - Collection 3

Version 1

October 2025

Executive Summary

This document describes the theoretical foundations, methodologies, and results of the process for generating annual land cover and land use maps in Venezuela, developed under the **MapBiomas Venezuela** initiative.

Collection 3, covering the period from 1985 to 2024, employs Landsat satellite images and advanced cloud-based processing techniques through Google Earth Engine (GEE), ensuring speed, scalability, and cost efficiency.

This document serves as an essential technical reference, detailing each phase of the process—from mosaic generation to accuracy analysis—establishing a robust standard for monitoring changes in natural land cover and land use in Venezuela.

To facilitate processing and reflect the contrasting dynamics of the territory, the project divides Venezuela into two macro-regions: **north and south of the Orinoco River**. This division captures the unique characteristics of each area, such as high population density and agricultural activity in the north, compared to vast forested and protected areas in the south. The approach is further refined with 162 classification regions, improving local accuracy and consistency of the results.

The **MapBiomas Venezuela platform** provides public access to the maps, statistics, and transition analyses, promoting transparency and democratizing data. This initiative offers historical and up-to-date information for supporting conservation, territorial planning, protected area management, and climate change assessments, among others.

All generated data is freely accessible through the MapBiomas Venezuela platform, fostering transparency and the broad use of information for research, decision-making, and education.

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Acronyms and Abbreviations

ATDB	Algorithm Theoretical Basis Document
CAI	Color Alteration Index
CCI	Climate Change Initiative
CFMask	The C Function of Mask. It is an algorithm that fills pixels covered by clouds, cloud shadows, and snow/ice pixels.
CLC	The CORINE Land Cover (CLC) product
CLOUD	Fractional abundance of clouds within the pixel
CORINE	Coordination of Information on the Environment
ESA	The European Space Agency
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
EVI2	Enhanced Vegetation Index 2..
FNS	Index based on fractions of green vegetation (GV), shade, and soil
GCVI	Green Chlorophyll Vegetation Index
GEE	Google Earth Engine
GLC	Global Land Cover
GLI	Green Leaf Index

GV	Green Vegetation, fractional abundance of green vegetation within the pixel
HALLCOVER	Spectral index for **land cover**
HAND	Height Above the Nearest Drainage
LULC	Land Use / Land Cover
NASA	The National Aeronautics and Space Administration
NDBI	ÍNormalized Difference Built-up Index
NDFI	Normalized Difference Fraction Index): Index that combines fractions of green vegetation (GV), non-photosynthetic vegetation (NPV), soil, and shade
NDFIB	Normalized Difference Fraction Index for the Andes: An adaptation of the NDFI specifically designed for the Andean region, considering its unique vegetation and environmental conditions.
NDGB	Normalized Difference Green-Blue Index
NDMI	Normalized Difference Moisture Index
NDRB	Normalized Difference Red-Blue Index
NDSI	Normalized Difference Snow Index
NDSI2	Normalized Difference Snow Index 2
NDVI	Normalized difference vegetation index
NDWI_GAO	Normalized Difference Water Index - Gao
NDWI_MCFEETERS	Normalized Difference Water Index - McFeeters
NIR	Near infrared
NPV	Fractional abundance of non-photosynthetic vegetation
NUACI	Normalized Urban Area Composite Index
MDMIR	Median of the Difference in the Mid-Infrared
MNDWI	Modified Normalized Difference Water Index
PRI	Photochemical Reflectance Index
RAISG	Amazonian Georeferenced Socio-Environmental Information Network

SAVI	Soil-Adjusted Vegetation Index
SEFI	Seasonal-Evergreen Forest Index
SERENA	Latin American Network for Monitoring and Study of Natural Resources
SHADEMASK2	A mask designed to identify and filter shaded areas
SLPPOST	Slope-related adjustments that help refine land cover and land use classifications by incorporating terrain information
SOIL	Fractional soil abundance within the pixel
SHADE	Fractional shadow abundance within the pixel
SNOW	Fractional snow abundance within the pixel
TEXTG	Texture Green Index
TIRS	The Thermal Infrared Sensor
TM	Thematic Mapper
OLI	The Operational Land Imager
USGS	United States Geological Survey (Servicio Geológico de EEUU).
WEFI	Wetland Ecosystem Functional Index

1. Introduction

1.1. Scope and Content of the Document

This document describes the theoretical basis, justification, and methods used to produce annual land cover and land use maps for Venezuela, corresponding to Collection 3 of MapBiomas Venezuela, covering the period from 1985 to 2024.

It includes details on image processing architecture, the generation of annual Landsat image mosaics (L5, L7, L8, and L9), classification methodologies, and post-processing techniques. Additionally, it provides historical context and background of the project, along with a general description of satellite datasets and the accuracy assessment methods employed.

1.2. General Overview

The MapBiomas Venezuela project began in early 2023 with the goal of generating annual multitemporal maps of land cover and land use (LULC) from 1985 onward. The initiative aims to provide a detailed, nationwide view of both natural and anthropogenic land cover changes over time. This effort is made possible by:

- Technological advancements that allow processing large volumes of spatial data in the cloud using Google Earth Engine (GEE) algorithms.
- Specialized image processing methods designed for land cover and land use monitoring, aligned with MapBiomas methodologies.
- A multidisciplinary technical team contributing expertise in mapping the territory.
- Support from institutions and funding organizations committed to the project's vision.

MapBiomas Venezuela provides a reliable and efficient methodology for processing vast amounts of data and generating historical series of annual maps. All information, including statistics, codes, and analyses, is available free of charge on the official MapBiomas Venezuela platform.

The main products include:

- **Annual thematic maps** covering the entire national territory, with a **30-meter spatial resolution**.
- **Annual satellite image mosaics** (with minimal or no cloud coverage) generated from **Landsat 4, 5, 7, 8, and 9**.
- **Annual and transition LULC statistics**, organized by various analysis units.
- **Wall maps and infographics** on land cover and land use, updated to 2024.
- **Technical documentation** describing the methodologies used.

Collection 3 integrates machine learning algorithms (Random Forest) to generate land cover and land use maps. These maps are based on Landsat Collection 3 mosaics, incorporating 141 layers of information, including original bands, fractional data, and specific indices. The collection features 25 land cover and land use classes, improving classification accuracy and providing a higher level of detail.

1.3. Study Area

The geographic scope of MapBiomas Venezuela covers the entire national territory, including Guayana Esequiba and its insular region, with the exception of Isla de Aves.

Venezuela has a diverse geography and unique landscapes, ranging from towering mountains to vast plains, dense forests, and river deltas.

- In the west, the Andes Mountains and the Sierra de Perijá rise with páramo ecosystems and cloud forests, which also serve as key agricultural regions.
- To the north, the Coastal Mountain Range extends across the country, hosting dry forests, cloud forests, and dense urban centers, making it one of the most populated and developed regions.
- In the center and southwest, the Llanos (savannas) form an extensive, seasonally flooded plain, supporting extensive cattle ranching and cereal production, as well as being a critical habitat for diverse wildlife.
- To the south, the Guiana Shield represents one of the oldest geological formations on Earth, encompassing the Venezuelan Amazon, a region covered by tropical rainforest with

extraordinary biodiversity. This area, known for its iconic tepuis (tabletop mountains), is home to numerous Indigenous communities who rely on natural resources for their livelihoods but face growing pressures from mining activities.

- To the east, the Orinoco Delta is a vast network of rivers and channels flowing into the Atlantic Ocean. It is an ecologically rich region, hosting wetlands and mangrove forests, and inhabited by Indigenous communities practicing subsistence economies.
- In the northwest, the Lake Maracaibo Basin is both ecologically significant and the center of Venezuela's oil industry, which has had a major impact on the landscape and economy.

Venezuela's population is primarily concentrated in the north and central-north regions, especially in coastal valleys and urban areas such as Caracas, Valencia, and Maracaibo, where industry, commerce, and services dominate. In terms of land use, the main activities include:

- Agriculture and cattle ranching in the Llanos and Andes.
- Mining exploitation in Bolívar State.
- Oil extraction in Lake Maracaibo and the Orinoco Oil Belt.

The country also has an extensive network of protected natural areas, including national parks that aim to conserve biodiversity and natural resources in the face of increasing development pressures.

This rich diversity of landscapes, natural cover, land use, and human settlements presents the main challenges for MapBiomas Venezuela in mapping the national territory.

With the enactment of the Organic Law for the Defense of Guayana Esequiba, published in the Official Gazette No. 6798 Extraordinary on April 3, 2024, the Venezuelan government formally recognized Guayana Esequiba as a state within the country's political-administrative division. This newly established state covers the territory under dispute, governed by the Geneva Agreement of February 1, 1966.

Starting with Collection 2, Guayana Esequiba has been incorporated into MapBiomas Venezuela's products. However, areas south of the Orinoco River were processed separately:

Amazonas, Bolívar, and Delta Amacuro states were classified directly by the MapBiomas Venezuela technical team. Guayana Esequiba was processed by the Amazon Environmental Research Institute (IPAM) in Brazil, responsible for classifying areas of Guyana within MapBiomas Amazonía. This collaboration ensures that Guayana Esequiba is fully integrated into the national land cover dataset, while maintaining consistent methodologies for monitoring Venezuela's territory.

1.4. Applications

The MapBiomas Venezuela land cover and land use maps serve as a fundamental resource for understanding landscape changes. Covering the period 1985 to 2024, these datasets provide a detailed record that enables analysis of transformations in key sectors. Below are some of the primary applications of these maps in the Venezuelan context:

- **Deforestation Monitoring and Ecosystem Conservation**. Venezuela is home to important ecosystems, including rainforests, savannas, and mangroves, which play a crucial role in biodiversity and climate change mitigation. The MapBiomas maps help track forest loss and vegetation changes, allowing for the identification of priority areas for conservation.
- **Protected Areas Management**. The LULC maps provide a detailed analysis of how protected areas have evolved over time. These areas are key for preserving ecosystems, and monitoring their transformation is essential for effective management.
- **Territorial Planning and Land Use Management**. Sustainable land planning is crucial for minimizing conflicts between economic development and environmental conservation. MapBiomas land use maps offer detailed insights that help evaluate the suitability of areas for agriculture, urban expansion, and industrial activities. This tool supports the development of land management plans.
- **Climate Change and Environmental Resilience**. The historical datasets from MapBiomas Venezuela are valuable for analyzing how land use patterns have changed in response to climate events and human pressure. This information helps assess land degradation, desertification, and water resource depletion, contributing to strategies that reduce ecosystem and community vulnerability.
- **Ecological Restoration Projects**. Detailed, high-precision data on land cover changes help identify areas that have suffered significant degradation and are suitable for ecological restoration projects. This is particularly relevant in regions affected by extractive industries and intensive agriculture. Using MapBiomas maps, decision-makers can better define areas for

reforestation, soil recovery, and wetland restoration, promoting the restoration of ecosystem services and biodiversity.

- **Scientific Research and Environmental Education**. The availability of a historical land use record facilitates research on the impacts of land use changes on biodiversity, water quality, and ecosystem health. Additionally, the maps serve as an educational tool, helping to raise awareness about conservation and responsible natural resource management.

In summary, MapBiomas Venezuela maps provide a detailed and continuous view of landscape changes, serving as an invaluable resource for conservation, planning, education, and climate change response efforts. By accessing these datasets, Venezuela has an opportunity to promote sustainable development while preserving its valuable ecosystems.

2. Basic Information and Background

Understanding the origins of the MapBiomas Venezuela initiative requires an overview of the key institutions involved and the historical background.

This initiative emerged from collaborative projects in the Amazon, involving various organizations from different countries. These joint efforts led to the creation of MapBiomas Amazonía, which later inspired the expansion of national land mapping initiatives, including MapBiomas Venezuela.

The following sections provide an overview of:

- The participating institutions and the relationships that enabled the establishment of MapBiomas Venezuela.
- The datasets and tools used for data processing, which have been fundamental in producing the maps and services offered by the initiative.

2.1 Institutional Context

The **Amazonian Network of Georeferenced Socio-Environmental Information (RAISG)** is a consortium of civil society organizations from Amazonian countries, working to promote the socio-environmental sustainability of the Amazon. With support from international cooperation, RAISG generates and disseminates socio-environmental and geospatial data about the Amazon using uniform protocols to ensure data consistency and comparability at the regional level.

RAISG includes experts from Bolivia, Brazil, Colombia, Ecuador, Peru, and Venezuela, specializing in remote sensing, geography, ecology, environmental and social sciences, and other fields.

MapBiomas, on the other hand, is a collaborative network made up of non-governmental organizations, universities, and private sector institutions in Brazil. Its goal is to use high-quality, low-cost technology to produce annual land cover and land use maps covering more than three decades of satellite data. Since its launch in 2015, MapBiomas has provided a continuous series of land cover and land use maps in Brazil.

2.2 Historical Background

Since 2009, RAISG has been working on the development of deforestation maps of the Amazon using images from Landsat satellites. This effort began with the formation of a Deforestation Technical Group, composed of a representative from each RAISG member institution. The Instituto do Homem e Meio Ambiente da Amazônia (IMAZON) was identified as the tutoring group, providing the methodology and technical tools through the IMGTools software (Souza & Siqueira, 2013).

The IMGTools software was used to generate RAISG's deforestation maps. The methodology established the year 2000 as the baseline and analyzed the years 2005, 2010, and 2013 to detect forest loss. Based on the results, deforestation maps were produced. Later, IMGTools was migrated to the GEE platform, enabling the creation of the deforestation map for the period 2013–2015. This transition allowed RAISG to provide the public with standardized deforestation maps of the Amazon, leveraging a unified methodology applied across the region, supported by the local expertise of specialists in each country.

In 2017, RAISG and MapBiomas formed a strategic alliance, adopting cloud-based processing of large datasets from MapBiomas Brazil. This collaboration led to the creation of MapBiomas Amazonía. Under this initiative, Venezuela began generating annual land cover and land use maps of the Venezuelan Amazon, enabling spatial change analysis over time using MapBiomas common standards. Since 2018, annual map collections have been released, progressively improving both temporal coverage and mapped areas.

In 2022, MapBiomas expanded its scope beyond the Amazon region, covering the entire territory of six of the nine Amazonian countries (Bolivia, Brazil, Colombia, Ecuador, Peru, and Venezuela). Only Guyana, Suriname, and French Guiana remain fully contained within the Amazon region. In 2023, the first national land cover and land use map collections were launched, integrating both Amazonian and non-Amazonian regions of each country. This marked the creation of MapBiomas Venezuela.

2.3 Toward the Formation of a National Network: MapBiomas Venezuela

In Venezuela, the organization Provita leads the RAISG and MapBiomas land cover and use initiatives, establishing strategic alliances with various organizations to strengthen MapBiomas Venezuela (see Figure 1). In the MapBiomas Amazonia collections, Provita has collaborated with the NGO Wataniba, which has contributed its expertise on issues related to indigenous territories and mining. Wataniba, dedicated to territorial management and strengthening the identity of indigenous peoples in the Venezuelan Amazon, has been a key partner in consolidating the project.

The formation of MapBiomas Venezuela has begun with the vision of establishing a national network of organizations that contribute regionally to the generation of maps and data. One of the first nodes created is the Geographic Information Systems and Environmental Modeling Laboratory (LSIGMA), affiliated with Simón Bolívar University, which has been responsible for generating the collection in regions such as the central and eastern Llanos, the Unare basin, and Barlovento, covering 23.4% of the study area north of the Orinoco River. Additionally, a group of experts from various universities has participated in quality control and review of the collections, guiding the process of consolidating the network and exploring the creation of new regional and thematic nodes.

The objective of MapBiomas Venezuela is to expand the participation of universities, research centers, and NGOs in the production of annual land cover and use maps, promoting broader and more diverse collaboration throughout the country. Thus, organizations such as Provita, Wataniba, and SIGMA are laying the foundations for the creation of a solid and sustainable network capable of generating critical information for environmental management and the conservation of Venezuela's natural resources, following the guidelines of the MapBiomas DNA:

- **User-friendly data platform**: MapBiomas facilitates access to and use of data through intuitive platforms that allow users to view, analyze, select, and download information easily. Users can personalize their experience by creating accounts to store data of interest.

- **Transparent methodology and technology**: Each MapBiomas initiative includes an Algorithm Theoretical Basis Document (ATBD), which is updated annually with each new collection release. This allows the public to freely access and download all technical documentation from the website, ensuring transparency in the methods used.

- **Open and free data**: All data generated in each MapBiomas collection and module is available for public use without restrictions. Each product includes its corresponding citation on the website, thus promoting the free distribution and responsible use of information.
- **Local expertise and thematic knowledge in land cover and use**: The participating organizations, from different regions and with specific thematic expertise, contribute to ensuring that the maps accurately and contextually reflect the territory, based on direct field knowledge.
- **Cloud-based data processing**: MapBiomas performs all processing on Google Earth Engine, avoiding the use of private servers for data storage or pre-processing. This technology enables efficient and secure management of large volumes of information.
- **Technical capacity in remote sensing and programming**: The initiatives rely on advanced knowledge of technology and programming to ensure the quality of data production. This technical approach allows the results to meet high standards of accuracy and reliability.
- **Independence in data publication**: The organizations and experts involved in MapBiomas have full autonomy to publish their results without requiring prior political or institutional approvals, promoting the free dissemination of information.
- **Continuous improvement and evolution of collections**: The annual development of each collection allows the MapBiomas team to refine map accuracy, expand land use and cover classes, and integrate new sensors, ensuring a constant update of the generated products.
- **Distributed and decentralized network**: The MapBiomas teams operate from different cities and countries, integrating their data like pieces of a puzzle so that the results maintain local relevance without losing the regional perspective, strengthening the collaborative approach.
- **Collaborative work spirit**: MapBiomas fosters a work environment where all institutions and individuals share knowledge and resources through communication channels and thematic working groups that address key topics such as biodiversity, water, and land degradation.

- **Commitment to technical-scientific robustness**: MapBiomas teams apply cutting-edge technology and methodologies to obtain reliable results. Additionally, data uncertainties are evaluated and published, ensuring the credibility of the products.
- **Capacity building promotion**: MapBiomas offers various training opportunities, such as programming workshops, thematic webinars, and specialized training sessions tailored to different sectors, strengthening the technical skills of participants and promoting knowledge dissemination.

These elements contribute to consolidating MapBiomas as an accessible, collaborative, and technically robust geospatial data network, aimed at providing critical information for environmental management and conservation.

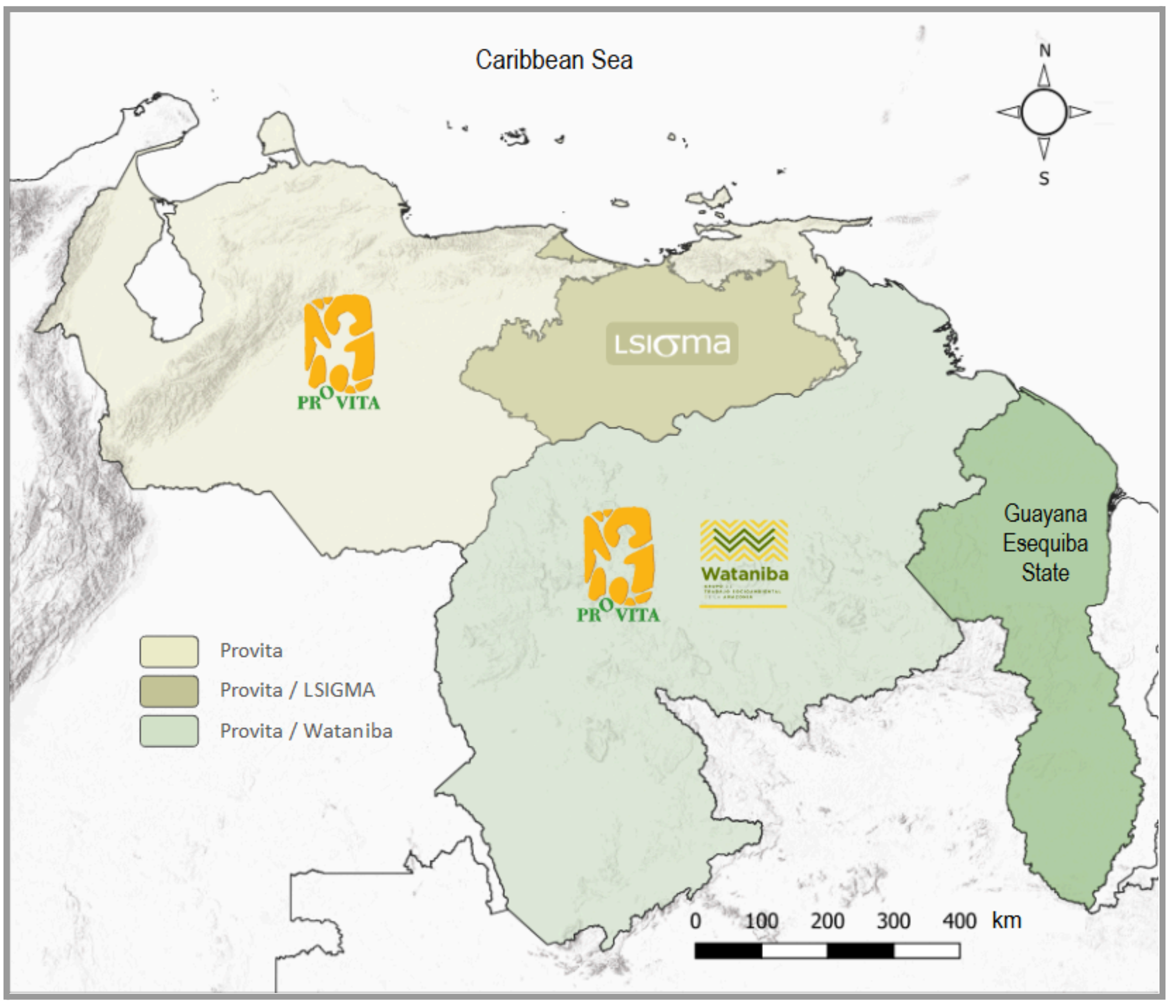

Figure 1. Organizations that make up the MapBiomas Venezuela initiative.

2.4 Remote Sensing Data

To generate multitemporal land cover and land use maps, the MapBiomas Venezuela initiative relies on Landsat satellite images. This approach required careful consideration of both the specific characteristics of Landsat data and the requirements for long-term analysis. The key attributes of Landsat data that support this project include:

- **Consistency and longevity of data**
  Landsat has provided Earth observation data for Venezuela since 1984, ensuring a long and consistent time series through its consecutive satellite missions (Landsat 4 to 9). This enables reliable multitemporal analysis to study long-term changes such as deforestation and urbanization.
- **Appropriate spatial resolution**
  With a 30-meter spatial resolution, Landsat data is ideal for mapping forests, crops, and urban areas at regional and national scales. This resolution balances detail and efficient data processing.
- **Useful spectral bands**
  The Landsat satellites capture data from the visible to infrared spectrum, which is essential for calculating indices such as NDVI (Normalized Difference Vegetation Index) and for analyzing soil moisture and vegetation health. This spectral range enhances the ability to differentiate land cover types and monitor environmental changes.
- **Accessibility and cost**
  Since 2008, all Landsat data has been made freely available, making it accessible for research, government agencies, and NGOs. This is particularly valuable for large-scale, long-term environmental monitoring projects.
- **Temporal resolution**
  Each Landsat satellite revisits the same location every 16 days, and with multiple satellites in operation, the frequency of available images increases, improving data coverage and analysis possibilities.
- **High radiometric quality and corrections**
  Landsat data undergoes calibration, radiometric correction, geometric correction, and

atmospheric correction, ensuring high precision in measurements and consistency in data comparisons over time.

- **Versatility in applications**
  Landsat imagery is used across a wide range of geographic and ecological contexts, from Amazonian forests to urban environments, enabling effective monitoring at multiple scales.

Overall, Landsat provides a reliable and robust dataset for multitemporal environmental analysis, covering up to four decades of land cover changes. This makes it an essential tool for mapping natural vegetation and human land use, providing critical data for decision-making in resource management and sustainable planning. For more information about Landsat and its applications in land cover studies, visit: USGS Landsat Missions and NASA Landsat Science.

The data used by MapBiomas Venezuela includes Landsat satellite images from 1985 to 2024, collected by the following sensors:

- Landsat 5 (L5): Used for data from 1985 to 2012
- Landsat 7 (L7): Used for data from 2000 to 2021
- Landsat 8 (L8): Used from 2013 onward
- Landsat 9 (L9): Used from 2021 onward.

The surface reflectance images belong to Collection 3 of the Landsat Data Catalog[1] with Tier 1 correction level. These datasets undergo radiometric calibration, geometric correction, and orthorectification, using ground control points and digital elevation models to ensure high positional accuracy. Additionally, atmospheric corrections further improve the quality and reliability of the data compared to the earlier Landsat Collection 1.

2.5 Google Earth Engine and MapBiomas Venezuela

To process satellite images and generate annual land cover and land use maps (LULC), MapBiomas Venezuela uses Google Earth Engine (GEE). The following characteristics justify its selection as the primary processing platform:

[1] https://developers.google.com/earth-engine/datasets/catalog/landsat/

- **Google Earth Engine Data Catalog**. GEE provides instant access to Landsat's complete satellite image archive, which is essential for projects like MapBiomas Venezuela. The platform allows the integration of multiple data sources, eliminating the need for local data storage and processing, thus saving time and computational resources.
- **Pixel-by-pixel processing**. GEE enables independent analysis of each pixel over time, facilitating the detection of subtle land use changes. The cloud-based processing allows for simultaneous calculations across large datasets, ensuring that variations in each pixel are documented and analyzed over decades.
- **Built-in image processing libraries**. GEE includes machine learning tools and classification algorithms like Random Forest, which help automate and improve land cover classification. These advanced libraries support the development of complex algorithms, allowing the adjustment and refinement of classification models to improve accuracy for diverse landscapes across Venezuela.
- **Parallel cloud processing**. GEE accelerates large-scale data analysis by utilizing parallel computing across distributed cloud servers. This significantly reduces processing times and eliminates the need for local high-performance computing infrastructure, which is critical for projects such as MapBiomas Venezuela.
- **Google Earth Engine API Features**. The GEE API allows for programming and automating analysis workflows using JavaScript (for rapid prototyping in the Code Editor) and Python (for complex projects). The API enhances automation, reproducibility, and scalability, ensuring efficient workflows and transparency in projects like MapBiomas Venezuela. Key benefits of the GEE API include:
    - **Automation and flexibility**. The API enables automated tasks, such as data collection, processing, and export, which helps streamline workflows and minimize human errors.
    - **Reproducibility**. Scripts created with the API are easily reproducible and shareable, ensuring transparency and collaborative work. This also allows for regular updates of land cover maps without requiring major process redesigns.
    - **Scalability**. The API supports large-scale data analysis without requiring local computing resources, leveraging cloud-based processing power to handle massive datasets efficiently.

These features make Google Earth Engine one of the best available tools for multitemporal land cover change analysis, providing scalable, automated, and efficient processing capabilities.

The use of GEE in the MapBiomas Venezuela initiative has enabled the following tasks:

- Process satellite images using cloud-based computational infrastructure
- Develop scripts in JavaScript and Python to automate analysis workflows
- Store and manage datasets in the cloud, ensuring easy access and data integrity
- Share and disseminate results through an interactive web platform, providing access to: Annual mosaics and land cover maps, land cover change analysis and transition statistics and methodological documentation for transparency.

Figure 2 shows an example of the MapBiomas Venezuela dashboard, which allows users to query land cover data based on different spatial units over time.

Figure 2. Interface of the MapBiomas Venezuela dashboard.

2.6 Global, Regional, and National Mapping Initiatives

In recent years, multiple land cover and land use (LULC) mapping tools have been developed at global, regional, and national scales. These initiatives—many of which partially or fully cover Venezuela—use increasingly advanced approaches to provide updated information on landscape transformations.

Through detailed inventories or long-term monitoring, these projects focus on key environmental challenges such as deforestation, ecosystem monitoring, forest loss, landscape fragmentation, and land use transformation. Additionally, they support conservation efforts, climate change mitigation, and environmental research.

2.6.1 Global Data Sources

- **ESA CCI Land Cover**. The Climate Change Initiative (CCI) Land Cover program, developed by the European Space Agency (ESA), provides annual global land cover maps with 22 land cover classes. This dataset covers the period from 1992 to 2018.

- **CORINE Land Cover (CLC) inventory.** It was launched in 1985 (reference year 1990) and has been updated in 2000, 2006, 2012, and 2018. It classifies 44 land cover categories with a minimum mapping unit (MMU) of 25 hectares for areas and 100 meters for linear features. Time series updates also include change detection layers with a 5-hectare MMU.

- **ESRI 2020 Global LULC (Sentinel-2)**. This dataset provides a global LULC map for 2020, derived from ESA Sentinel-2 images at 10-meter resolution, covering 10 land cover classes. The classification model was trained using over 5 billion labeled Sentinel-2 pixels from 20,000 sites worldwide.

- **ESA WorldCover (2020 and 2021**). It is a global reference land cover product with a spatial resolution of 10 m, generated from Sentinel-2 and Sentinel-1 images, featuring 10 land cover classes and an overall accuracy of 75%. The legend includes 11 generic classes that adequately describe the Earth's surface: "Tree cover," "Shrubland," "Grasslands," "Croplands," "Built-up," "Bare/sparse vegetation," "Snow and ice," "Permanent water bodies," "Herbaceous wetland," "Mangroves," and "Mosses and lichens."

- **Dynamic World**. A global, near real-time land cover dataset with 10-meter resolution, generated using deep learning from Sentinel-2 imagery. This dataset, developed by Google and the World Resources Institute, assigns probability values per pixel for nine land cover classes, including water, forests, shrublands, grasslands, wetlands, croplands, built-up areas, bare land, and snow/ice.

2.6.2 Regional Data Sources (South America)

- **Ecological Systems of Latin America and the Caribbean**. This classification framework describes recurrent groups of biological communities in similar physical environments, influenced by ecological dynamics such as fire or flooding. Developed by NatureServe and The Nature Conservancy, the dataset includes nearly 700 ecological systems, emphasizing the natural portion of the landscape.

- **Land Cover Map of South America**. A 1-km resolution digital land cover map based on 1995-2000 satellite imagery, produced as part of the Global Land Cover 2000 (GLC 2000) project.

- **SERENA Land Cover Map for Latin America and the Caribbean (2008).** Developed under the Latin American Network for Natural Resource Monitoring and Study (SERENA) project, this dataset integrates: Local expertise from SERENA network members for training and validation data. A decision-tree classification methodology using MODIS time-series data and Class membership estimates to account for pixel heterogeneity.

- **Ecosystems of the Northern and Central Andes Maps.** A regional mapping project that generated Andean ecosystem maps from Venezuela to Bolivia (Josse et al., 2009).

- **Amazon Deforestation Monitoring (RAISG).** A study analyzing deforestation trends from 2000 to 2015, using RAISG-standardized methodologies to ensure regional comparability. The dataset includes deforestation statistics for: The entire Amazon region. For each Amazonian country, protected areas, indigenous territories and watershed basins.

- **MapBiomas Amazonia Collection 1** is a study based on Landsat satellite images that generated annual land cover and use maps for the Amazon region from 2000 to 2017, with a spatial resolution of 30m. It employs a methodology based on empirical decision trees to classify seven land cover and use classes. This collection was the first to establish a baseline for monitoring the Amazon territory and was launched in March 2019. The project was developed by the RAISG network and its partners in Amazonian countries.

- **MapBiomas Amazonia Collection 2** is the continuation of Collection 1, expanding the number of land cover and use classes and extending the period to 1985–2018. It implements the Machine Learning - Random Forest methodology to classify a greater number of land cover classes compared to Collection 1. This collection was launched in 2020, increasing both the specificity of the classes and the temporal scope of the project.

- **MapBiomas Amazonia Collection 3** covers the period from 1985 to 2020. It employs the Machine Learning - Random Forest methodology and classifies 14 land cover and use classes, enabling a more detailed analysis of changes in the Amazon. It was launched in September 2021.

- **MapBiomas Amazonia Collection 4** follows the approach of Collection 3, expanding the number of land cover and use classes to 18 and extending the analysis to 2021. It broadens the mapped classes to include agriculture, pastures, forestry, and oil palm plantations. It was launched in 2022.

- **MapBiomas Amazonia Collection 5** covers the period from 1985 to 2022, increasing the classification to 19 land cover and use classes. As with previous collections, this project was developed by the RAISG network and its partners in Amazonian countries. It was launched in 2023.

- **MapBiomas Amazonia Collection 6** spans the period from 1985 to 2023, classifying 20 land cover classes, including a new class for natural areas without vegetation. This collection enhances the monitoring of Amazonian landscapes and was launched in September 2024.

2.6.3 Development of Vegetation and Ecosystem Maps in Venezuela

In Venezuela, vegetation cartography began in 1920 with the publication of the *Ecological Map of Venezuela* at a scale of 1:2,000,000, prepared by the Swiss botanist Henri Pittier. In 1955, Francisco Tamayo presented the *Preliminary Phytogeographic Map of the Republic of Venezuela*. Later, in 1960, Kurt Hueck published the third vegetation map at a 1:2,000,000 scale, titled *Vegetation Map of the Republic of Venezuela*. In 1968, the Ministry of Agriculture and Livestock released the *Ecological Map*, based on L.R. Holdridge's life zone classification.

Starting in the 1980s, Landsat images were used to generate the *Current Vegetation Map of Venezuela* (scale 1:250,000), published in 1982. In 1988, Otto Huber and Clara Alarcón published the *Vegetation Map of Venezuela* at 1:2,000,000 scale, based on extensive fieldwork and visual interpretation conducted by Huber during his career as a botanist and ecologist (Huber and Oliveira-Miranda, 2010).

Over the past 25 years, various cartographic initiatives on vegetation coverage and land use have been developed in Venezuela at both national and regional levels. These large-scale initiatives (between 1:250,000 and 1:2,000,000) have served as references for MapBiomas Venezuela. The most notable among them include:

1995: Otto Huber presents the *Guayana Venezolana Map*, based on his 1988 publication, at a 1:2,000,000 scale (Figure 3). This map was part of the Flora of the Venezuelan Guayana eight-volume series (Steyermark et al. 1995).

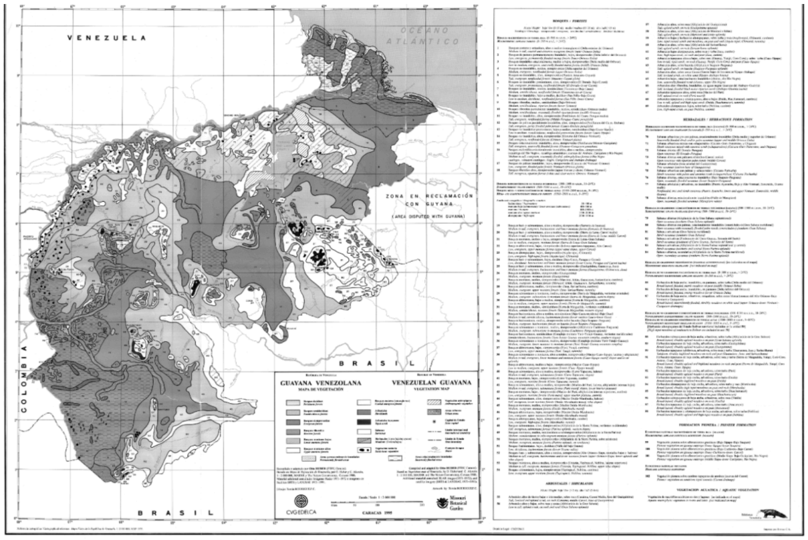

Figure 3. Venezuelan Guayana Map (Huber, 1995).

- 2003: The Ministry of the Environment publishes an update of Huber and Alarcón's map, titled *Vegetation Map of Venezuela*, at a 1:2,000,000 scale (Figure 4).

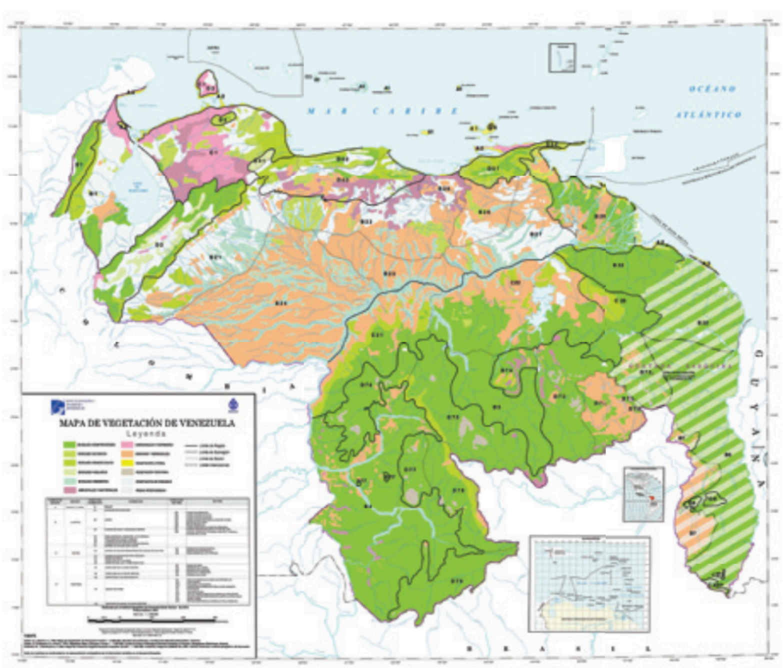

Figure 4. Vegetation Map of Venezuela (MARNR, 2003).

- 2010: Provita publishes the R*ed Book of Terrestrial Ecosystems of Venezuela*, which includes a *Vegetation Formations Map of Venezuela*, developed by Huber and Oliveira (Figure 5).

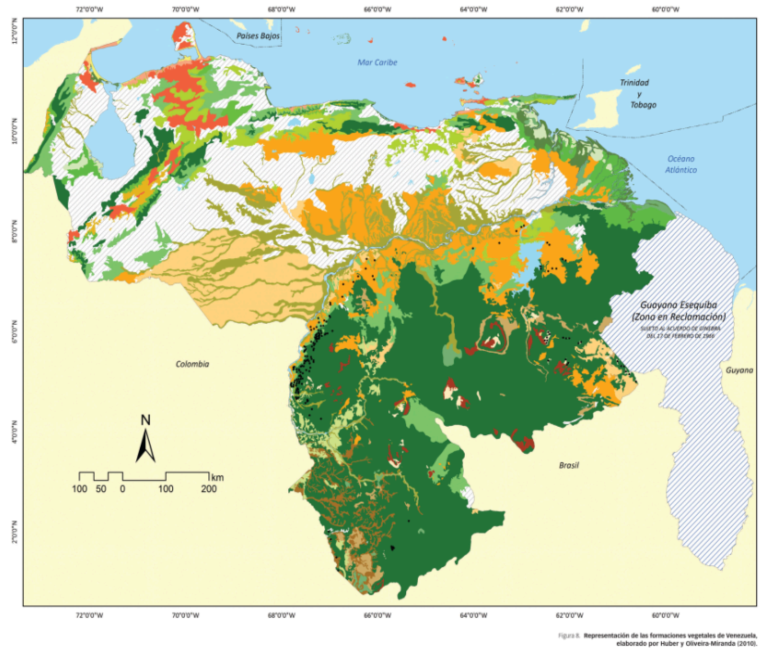

Figure 5. Map of Vegetation Formations of Venezuela (Huber & Oliveira, 2010).

- 2014: The Ministry of Popular Power for the Environment (MPPA) publishes the *Ecosystems Map of Venezuela* at a 1:2,000,000 scale (Figure 6).

Figure 6. Ecosystems Map of Venezuela (MPPA, 2014).

3. Methodology

The processing of satellite images to generate annual Land Cover and Land Use (LCLU) maps is a key component of the MapBiomas methodology, designed to ensure consistent, comparable, and high-quality products. This chapter describes the processing sequence implemented in Google Earth Engine (GEE), covering the entire workflow, from generating annual mosaics to integrating and validating the results. The standardization of data sources, algorithms, and procedures ensures consistency across countries within a diverse region, allowing cross-border comparisons and large-scale analyses. Additionally, this section explains the importance of a hierarchical legend and the classification region divisions, which help address the geographical and ecological complexity of territories like Venezuela. This methodology serves as the technical foundation that enables MapBiomas to capture, analyze, and monitor changes in land use, providing key tools for territorial management and environmental decision-making.

The data processing follows nine phases, summarized below (Figure 7):

- **Phase 1: Generation of annual Landsat mosaics.** It consists of integrating multiple images captured throughout a year, selecting specific time windows to maximize spectral contrast, and applying statistical reducers, such as the median, to combine pixel values, thereby minimizing areas without information or those affected by clouds. Additionally, the mosaic is enriched with bands derived from spectral indices (NDVI, EVI, etc.), spectral fractions, and additional statistics. This classification consistency allows the same pixel to be used as a training sample for all years in the series, improving classifier efficiency and reducing significant variations in the time series.
- **Phase 2: Identification of Stable Pixels.** For each class in the legend, training samples called “stable pixels” are extracted. These correspond to pixels consistently classified in the same class over time in the previous collection. If no prior collection is available, alternative sources such as high-resolution images, relevant classifications, or reference maps can be used, although additional processing and legend harmonization may be required. This consistency allows the same pixel to serve as a training sample for all years in the series, improving classifier efficiency and reducing significant variations over time.
- **Phase 3: Generation of Samples per Year.** Based on image mosaics and stable pixels, samples are generated for each class to train the classifier in the next phase. The number of samples is

approximately proportional to the area of each class and includes variables derived from the original Landsat bands, such as spectral indices, fractions, and statistical and temporal metrics. These variables enhance the ability to capture spectral, spatial, and temporal differences between classes.

- **Phase 4: Classification.** The Random Forest classifier generates a land cover and land use (LCLU) map for each year and classification region. The results are evaluated, and if necessary, class samples are supplemented, repeating the classification process as many times as needed. For years where certain areas were not classified due to missing data in the mosaics (resulting from a lack of images), the Gap Fill filter is applied to fill in pixels without information using values from subsequent years.

  In some cases, certain classes in the legend are classified independently, without considering other classes simultaneously. This approach is used because, in general classifications with multiple classes, these specific classes tend to be confused with others. In MapBiomas, these classes are referred to as cross-cutting themes, which are further explained in the integration section of the document..
- **Phase 5: Post-Classification.** To eliminate noise and stabilize temporal variations, spatiotemporal filters are applied to the classified data.
- **Phase 6: Integration.** In this phase, the regional classifications for each year are integrated, and cross-cutting themes are added when applicable, following a set of predefined prevalence rules.
- **Phase 7: Statistics.** Statistics are generated for the areas covered by each land cover and land use class, as well as their evolution over time. The statistical analysis is conducted at the national level, but calculations are also processed for various spatial units, such as states, municipalities, watersheds, and protected areas, among others.
- **Phase 8: Transitions.** Based on the final classifications, transitions between classes over time are analyzed for predefined periods. This process generates both change maps and their corresponding statistics.
- **Phase 9: Accuracy Analysis**. To assess the overall and class-specific accuracy of the classifications, a validation of the collection is conducted.

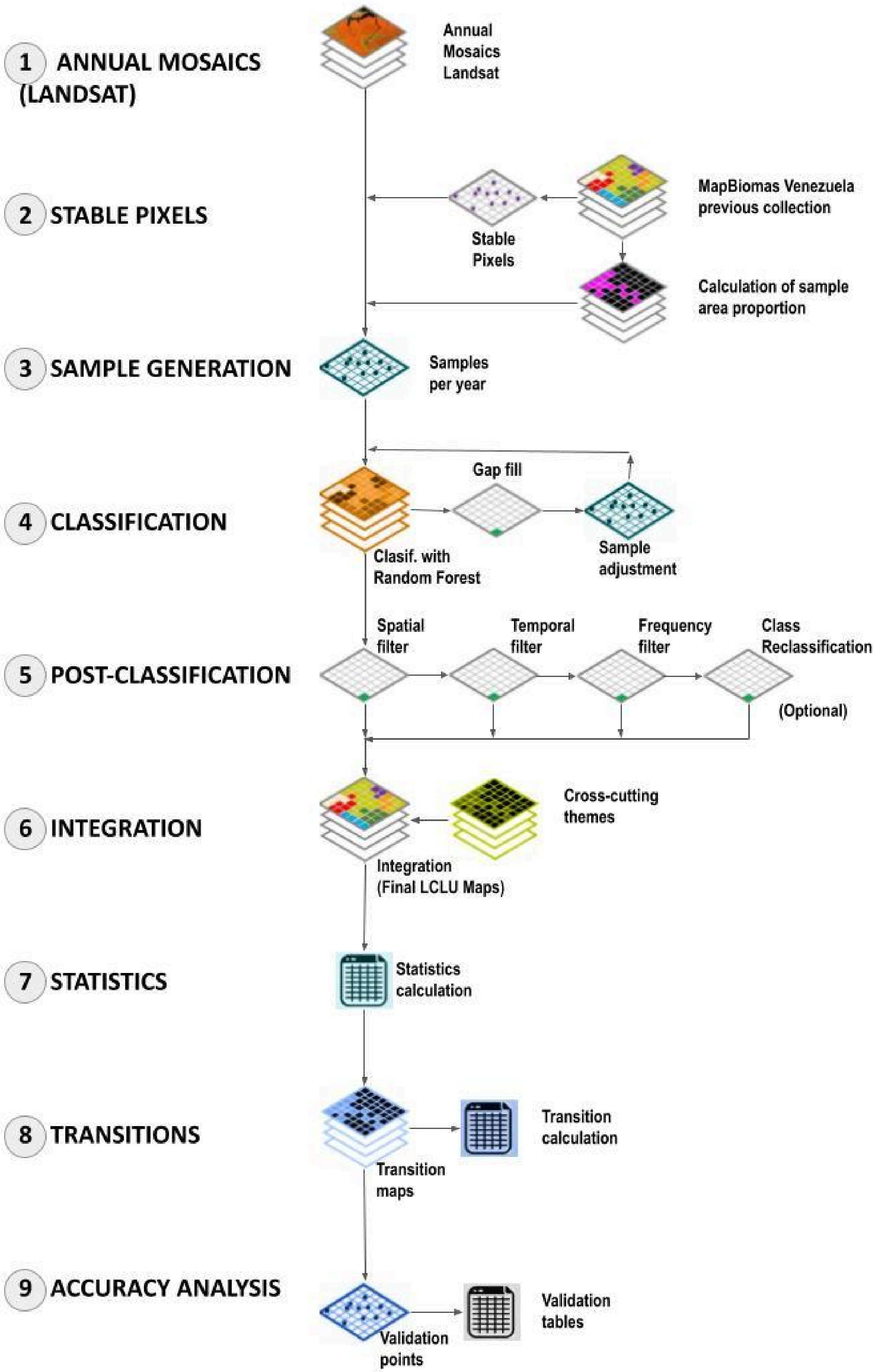

Figure 7. Diagram of the methodological steps for classification in MapBiomas.

Processing regions

To process satellite images for the entire country, MapBiomas Venezuela divides the territory into two processing regions: north and south of the Orinoco River. This division accounts for Venezuela's significant landscape and land-use contrasts, influenced by historical, economic, and natural factors that shape territorial and population dynamics.

This division enhances the representation of geographical, ecological, socio-economic, and logistical differences between both zones. The northern region, home to over 90% of the population, is characterized by a high density of human settlements, agriculture, infrastructure, transportation hubs, and industrial areas, creating a complex and heterogeneous landscape with extensive human intervention. In contrast, the southern region, covering 79% of Venezuela’s forest formations, hosts vast protected areas, indigenous communities, and mining activities. This region has limited accessibility, resulting in a distinct territorial occupation and land use compared to the north.

By applying this division, MapBiomas Venezuela captures regional differences in land cover and land use change, reflecting physiographic patterns and human pressures. The two macro-regions are:

- **Southern Orinoco Region**: Includes the states of Amazonas, Bolívar, and Delta Amacuro, part of the Venezuelan Amazon.
- **Northern Region**: Encompasses all other states and the insular territories.

Since 2017, Provita and its local partners have produced annual land cover and land use maps for the **Southern Orinoco Region**, following MapBiomas methodologies to track spatial changes over time. Since 2018, annual map collections have been published as part of MapBiomas Amazonía, with the latest Collection 6 (1985–2023) recently released.

The **Northern Region** is processed by Provita, with support from the Geographic Information Systems and Environmental Modeling Laboratory (LSIGMA) at Simón Bolívar University. LSIGMA has generated data for the Eastern Llanos, Central Llanos, Unare Basin, and Barlovento, covering 23.4% of the northern region.

For Collection 3, the Guayana Esequiba region was processed by the Institute for Environmental Research of the Amazon (IPAM) in Brazil, which also handles Guyana's data for MapBiomas Amazonía. In the post-processing stage, IPAM's annual classifications of Guayana Esequiba are integrated with the north and south Orinoco maps, ensuring comprehensive national coverage in MapBiomas Venezuela products.

Classification Regions

The processing regions of Venezuela, as explained in the previous sections, cover vast territorial extensions. Despite the computational capabilities of Google Earth Engine (GEE), classifying land cover and land use at such a large scale exceeds its processing limits. Therefore, it is essential to subdivide the territory into **classification regions**. These regions are predefined geographic areas that divide the analysis space into smaller, more homogeneous subregions. Their delimitation can be based on physiographic regions, environmental characteristics, or specific land cover and land use patterns. This approach is crucial for managing the diverse environmental, ecological, and land-use conditions that vary significantly across the country.

The subdivision into classification regions is fundamental because it allows processing models to be adjusted to the particularities of each area, improving the accuracy of the results. By working with homogeneous subregions, the algorithms can be specifically calibrated to address the unique characteristics of each region, such as vegetation types, flood patterns, or land-use dynamics. This is especially relevant in extensive and diverse territories, where a single approach for the entire country would be less efficient and less precise.

Among the advantages of this approach is the ability to reduce classification errors, as classification regions limit the possibility of confusion between classes due to landscape heterogeneity. Additionally, it allows for more flexible classification strategies, adjusting the parameters and variables used in each region according to local needs. It also facilitates validation with regional reference data, such as pre-existing thematic maps or information obtained from local knowledge, improving the quality of training and validation of the models. Another key advantage is computational efficiency. By processing data in smaller regions, it is possible to conduct analyses in parallel or divide processing into stages, significantly reducing the time and resources needed to complete the project. Finally, classification regions also enhance the interpretation of final results, as the generated products, such as land cover and land use maps, more accurately reflect local particularities, making them more useful tools for territorial planning, environmental monitoring, and decision-making.

In conclusion, classification regions are not only a technically essential component for addressing the complexity of processing a diverse territory like a country, but they also represent a key methodological strategy to ensure the quality, accuracy, and usefulness of the final products in land cover and land use analysis.

From Collection 2 of MapBiomas Venezuela, the country was divided into 162 classification regions, of which 61 are south of the Orinoco River and 101 regions are north. Figure 8 presents the classification regions of MapBiomas Venezuela

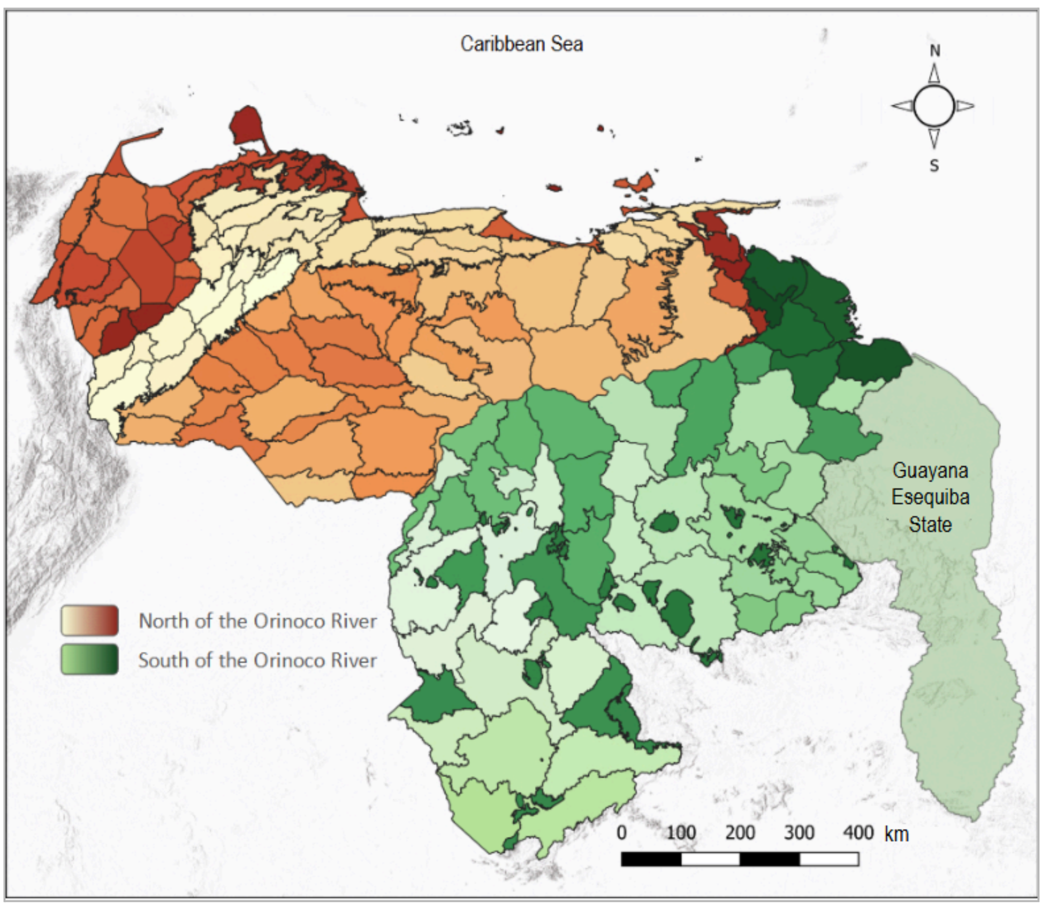

Figure 8. Map of classification regions of MapBiomas Venezuela. In earth tones, the 101 regions north of the Orinoco River are shown, while in green tones, the 61 regions correspond to the south region.

3.1. MapBiomas Venezuela Legend

The MapBiomas legend is designed to facilitate analysis at local, regional, and global levels. Below are the structure and key characteristics of the MapBiomas legend:

- **Hierarchical Structure**: The MapBiomas legend is organized hierarchically, allowing classification of different land cover and land use types at various levels. These levels provide a more detailed and precise understanding of territorial characteristics:
    - **Level 1:** This is the most general level and includes the main land cover classes. It consists of five main classes: **(1) Forest formations, (2) Grasslands and shrublands, (3) Agricultural areas, (4) Non-vegetated areas, and (5) Water bodies**. The classes at this level are consistent across all MapBiomas country and regional initiatives, such as Amazonia and Chaco, to ensure compatibility and comparability between territories.
    - **Level 2**: At this level, the general classes are subdivided into more specific categories, such as "Flooded forest," "Grassland," "Forest plantation," and "Urban," among others. From this level onward, countries and regions can differentiate based on local needs while maintaining overall coherence.
    - **Level 3 and lower levels**: These levels allow for greater specificity in classification. For example, in "Agriculture," "Soybean" and "Maize" could be distinguished as Level 3 classes. **MapBiomas Venezuela does not include Level 3 in its legend**.
- **Unique Class Codes**: Each class in the legend has a unique numeric code that identifies it in all maps and associated documents. These codes remain constant across all MapBiomas network initiatives, ensuring that the information is consistent and easily comparable between different countries and regions, even when class names vary.
- **Specific Colors for Each Class**: Each class in the legend is assigned a **unique color in hexadecimal format** to represent it visually on maps. This color assignment remains consistent across the entire MapBiomas network, facilitating visual interpretation and ensuring graphical consistency across representations.
- **Standardized Legend**: One of the key objectives of the legend is to ensure **harmonization across territories**. This means that while each country or region can define specific classes at Level 2 or below, the Level 1 classes must be consistent and equivalent across all countries.

Additionally, Level 2 classes should be harmonized with neighboring territories to prevent discrepancies in border areas, enabling smoother regional analysis.

- **Compatibility with Other Classification Systems**: The MapBiomas legend is designed to be compatible with other global and national classification systems. This includes comparison with international standards such as those from the FAO and IUCN. This compatibility ensures that MapBiomas products are useful at an international level and can be used in global reports and studies, facilitating integration and analysis at different scales.
- **Legend Evolution**: The legend is not static. As each new collection is developed, new classes may emerge to represent the heterogeneity of natural cover or land use. Any new class that is added must be mapped throughout the historical series of the collection and is considered "Beta" until it demonstrates sufficient consistency. This cyclical evolution is reviewed before each new collection to maintain class quality and consistency, allowing the legend to continuously adapt and improve.
- **Associated Documentation**: To facilitate the use of the legend and ensure its understanding, several documents have been developed that contain detailed information about the legend:
  - **Legend Code**: A document that includes the class level, class name, identification number, and hexadecimal color code. This is available for download on the MapBiomas Venezuela website.
  - **Legend Description**: A document describing each class, its level, name, and equivalence with other global and national systems. This document is also available on the MapBiomas Venezuela website.

The MapBiomas Venezuela legend for Collection 3 is organized into **5 main categories at Level 1 and 25 subcategories at Level 2**. Each class is identified by a **unique code and a hexadecimal color code**, which facilitates its visual representation on maps and ensures harmonization and comparability with other regions.

In Collection 3, within the *Grasslands and shrublands group*, two new classes were added compared to the previous collection:

- **Andean Herbaceous/Shrubland (code 81):** This land cover has a high diversity of herbaceous and shrubby growth forms, including caulescent rosettes, subshrubs–shrubs, as well as graminoid and non-graminoid herbs. It occurs in the Andean to High Andean altitudinal belts (3,000 to 4,600 m a.s.l.), where ground cover gradually decreases above 4,200 m a.s.l. These ecosystems exhibit high diversity and endemism.

- **Flooded Andean Herbaceous/Shrubland (code 82):** This class is associated with aquatic systems such as lagoons, peatlands, and seepage areas located in Andean regions where high-elevation wetlands and moraine-origin lakes develop at elevations above 2,800 m a.s.l.

In Table 1, the legend for Collection 3 of MapBiomas Venezuela is presented, showing the Level 1 and Level 2 classes, along with their corresponding codes and color palette. A more detailed description of each class is available in Appendix Table 2

Table 1. Codes for land cover and land use classes, along with the color palette used in MapBiomas Venezuela Collection 3.

COLLECTION 3 - CLASSES	COLECCIÓN 3 - CLASES (Spanish)	Code	Hexadecimal color	Color
1. Forest formations	**1. Formaciones boscosas**	**1**	**#1f8d49**	
1.1. Forest	1.1. Bosque	3	#1f8d49	
1.2. Wooded savanna	1.2. Sabana arbolada	4	#7dc975	
1.3. Mangrove	1.3 Manglar	5	#04381d	
1.4. Flooded forest	1.4. Bosque inundable	6	#026975	
2. Grasslands and shrublands	**2. Herbazales y arbustales**	**10**	**#d6bc74**	
2.1. Flooded grassland/shrubland	2.1. Herbazal/Arbustal inundable	11	#519799	
2.2. Grassland	2.2. Sabana/Herbazal	12	#d6bc74	
2.3. Rocky outcrop	2.3. Afloramiento rocoso	29	#ffaa5f	
2.4. Hypersaline tidal flat	2.4. Planicie de marea hipersalina	32	#fc8114	
2.5. Shrubland	2.5. Arbustal	66	#a89358	
2.6. Xerophytic grassland/shrubland	2.6. Herbazal/Arbustal xerófilo	50	#ad5100	
2.7. Other non-forest natural formations	2.7. Otras formaciones naturales no forestales	13	#d89f5c	
2.8. Andean herbaceous/shrubby vegetation	2.8. Herbazal/Arbustal andino	81	#dfeb62	
2.9. Flooded Andean herbaceous/shrubby vegetation	2.9. Herbazal/Arbustal andino inundable	82	#6fc179	
3.Agricultural areas	**3. Áreas agrícolas**	**14**	**#ffefc3**	
3.1. Pasture/fallow lands	3.1. Uso pecuario/Tierras en descanso	15	#edde8e	
3.2. Agriculture/fallow lands	3.2. Uso agrícola/Tierras en descanso	18	#e974ed	
3.3. Cropland/pasture/fallow lands	3.3. Uso agropecuario/Tierras en descanso	21	#ffefc3	

COLLECTION 3 - CLASSES	COLECCIÓN 3 - CLASES (Spanish)	Code	Hexadecimal color	Color
3.4. Forest plantation	3.4. Plantación forestal	9	#7a6c00	
4. Non-vegetated areas	**4. Áreas sin vegetación**	**22**	**#d4271e**	
4.1. Beach or dune	4.1. Playa o duna	23	#ffa07a	
4.2. Urban	4.2. Uso urbano	24	#d4271e	
4.3. Mining	4.3. Uso Minero	30	#9c0027	
4.4. Other non-vegetated natural areas	4.4. Otras áreas naturales sin vegetación	68	#e97a7a	
4.5. Other non-vegetated anthropic areas	4.5. Otras áreas antrópicas sin vegetación	25	#db4d4f	
5. Water bodies	**5. Cuerpos de agua**	**26**	**#2532e4**	
5.1. River, lake or ocean	5.1. Río, lago u océano	33	#2532e4	
5.2. Glacier	5.2. Glaciar	34	#93dfe6	
5.3. Aquaculture	5.3 Acuicultura	31	#091077	

3.2 Phase 1: Generation of Annual Mosaics

Annual Landsat image mosaics are generated to improve image quality, offering several advantages:

- **Maximization of Spectral Contrast:** Low-quality images, such as those with high cloud cover or noise, are discarded. Additionally, images from a specific period of the year can be selected to ensure better contrast between land cover classes.
- **Cloud Removal, Noise Reduction, and Quality Enhancement**: Clouds and shadows represent a major limitation in the classification of satellite images. By evaluating pixel quality (QA band) and removing extreme values such as clouds or shadows, noise is reduced, and data quality is improved. Median calculation across images generates mosaics that maximize interference-free pixels. This ensures more accurate and consistent annual LCLU maps with fewer classification errors, such as false positives or negatives in land cover classes.
- **Temporal Consistency and Homogeneity**: By using Landsat data and maintaining temporal consistency in the generation of mosaics, homogeneous products are obtained over the years. This allows for consistent annual comparisons and the detection of changes over time, which is crucial for studies on deforestation, climate change, and agricultural expansion.

- **Detailed Detection of Spatial Changes**: High-resolution (30 m) mosaics allow for detailed and precise identification of land cover changes. This is particularly valuable for monitoring phenomena such as deforestation or agricultural expansion, which require high spatial accuracy.

To generate annual mosaics, the country must be subdivided to facilitate their construction through a parameterization tailored to selected spatial units in each case. In this subdivision, units are processed separately and then merged into a continuous annual mosaic.

In **regions south of the Orinoco River**, the MapBiomas methodology divides the project area into a grid of regular map sheets, based on the International Map of the World (IMW) grid at a 1:250,000 scale. Each rectangular sheet covers an area of 1°30' longitude by 1° latitude. A total of 45 sheets cover the Venezuelan Amazon. The regular division of space resulting from the IMW grid implies that each sheet requires a total or partial combination of Landsat images, given that the Landsat image grid is oblique to the MapBiomas map sheet grid.

For **regions north of the Orinoco**, instead of using 1:250,000-scale map sheets as a reference, each of the 32 Landsat image scenes (170 × 185 km) is directly employed (Figure 9). This difference arises because, since 2017, the mosaic generation process has been standardized for the entire Amazon region using map sheets as a reference, as part of the MapBiomas Amazonia initiative. In contrast, in the north, flexibility was allowed to use the entire area of each Landsat scene, simplifying the process. In the future, all MapBiomas Venezuela mosaics will be subdivided by Landsat scenes to facilitate processing and generation.

3.2.1. Parameterization of Annual Mosaics

An annual mosaic is the combination of two or more Landsat images within a given time frame. The MapBiomas methodology recommends evaluating and defining an optimal time period based on the following criteria: data availability or coverage, spectral contrast between classes, and the phenological characteristics of vegetation cover at different times of the year. In MapBiomas Venezuela, images from all 12 months of the year were used due to the scarcity of data, especially at the beginning of the time series (1985–2000).

To select the images used in the mosaics, the following parameters are defined:

- **ID**: Unique identifier of the map-region unit or Landsat scene (Path/Row).
- **Year**: Year of the series to which the mosaic corresponds.
- **Spatial Unit**: Identifying code of the map sheet or Landsat scene (Path/Row).
- **Start Date / End Date**: Time period (start and end date) for selecting images from the Google Earth Engine (GEE) Landsat image catalog.
- **Sensor**: Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, Landsat 9 OLI-2, or a combination of Landsat 5 and Landsat 7.
- **Cloud Cover**: Maximum cloud cover threshold percentage allowed for each Landsat image to be used in mosaic construction. This information comes from the Landsat image metadata.
- **Blacklist**: Images that are excluded from the mosaic construction due to low quality.

The parameters for annual mosaic construction are defined by the interpreter, considering available dates, visual inspection of cloud cover, and image quality. In exceptional cases, where no images are available for the selected period, the temporal search range is expanded.

As part of the mosaic preparation protocol, clouds and cloud shadows are masked to maximize the usable surface area of the image. For cloud masking and shadow removal, Google Earth Engine (GEE) routines such as *Cfmask* and *CloudScore* are used. The images selected each year are reduced to a single annual mosaic using reducers available in GEE, which are mathematical or statistical operators designed to synthesize values from large datasets. In MapBiomas, the median reducer is used for the original visible, near-infrared (NIR), and mid-infrared (MIR) bands of Landsat, as illustrated in Figure 10.

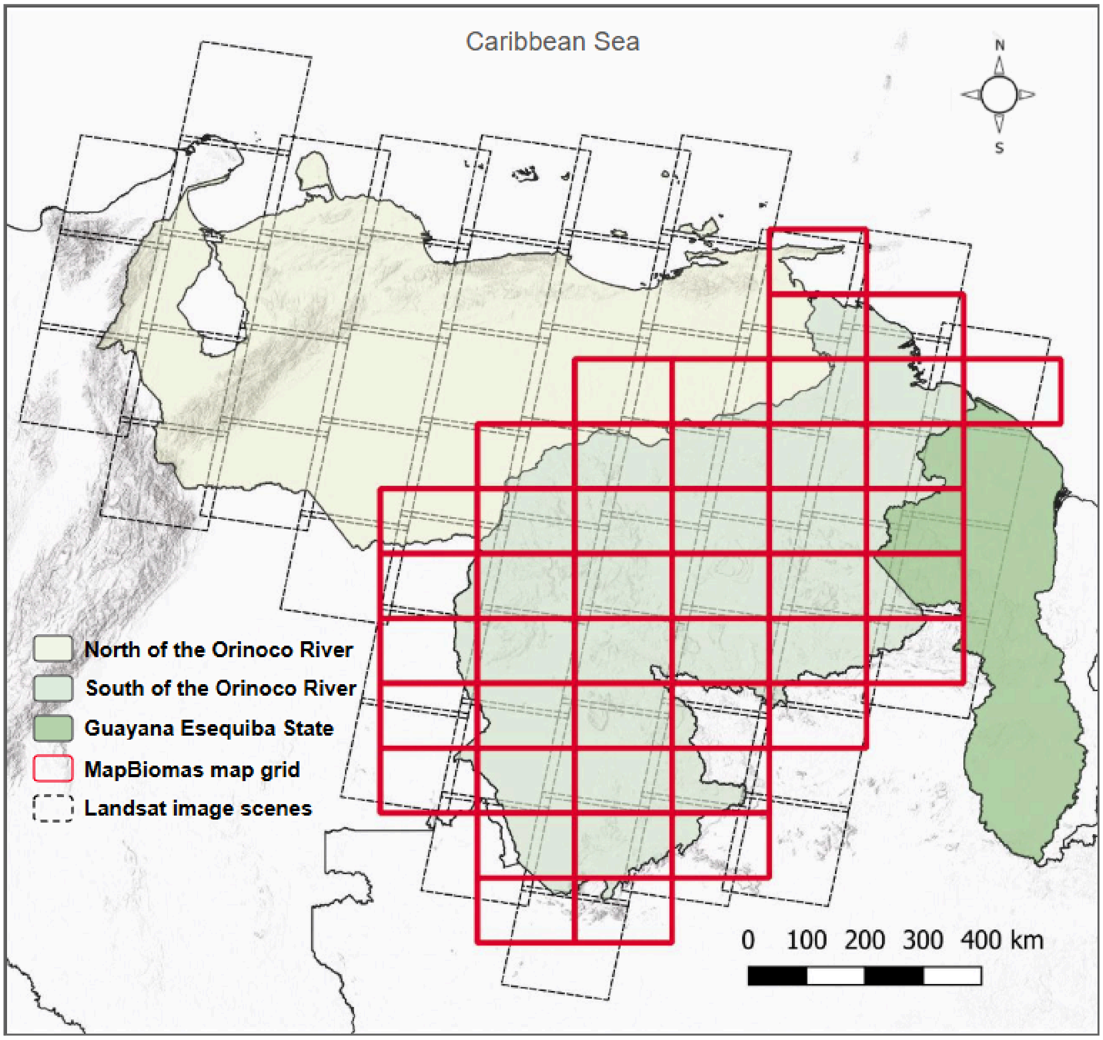

Figure 9. Coverage of MapBiomas Venezuela mosaics. The mosaics south of the Orinoco River are shown as red rectangles. North of the Orinoco, the mosaics align with the boundaries of Landsat scenes.

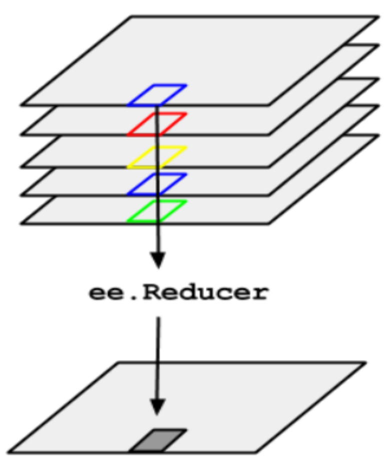

Figure 10. Scheme of the application of a reducer to an image collection (Google, 2020).

3.2.2. Classification Variables *(feature space)*

The annual mosaic not only includes medians of the original Landsat bands. During its creation, new bands or variables are incorporated for each year, defining a spectral feature space. These bands mathematically represent image properties, optimizing the classification algorithm's ability to distinguish between different land cover and land use types. From the original Landsat bands, new bands with additional characteristics are derived, including:

- **Spectral Indices**: These indices highlight specific features of vegetation, moisture, soil, etc. Some examples are:
    - **NDVI (Normalized Difference Vegetation Index)**: Measures vegetation density.
    - **EVI (Enhanced Vegetation Index)**: Improved performance in areas with dense vegetation.
    - **NDWI (Normalized Difference Water Index)**: Highlights water-covered areas.
    - **Vegetation Fractions**: A linear spectral mixture model is used to calculate fractions such as green vegetation, non-photosynthetic vegetation, soil, and clouds.
- **Statistical and Temporal Characteristics**: Values such as median, standard deviation, range, and other statistical parameters are derived for each band. These characteristics reflect how pixel values change over time, providing additional insights into landscape dynamics.

The process of calculating bands that compose the annual Landsat image mosaics is illustrated in Figure 11. The different reducers used in MapBiomas Venezuela include:

- **Median**: A measure of central tendency that divides a dataset into two equal parts, making it resistant to extreme values. It is calculated for the annual mosaics.
- **Dry Season Median**: Median calculated using pixels from the 25th percentile (lowest NDVI values) as an approximation of the dry season.
- **Wet Season Median**: Median calculated using pixels from the 75th percentile (highest NDVI values) as an approximation of the rainy season.
- **Amplitude**: The range of variation across all available pixels in the annual mosaic.
- **Standard Deviation**: Measures the dispersion of pixel values in the annual mosaic for a given location.
- **Minimum**: The lowest value among all pixels available in the annual mosaic at a given location.

- **Maximum**: The highest value among all pixels available in the annual mosaic at a given location.
- **Minimum Dry Period**: The lowest value from all pixels in the 25th percentile NDVI images, approximating the dry season.
- **Minimum Wet Period**: The lowest value from all pixels in the 75th percentile NDVI images, approximating the rainy season.
- **Maximum Dry Period**: The highest value from all pixels in the 25th percentile NDVI images, approximating the dry season.
- **Maximum Wet Period**: The highest value from all pixels in the 75th percentile NDVI images, approximating the rainy season.
- **QMO Dry Period**: The highest value for the EVI2 index during the dry season.
- **QMO Rainy Period**: The highest value for the EVI2 index during the rainy season.

In the appendices, Table 3 presents the complete list of bands[2] from the final mosaics (feature space). Each band represents a training variable for the classifier.

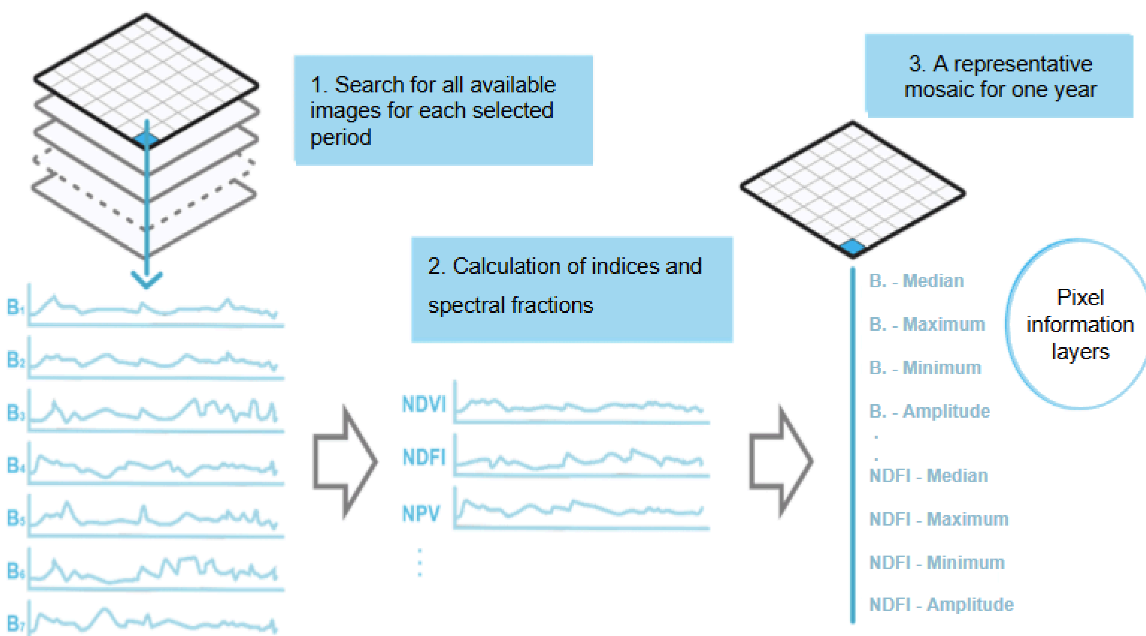

Figure 11. Process of calculating bands that compose the annual Landsat image mosaics.

[2] For these collections, MapBiomas Venezuela evaluated the variables that had been previously used in MapBiomas Amazonia.

3.3 Phase 2: Identification of Stable Pixels

The classification process begins with the collection of training samples, a critical step that requires identifying representative pixels for each class to be classified in each classification region. In this context, the identification of stable pixels is particularly important, as its purpose is to select areas that have remained unchanged within the same land cover or land use class over a prolonged period, ensuring consistency and reliability in the classification process. For each class defined in the legend, samples known as "stable pixels" are extracted. These correspond to pixels that have been consistently classified in the same class over time in the previous collection. This approach ensures that the data used to train classification algorithms, such as Random Forest, is of high quality, resulting in greater accuracy and consistency in the generated maps.

In cases where no previous collection is available, other information sources may be used, such as high-resolution images, relevant classifications, or reference maps. However, this alternative approach may require additional effort in processing and harmonizing the legend to ensure data compatibility with project standards.

Once identified, these stable pixels become the training dataset, allowing the same samples to be used for all years in the time series, thereby optimizing classifier efficiency. This approach not only facilitates classification but also minimizes significant variations between data from different years, contributing to the stability of the time series.

The identification of stable pixels also plays a key role in reducing noise and errors in the data, as it enables the detection and correction of potential inconsistencies or temporal anomalies that may arise during analysis. This process ensures that selected areas accurately reflect real terrain characteristics, leading to a more precise representation of land use and land cover changes over time.

3.4 Phase 3: Generation of Samples per Year

The generation of samples per year is a key component of the MapBiomas classification process, designed to establish a solid foundation for training classification algorithms efficiently and accurately. This process begins by calculating the sample size proportionally to the area occupied by each class within the classification regions, ensuring a balanced representation between dominant and less frequent classes to minimize biases during classifier training.

The stable pixel layer, previously identified in each classification region, serves as the initial input for this phase. These pixels undergo visual inspection to ensure their representativeness, and if necessary, new samples are added, particularly in areas where stable pixel coverage is insufficient or where inconsistencies have been detected. This step ensures that the selected samples accurately reflect the characteristics of each land cover and land use class.

Once the sampling points are defined, samples per year are generated by extracting spectral values from the corresponding Landsat mosaics. This dataset includes not only the original satellite bands but also derived variables such as: spectral indices (e.g., NDVI, NDWI), cover fractions (vegetation, soil, shadow, etc.), temporal metrics (e.g., medians, amplitudes, standard deviations). These variables help capture key differences in the spectral, spatial, and temporal characteristics of the classes, enhancing the model's ability to differentiate between them.

By employing a proportional sample size, visual inspections, and derived variables, this process ensures a robust reference dataset for the classifier, minimizing omission and commission errors. As a result, it produces high-precision annual maps that reliably reflect changes in land use and land cover throughout the time series.

3.5 Phase 4: Classification

MapBiomas uses the Random Forest algorithm to process satellite images and generate land cover and land use maps. This machine learning algorithm is widely used in supervised classification tasks due to its ability to handle complex data, such as satellite images with multiple spectral bands and derived indices. Random Forest creates decision trees using random subsets of the training data (Phase 3: Generation of Samples per Year), introducing diversity and improving accuracy. Each tree makes its own prediction, and the final result is determined by a majority vote. This structure makes the algorithm resistant to noise and prevents overfitting.

Additionally, its implementation in platforms like Google Earth Engine (GEE) allows for the efficient processing of large datasets. It can also classify imbalanced data (with dominant and minor categories) without requiring prior adjustments. Another advantage is its ability to identify the most important variables, facilitating validation and interpretation by multidisciplinary teams.

In this phase, after completing the initial annual classifications, a visual assessment of the results is conducted, and line graphs per class are generated based on cover area over the entire time series to analyze and track trends. This process helps detect abrupt or unnatural changes in the time sequence. If the result is unsatisfactory or requires adjustments in certain areas, the training samples are modified and updated, and the classification process is repeated to enhance accuracy and product quality.

Some classes may be difficult to differentiate due to their spectral heterogeneity, leading to confusion with other classes. In such cases, these classes must be classified independently using alternative methodologies and integrated at the final stage of the process. These independent classes are referred to as “cross-cutting themes”, which are detailed in subsection 3.7.1.

3.5.1 Filling Information Gaps *(Gap fill)*

In the classification results, pixels without data may appear, commonly referred to as "gaps". This occurs because the source (annual mosaics) contains areas with missing information, mainly due to persistent cloud cover in regions such as mountainous areas and tepuis. The constant presence of clouds makes it difficult to construct annual mosaics, as these areas inevitably appear in the images. When applying filters to remove clouds, data gaps are inevitably created.

To address these residual gaps, a gap-filling filter known as *Gap Fill* is applied. This filter assigns values to missing pixels by replacing them with the closest available temporal data. If a future pixel is also missing information, the filter assigns the nearest available value from another year within the time series, ensuring greater data continuity (see Figure 12).

The gap-filling process is carried out in two stages:

- *Backward Filling*: Gaps are first filled using data from previous years.
- *Forward Filling*: If any gaps remain, they are filled with data from the nearest subsequent year.

This approach ensures greater consistency in the time series, reducing areas without data and facilitating the analysis of annual classifications.

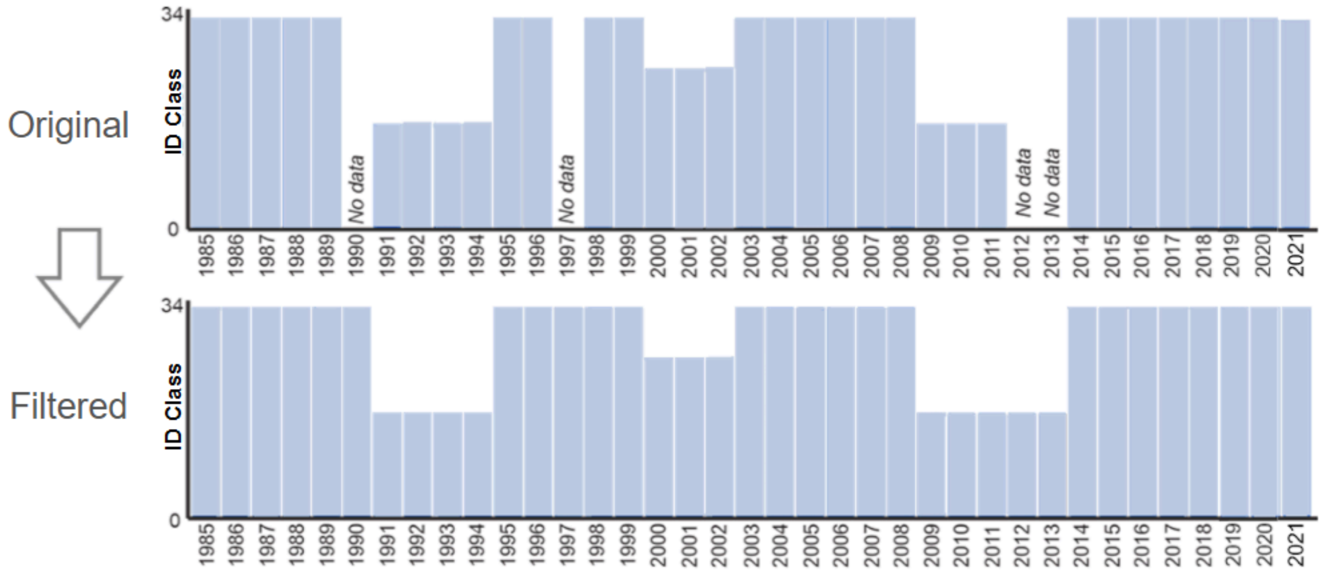

Figure 12. Example of the functionality of the Gap Fill.

3.6 Phase 5: Post-Classification

The post-classification phase is necessary to ensure the quality and multitemporal consistency of the classifications. Its primary objective is to correct or reduce residual classification errors, eliminate noise, and stabilize temporal transitions in the data. This is achieved by applying specific filters, such as: Spatial Filter, which removes the "salt-and-pepper" effect by replacing small areas with the dominant class from neighboring pixels and the Temporal Filter, which adjusts improbable transitions between classes over time. In some cases, a Frequency Filter is used for natural classes to reduce temporal variability or a manual reclassification is applied in specific areas when necessary. These tools ensure coherent and reliable maps, which are essential for analysis and decision-making.

To apply these filters to the classification, the post-classification process uses a set of specific decision rules tailored to each classification region based on its particular requirements. These rules include exceptions, such as the exclusion of certain years or classes, and even the repetition of filters in necessary cases. All post-classification tools were implemented in Google Earth Engine (GEE) using JavaScript scripts. The following sections provide a more detailed explanation of these tools.

3.6.1 Temporal Filter

The temporal filter analyzes the classified pixel values in relation to their values in consecutive years. Its main function is to identify how a value changes over time and adjust those that do not follow expected or possible patterns. To achieve this, the filter applies a unidirectional moving window that considers sequences of 3 to 5 years, identifying and correcting disallowed temporal transitions. This filter is applied to each pixel for all years included in the collection.

Depending on the year that needs modification, three types of rules are distinguished:

- **General Rule (GR)**: Applied to pixels in intermediate years within 3- to 5-year sequences. These rules correct temporal inconsistencies, such as when pixels in consecutive years have identical values, except for the central pixel. In these cases, the filter adjusts the central pixel value to align with the adjacent years. In 3-year sequences, there is one intermediate year. In 4- or 5-year sequences, there are two or three possible central positions.
- **First Year Rule (FYR)**: Exclusive to the first year of the time series. These rules modify the classification values of 1985.
- **Last Year Rule (LYR)**: Exclusive to the last year of the time series, adjusting classification values for that year.

These temporal filters correct inconsistencies and reduce gaps in information or implausible changes (Figure 13). For example, if in three consecutive years a pixel has the values: "Forest" | "Other Natural Non-Vegetated Areas" | "Forest", the filter will adjust the intermediate year's value. This type of error is commonly caused by the presence of haze or clouds in the mosaic for that year. The size of the temporal window is defined based on the characteristics of each region.

Figure 13. Example of the functionality of the temporal filter.

3.6.2 Spatial Filter

The spatial filter utilizes the native function *connectedPixelCount* in Google Earth Engine (GEE), which identifies neighboring pixels connected with the same value within a moving window. Pixels that do not meet a minimum number of connections with similar neighbors are considered isolated pixels. For MapBiomas, the minimum mapping unit was defined as 0.5 hectares (equivalent to 5 connected pixels). This means that a group of pixels must have at least five connections to meet the minimum connectivity criterion.

This filter smooths local differences by removing isolated pixels or edge pixels that cover areas smaller than 0.5 hectares, improving the spatial consistency of classifications (Figure 14).

However, in some classification regions, exceptions were applied, allowing a minimum unit of 3 pixels in specific cases.

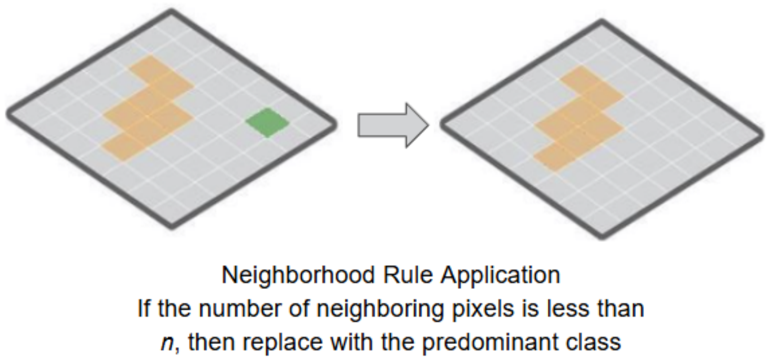

Figure 14. Example of the application of the spatial filter.

3.6.3 Frequency Filter

This filter considers the occurrence frequency of natural classes throughout the entire time series. Classes that appear less frequently than a threshold percentage—defined by the analyst—are replaced with the most frequently occurring class. This mechanism helps reduce temporal variability associated with a natural class, decreasing the frequency of false positives while preserving established land cover trajectories (see Figure 15). Depending on the needs of each subregion and/or cross-cutting theme, the filter criteria were adapted for each classification region. However, this filter is not always applied in all classification regions, as its implementation depends on the specific characteristics and requirements of each one.

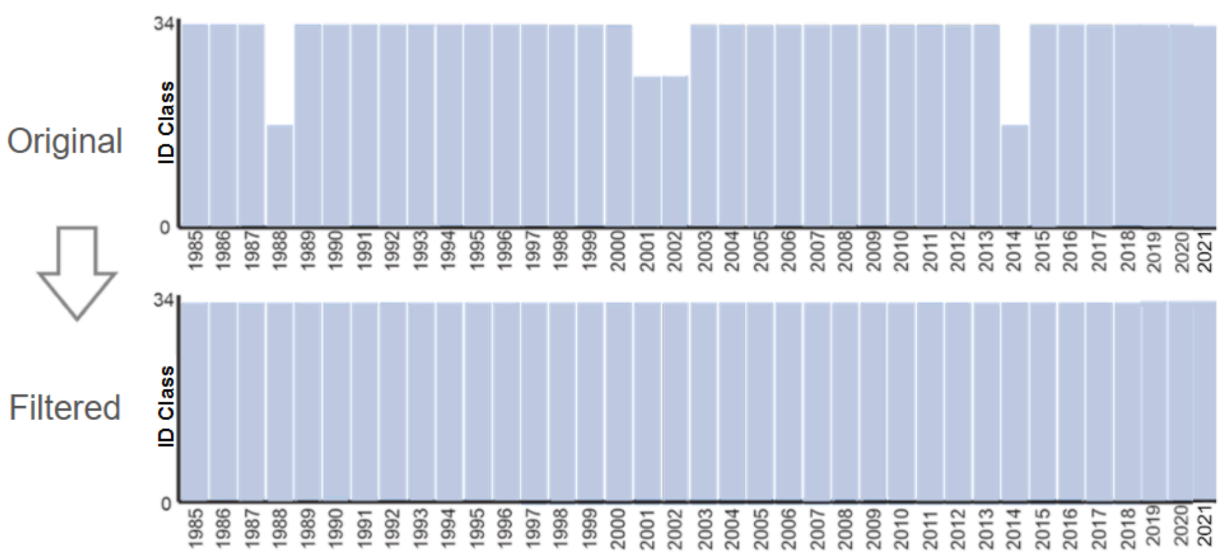

Figure 15. Example of the functionality of the frequency filter.

3.6.4. Reclassification

The reclassification of a class, also known as remapping, is applied when it is necessary to redefine, adjust, or correct a specific class within an area. This can be useful in various situations, such as:

- Correction of classification errors, where pixels have been incorrectly assigned to a class.
- Simplification and unification of similar categories into a single class.
- Adjustments for inconsistencies, ensuring that a class does not appear in areas where it should not be present, thereby improving data coherence.

The reclassification process is a manual procedure that requires identifying areas and classes that need correction. This includes defining the zones to be remapped using polygons or applying specific criteria, such as elevation thresholds or proximity to water bodies. Once these areas are defined, a simple script in Google Earth Engine (GEE) is used to update pixel values, ensuring that the correction is precise and aligned with the analysis requirements.

In summary, remapping is a valuable tool for customizing data based on specific needs, improving data quality, and enhancing accuracy, ensuring that maps accurately and logically represent the characteristics of the studied area.

3.7 Phase 6: Integration

The integration phase is the final step in the process of generating thematic maps, with the primary objective of unifying and consolidating the different inputs and results produced in the previous stages. This process ensures that the data is coherently integrated to produce a consistent and usable final product. The result is national and regional land cover and land use maps.

In MapBiomas, two types of inputs for integration are distinguished based on their purpose and data type:

- **Regional Classifications**: These are the classifications for the classification regions, generated using the methodology described in Sections 3.1 to 3.6. This input includes multiple land cover classes according to the legend, offering a detailed classification per region. These elements define the base map.

- **Cross-Cutting Theme Maps**: These are classifications of a single class from the legend to address specific topics. The integration process with regional classifications follows predefined precedence rules. These maps and their integration process are described in detail in Subsection 3.7.1.

In MapBiomas Venezuela, integration occurs at different regional levels, with several specific scenarios:

- **Annual land cover and land use maps of the Venezuelan Amazon**:
  - Integration of classification regions south of the Orinoco River.
  - Updating the integration with cross-cutting themes.
- **Annual MapBiomas Amazonia map**s:
  - Integration of the Venezuelan Amazon with land cover and land use maps from other Amazon Basin countries.
- **Annual land cover and land use maps north of the Orinoco River**:
  - Integration of classification regions north of the Orinoco River.
- **MapBiomas Venezuela maps**:
  - Integration of the Venezuelan Amazon maps with northern Venezuela maps and the Guayana Esequiba region (extracted from MapBiomas Amazonia).

The main activities in the integration phase to ensure the quality and usability of MapBiomas products are:

- **Data Unification**: Combines information layers (classified regions, post-classification corrections, cross-cutting theme maps) to ensure class consistency with the legend across all regions and time periods.
- **Conflict Resolution and Cross-Validation**: Identifies and corrects inconsistencies between data from different sources or regions, verifying coherence between layers and integrated regions, ensuring logical transitions and the absence of evident errors.
- **Generation of Line Graphs**: Helps visualize land cover area trends throughout the time series, facilitating the identification of abrupt changes or unnatural patterns in specific years or

periods. These graphs are key tools for analyzing trends and assessing possible anomalies that may require further review.

- **Final Product Generation**: Consolidates all information into a single GEE asset, ready for analysis, visualization, or distribution.

3.7.1. Cross-Cutting Themes

In the classification process, some classes exhibit confusion with others, making them difficult to distinguish. To improve the identification of these classes, it is necessary to use specific classification strategies, for which particular methodologies were developed according to each class. These classes, referred to as "cross-cutting themes," are mapped independently using algorithms that focus exclusively on the class of interest. This approach was applied mostly in southern Venezuela, including Guayana Esequiba.

In total, 4 of the 25 classes that make up the MapBiomas Venezuela legend are mapped using this approach: Flooded forest (ID 6), Flooded grassland/shrubland (ID 11), Mining (ID 30), and Glacier (ID 34), as shown in Figure 16. The glacier classwas mapped only in the Andean region.

A detailed description of the methodology used for each of these cross-cutting themes is available in the corresponding ATBD documents, accessible on the project's website.

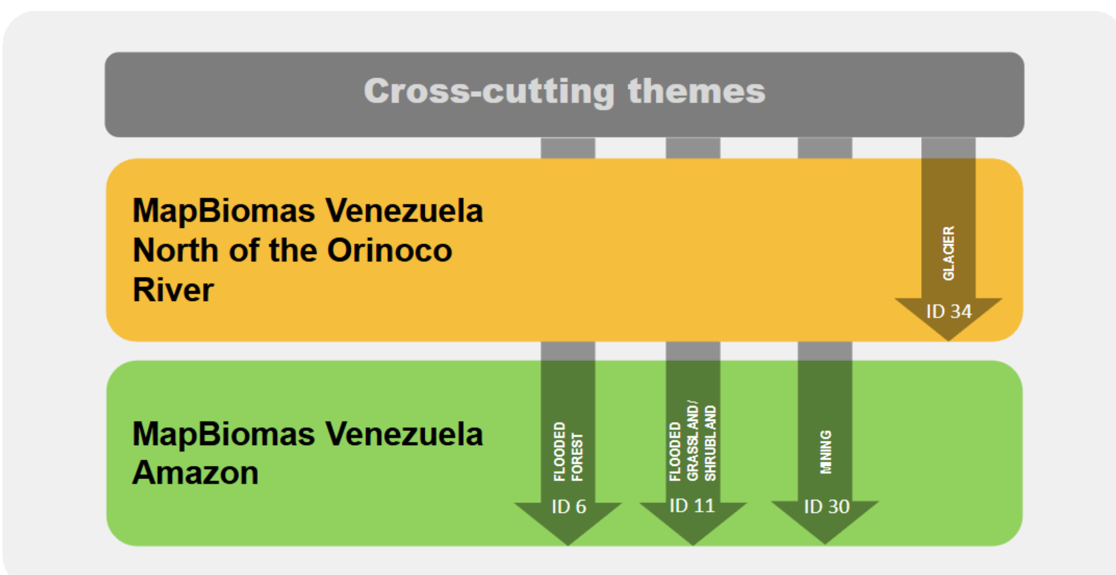

Figure 16. Scheme of cross-cutting themes applied in MapBiomas Venezuela.

Subsequently, this information is incorporated into the final map during the integration phase using a set of precedence rules that define the order of integration. These rules are designed to ensure that the classes mapped in the cross-cutting themes are consistently and logically integrated into the final product. These precedence rules establish priorities among classes, resolving conflicts when different layers classify the same pixel differently. The precedence rules follow a series of general principles:

- **Thematic Priority**: Classes mapped in cross-cutting themes typically have priority over the base map, as they are classified using specialized methodologies that provide greater accuracy.
- **Temporal Coherence**: Transitions between classes in different years must be logical, avoiding abrupt or inconsistent changes that do not reflect real-world landscape processes.
- **Class Hierarchy**: A hierarchy is established among classes, where more specific or critical classes (such as mining, mangroves, or flooded forests) take precedence over more general ones.
- **Context Validation**: Spatial and environmental criteria are used to validate class coherence, such as terrain characteristics or geographical location.

Below are some examples of these precedence rules:

- **Flooded forest** (ID 6) and **flooded grassland/shrubland** (ID 11): These classes prevail over forests, savannas, or grasslands in seasonally flooded areas.
- **Mining** (ID 30): Takes priority over any class in the base map, as it represents a specific activity that typically does not overlap with natural cover or other anthropogenic activities.
- **Glacier** (ID 34): Has priority over any class, as it is always on top of any type of land.

The process of applying precedence rules is as follows:

- Overlay the base map layers and cross-cutting themes.
- Apply precedence rules to resolve conflicts in pixels classified differently.
- Apply spatial and temporal filters to ensure the coherence of the final map.

This approach ensures that the final product accurately reflects the territory's characteristics, combining the comprehensiveness of the base map with the specificity and detail of the cross-cutting themes.

3.8 Phase 7: Statistics

The objective of statistics is to quantify and analyze the areas covered by each land cover and land use class, as well as their evolution over time. This stage transforms annual maps into useful metrics for assessing spatial and temporal dynamics, with a focus on various territorial units. The spreadsheets containing the metrics are available for download on the website, and they can also be visually explored on the map platform.

Statistics can be consulted by:

- **Zonal Statistics**: Calculated for specific areas, such as: country, states, municipalities, watersheds, protected areas, Indigenous territories, and physiographic regions.
- **Annual Statistics**: Represent the distribution of each land cover and land use class on a year-by-year basis.
- **Statistics by Legend Levels**: Data is presented for Level 1 and Level 2 of the legend.

The information provided by MapBiomas Venezuela offers multiple advantages for its users:

- **Trend and Change Analysis**: Enables the identification of annual change trends, stable zones, land use change rates, and class diversity in different regions.
- **Identification and Evaluation**: Facilitates the identification of critical areas, the assessment of ecosystem conditions, and the design of conservation strategies.
- **Support for Public Policies**: Provides detailed data to support the development of public policies related to territorial planning and the sustainable management of natural resources.
- **Compliance with Environmental Commitments**: Serves as a foundation for evaluating international environmental commitments, such as the preparation of greenhouse gas inventories and climate change adaptation analyses.
- **Research and Sustainability**: Provides solid data for research on territorial dynamics and sustainability strategies.

3.9 Phase 8: Transition Maps

Based on the final land cover and land use maps, transitions between classes are identified and represented by comparing pairs of maps from different years. This analysis allows for the detection of specific changes, such as deforestation, urbanization, natural regeneration, or agricultural expansion. Transition maps provide valuable information for understanding land use dynamics and evaluating environmental transformation processes over time.

The advantages of having this information include the ability to:

- **Territorial dynamics analysis**: Identifies trends such as agricultural frontier expansion or forest loss.
- **Decision-making support**: Provides crucial information for conservation policies, land use planning, and environmental impact monitoring.
- **Scientific research support**: Generates data inputs for studies on climate change, biodiversity, and sustainable resource management.

The generation of transition maps involves:

- **Calculation of transitions**: A pixel-by-pixel comparison is performed between annual maps, identifying land cover and land use class changes between a baseline year and a target year.
- **Definition of time periods**: Transitions are calculated for specific intervals, such as:
    - Consecutive years (e.g., 2001–2002).
    - Five-year periods (e.g., 2000–2005).
    - Entire time series (e.g., 1985–2024).
- **Classification of transitions**: Changes are grouped into the following categories:
    - Transitions from forest cover or non-forest natural areas to agricultural or vegetation-free areas.
    - Transitions from agricultural classes or areas without vegetation to forest cover or non-forest natural areas.
    - Transitions with gain in forest plantation.

The products generated in this phase include:

- **Transition Maps**: Spatial representations showing pixels where land cover and land use class changes occurred within a defined period. Includes:
    - Specific changes by category.
    - Stable areas (no changes in the assigned class).
- **Transition Statistics**:
    - By class: Total area gained or lost for each class in a specific period.
    - By region: Zonal analysis of transitions at different levels: Country, states, municipalities, watersheds, protected areas, Indigenous territories, and physiographic regions.
- **Indicators of Stability and Change**:
    - Cross-reference table comparing two time periods.

3.10 Phase 9: Accuracy Analysis

The accuracy analysis phase in MapBiomas Venezuela ensures that the generated products are reliable and accurately represent land cover and land use classes. This process includes the validation of annual maps, a key stage that is still pending execution. It is important to note that, at the time this document is published, the accuracy analysis is still under development.

The analysis begins with the design of a stratified sampling method, using a multinomial model with a 95% confidence level. This design ensures a balanced representation of all legend classes by proportionally and adequately assigning samples. From the selected sampling units, a team of specialized interpreters conducts visual interpretation of satellite images to generate the reference layer, which serves as the standard against which the generated maps are validated.

Once the reference layer is obtained, a confusion matrix is constructed, comparing classified values in the maps with those observed in the reference layer. This analysis identifies classification accuracies and errors for each class. Key validation metrics are then calculated, including: Overall accuracy, producer's accuracy, user's accuracy and KHAT index (Kappa coefficient estimator), which measures the agreement between the reference and classification, accounting for random chance.

The analysis also includes a spatial and temporal evaluation, allowing the identification of variations in accuracy over time and across different regions of Venezuela. This step is crucial for detecting potential areas of improvement and ensuring consistency in the results.

Among the products generated in this phase are the reference layer, the confusion matrix, detailed accuracy statistics, and reports summarizing the results. These reports, accompanied by visualizations, facilitate data interpretation and effectively communicate the quality of the final products.

The importance of this phase lies in its ability to ensure that MapBiomas Venezuela maps meet international standards, strengthening their credibility and usability. Additionally, it allows for methodological adjustments in future collections and supports their application in various contexts, such as territorial planning, natural resource monitoring, and scientific research.

4. Practical Considerations

A cartographic product is available that details land cover and land use across the entire national territory at a semi-detailed scale, updated annually, and spanning a 39-year time series. This dataset comprises approximately 22,581 maps, distributed in 579 sheets at a 1:100,000 scale for each year in the collection. This valuable collection is essential for various purposes, such as:

- Conducting up-to-date inventories of natural resources at the national level.
- Estimating forest loss and the increase in areas affected by land use changes.
- Analyzing the expansion of the agricultural frontier and urban growth.
- Developing projects focused on mitigating the effects of climate change, among others.

4.1 Methodology and Data Processing Platform

This project, with an unprecedented spatial and temporal scope in the region, was developed using a standardized methodology designed to be replicable in other parts of the world. The use of cloud-based platforms such as Google Earth Engine, combined with open-source technologies, has proven to be a promising solution for ensuring accessibility and efficient large-scale data processing.

The experience gained over the years in developing MapBiomas Amazonia collections, along with knowledge exchange with the MapBiomas Brazil teams, significantly optimized processing times and workflows. This achievement was made possible through collaborative network-based work by a multidisciplinary team, which adapted the methodology to the specific needs of each territory, ensuring more precise and useful results for the region.

4.2 MapBiomas Venezuela Collection

The MapBiomas Venezuela land cover and land use map collection is a strategic tool for monitoring spatial patterns of natural landscapes and those transformed by human activity in the country, covering a time window of over three decades. This extensive multitemporal dataset provides great potential for identifying trends and the main drivers of change affecting land use and cover patterns in different regions.

In terms of quality, the maps in the collection exhibit higher accuracy towards the end of the time series, whereas uncertainty increases in the classifications corresponding to the earlier years. This is mainly due to the limited availability and lower quality of Landsat images prior to 2000, as well as the scarcity of accurate cartographic sources for proper comparison and validation of data from that period.

While general patterns are correct, in certain regions and specific classes, especially in human-modified areas, it is necessary to apply review and correction strategies to improve the quality of future collections. These adjustments will ensure the development of even more precise and useful products for analyzing territorial changes in the country.

4.3 The MapBiomas Venezuela Legend

The MapBiomas cartography consists of 25 classes, a relatively limited number given the great diversity of landscapes present. This restriction arises from the need to produce a common legend for all countries in the region, which provides methodological and logistical advantages by facilitating the processing of homogeneous and comparable cartography at the regional level.

However, this simplification has limitations, as the legend categories are highly inclusive. This means that they group a wide variety of natural communities based on general criteria, such as the dominant vegetation type (trees, shrubs, or grasses) and its flooding regime (flooded or non-flooded). This generalization is applied to regions with great topographic, edaphic, and climatic diversity, resulting in highly variable ecological responses.

Consequently, land cover and land use classes are defined based on characteristic values, adjusted in each sampling region, to reflect particularities in: Physiognomy, deciduousness, vegetation moisture and land use patterns. This approach allows for a regionalized representation, although it remains limited by the broad inclusivity of the categories established in the legend.

4.4 Differences Between the Results North and South of the Orinoco River

As part of the MapBiomas Amazonia initiative, Venezuela has accumulated valuable experience through the analysis of six collections corresponding to the southern region of the country. This process has allowed for refinements in thematic accuracy, improving the quality of the cartography. Additionally, the high level of ecosystem conservation in this region facilitates the production of maps that more accurately reflect natural ecosystem variability, with a primary focus on identifying areas affected by human activities.

In contrast, northern Venezuela faces greater challenges due to: Lack of detailed prior data, marked landscape heterogeneity and high intensity of human intervention. These conditions significantly complicate classification processes and data quality verification, highlighting the need for more advanced strategies and additional resources to address these limitations.

4.5 Challenges

Future MapBiomas Venezuela collections face the challenge of improving product quality, particularly in the region north of the Orinoco River, to achieve uniform data quality across both northern and southern Venezuela. Additionally, there is a goal to gradually increase the number of classes in the legend, aiming to develop land cover and land use cartography that better represents the country's rich landscape heterogeneity and achieves a higher level of thematic accuracy, aligned with the spatial resolution of the collections.

At the same time, it is essential to maintain and enhance the use of advanced remote sensing technologies and tools to ensure the production of higher-quality products.

Another key objective is to expand the network of partner organizations, strengthening a community of researchers who actively contribute to the development of MapBiomas Venezuela products. This effort includes validating product quality in the field, leveraging the experience and local work of strategic partners.

5. References

1. Diniz, C.; Cortinhas, L.; Nerino, G.; Rodrigues, J.; Sadeck, L.; Adami, M.; Souza-Filho, P.W.M.(2019) Brazilian Mangrove Status: Three Decades of Satellite Data Analysis. Remote Sens. 11,808.
2. Google (2019, Marzo 01). Landat Collections. https://developers.google.com/earth-engine/datasets/catalog/landsat/.
3. Google (2019, Marzo 01). Google Earth Engine API. https://developers.google.com/earth-engine/.
4. Gorelick, Noel; Hancher, Matt; Dixon, Mike; Ilyushchenko, Simon; Thau, David; Moore, Rebecca (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, Vol. 202, 18-27.
5. Hernández, R. y García, L.F. (1993). Clima. Pp-38-41. En: G.A. Ruiz (ed). Imagen de Venezuela: Una visión espacial. Instituto de Ingeniería. Petróleos de Venezuela, S.A. Caracas. Venezuela.
6. Huber, Otto (1995). Guayana Venezolana: Mapa de Vegetación. 1:2.000.000.
7. Huber, O. y M.A. Oliveira-Miranda. (2010). Ambientes terrestres. Pp: 29-89. En: J.P. Rodríguez, F. Rojas-Suárez & D. Giraldo Hernández (eds.). Libro Rojo de los Ecosistemas Terrestres de Venezuela. Provita, Shell Venezuela, Lenovo (Venezuela). Caracas:Venezuela.
8. Huber O, Alarcón C (1988) Mapa de Vegetación de Venezuela. Ministerio del Ambiente y de los Recursos Naturales Renovables. The Nature Conservancy.
9. Hueck K (1960) Mapa de Vegetación de la República de Venezuela. Instituto Forestal Latinoamericano de Investigación y Capacitación. Mérida, Venezuela.
10. Instituto Nacional de Estadísticas (INE). Proyecciones de Población 2018, http://www.ine.gov.ve/. (2018).
11. Josse C., Cuesta F., Navarro G., Barrena V., Cabrera E., Chacón-Moreno E., Ferreira W., Peralvo M., Saito J. y Tovar A. (2009). Bolivia, Colombia, Ecuador, Perú y Venezuela. Secretaría General de la Comunidad Andina, Programa Regional ECOBONA, CONDESAN-Proyecto Páramo Andino, Programa BioAndes, EcoCiencia, NatureServe, LTA-UNALM, IAvH, ICAE-ULA, CDCUNALM, RUMBOL SRL. Lima.
12. MARN (2003) Mapa de Vegetación de Venezuela 1:2.000.000. Ministerio del Ambiente y de los Recursos Naturales (MARN), Instituto Geográfico de Venezuela Simón Bolívar; Caracas.
13. MPPAMB (2014). Mapa de Ecosistemas de Venezuela. 1: 2.000.000. Ministerio del Poder Popular para el Ambiente; Caracas.
14. Olson, David; Dinerstein, Eric; Wikramanayake, Eric; Burgess, Neil; V. N. Powell, George; C. Underwood, Emma; A. D'amico, Jennifer; Itoua, Illanga; E. Strand, Holly; Morrison, John; J. Loucks, Colby; F. Allnutt, Thomas; Ricketts, Taylor; Kura, Yumiko; Lamoreux, John; W. Wettengel, Wesley; Hedao, Prashant ; Kassem, Kenneth. (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth. BioScience. Vol 51, No 11. 933-938.
15. Souza, Carlos; Roberts, Dar A.; Cochrane Mark A. (2005). Combining spectral and spatial information to map canopy damage from selective logging and forest fires. Remote Sensing of Environment, Vol. 98, p329-343.
16. Souza, Carlos; Siqueira, J.V.(2013). ImgTools: a software for optical remotely sensed data analysis. Anais XVI Simpósio Brasileiro de Sensoriamento Remoto. 1571-1578.
17. Steyermark, J. A., Berry, P. E., Holst, B. K., & Yatskievych, K. (1995). *Flora of the Venezuelan Guayana* (Vol. 1, p. 320). St. Louis: Missouri Botanical Garden.

18. Proyecto MapBiomas Amazonía (2020) - Colección 2 de los mapas anuales de cobertura y uso del suelo. http://amazonia.mapbiomas.org.
19. Rodríguez, J.P., F. Rojas-Suárez y D. Giraldo Hernández (eds.) (2010). Libro Rojo de los Ecosistemas Terrestres de Venezuela. Provita, Shell Venezuela, Lenovo (Venezuela). Caracas: Venezuela. 324 pp.
20. Señaris, J. C., D. Lew y C. Lasso (eds.) (2009). Biodiversidad del Parque Nacional Canaima: bases técnicas para la conservación de la Guayana venezolana. Fundación La Salle de Ciencias Naturales y The Nature Conservancy. Caracas. 256 pp
21. Steyermark, Julian; Berry, Paul; Holst, Bruce (eds.) (1995). Flora of the Venezuelan Guayana Volume 1: Introduction. Missouri Botanical Garden. ISBN 0-88192-313-3.
22. Wulder, M. A., White, J. C., Loveland, T. R., Woodcock, C. E., Belward, A. S., Cohen, W. B., Fosnight, E. A., Shaw, J., Masek, J. G., and Roy, D. P. (2016). The global Landsat archive: Status, consolidation,and direction. Remote Sensing of Environment, Vol. 185, 271-283.

6. Appendix

Table 2: Description of the 25 classes in the MapBiomas Venezuela Collection 3 legend.

Level 1	Level 2	Region	Description
1. Forest formations	1.1. Forest	North / Amazon	Natural formation dominated by tree elements, generally with vertical stratification and the presence of various forms of growth according to the stratum: terrestrial herbs, vascular and non-vascular epiphytes, shrubs, and lianas. It has at least one continuous canopy stratum. These forest communities include evergreen, semi-deciduous, and deciduous species. They can be found in a wide variety of landscapes such as plains, plateaus, foothills, terraces, hills, ridges, mountains, and valleys
	1.2. Wooded savanna	North / Amazon	Formation dominated by grasses, in addition to other herbaceous components. Generally, it presents low and twisted tree and/or shrub individuals with adaptations to fire. The most common woody elements in savannas are the chaparro *(Curatella americana)*, the corkwood *(Bowdichia virgilioides)*, and the manteco *(Byrsonima crassifolia)*. Although there is great heterogeneity in savannas, where other woody species dominate, isolated tree clusters known as 'mata' can also be found, and occasionally isolated or grouped palms in various types of palm groves. The wooded savanna interrupts a more or less continuous and dominant matrix of often xeromorphic herbaceous plants, commonly known as savanna.
	1.3. Mangrove	North / Amazon	Forest restricted to coastal and estuarine deltaic areas, composed of halophytic trees. It is distributed in coastal zones, located in tidal influence areas and in brackish coastal lagoons. The four main constituent species of this type of forest are: red mangrove *(Rhizophora mangle)*, black mangrove *(Avicennia germinans)*, white mangrove *(Laguncularia racemosa)*, and buttonwood mangrove *(Conocarpus erectus)*.
	1.4. Wetland forest	North / Amazon	Forest formation is subject to a regime of permanent or seasonal, intra- or inter-annual flooding. Topographically, it is associated with river floodplains, depressions, marshy environments, or deltas, and alluvial plains affected by sedimentation and changes in river course.

Level 1	Level 2	Region	Description
2. Grasslands and shrublands	2.1. Flooded grassland / shrubland	North / Amazon	Formations in which herbaceous and/or shrub-like growth forms can dominate. These communities are subject to a regime of permanent or seasonal, intra- and inter-annual flooding. Topographically, these communities are associated with river floodplains, depressions, marshy environments, deltas, and alluvial plains affected by sedimentation and changes in river courses. It includes floodable savanna communities in Los Llanos. This class also encompasses aquatic vegetation communities and even floating vegetation, savannas with palms, and broad-leaved herbaceous vegetation over swamps. In the Andes it is associated with moraine lagoons and high-altitude wetlands at elevations above 3000 meters above sea level.
	2.2. Grassland	North / Amazon	It encompasses a wide variety of predominantly herbaceous formations. Savannas are primarily distributed in Los Llanos. These are communities characterized by a more or less dense and continuous herbaceous stratum dominated by grasses, often of the feather grass *(Trachypogon spicatus)* type, as well as other similar habit species belonging to the genera Axonopus, Panicum, and Paspalum.
	2.3. Rocky outcrop	North / Amazon	Naturally exposed rocks or young soils on the Earth's surface or exposure to lithological material from landslides. In the Andes, there are the Subnival and Nival elevations (> 4600 meters above sea level) where vegetation cover is scarce and gradually decreases with elevation. These are areas of great ecological importance, due to the tangible evidence of climate change, in substrates formerly occupied by glaciers, where processes of primary succession of vegetation occur. In the Amazon, occasionally with partial coverage of saxicolous vegetation (that which grows on rocky outcrops, rock walls, or hillside debris) or rupicolous vegetation (grows in rock crevices and fissures), which constitute highly specialized communities that grow on rocky substrates.
	2.4. Hypersaline tidal flat	North	Coastal lagoon formed by detrital sediments on coastal areas, bays, and estuaries. It is characterized by its concave and shallow topography. Generally, it exhibits high rates of evaporation. The salinity and depth of the water sheet depend on freshwater currents, precipitation, and the type of connection with tides.In this collection it includes salt flats.

Level 1	Level 2	Region	Description
	2.5. Shrubland	North	It is composed of a variety of shrub communities dominated by woody individuals that branch from the base. Generally, with heights of less than 5 meters and an irregular canopy. It may include armed species in communities of cardonales (cactus communities) and thorn scrub in coastal areas.
	2.6. Xerophytic grassland / shrubland	North	Formation composed of often succulent, creeping herbaceous plants and/or low, sparsely covered shrublands.
	2.7. Other non-forest natural formations	North / Amazon	In the Venezuelan Andes there is an association of Herbazal/Arbustal paramero, with a high diversity of growth forms that include: caulescent rosettes (stemmed), shrubby growth forms (paramo shrubland) as well as graminoid and non-graminoid herbs. It occurs in the Andino to Alto Andino elevation (3000 to 4600 meters above sea level) where soil cover gradually decreases from 4200 meters above sea level. These ecosystems exhibit high diversity and endemism. In the Amazon, there is vegetation specific to the tepuis, including the association of tepui grasslands/shrublands, composed of unique growth forms such as broad-leaved herbs, tubular plants, rosettes, and fruticose plants on rock, sand, and peat. These ecosystems exhibit high diversity and endemism.
	2.8. Andean herbaceous/shrubby vegetation	North	This cover type features a high diversity of herbaceous and shrubby growth forms, including caulescent rosettes, sub-shrubs, and graminoid and non-graminoid herbs. It is found in the Andean to High Andean altitudinal belts (3000 to 4600 meters above sea level), where ground cover gradually decreases from 4200 m.a.s.l. These ecosystems are known for their high diversity and endemism.
	2.9. Flooded Andean herbaceous/shrubby vegetation	North	This herbaceous/shrubland is associated with aquatic systems such as lagoons, peatlands, and runoff areas located in the Andean regions. It develops in high-altitude wetlands and moraine-origin lagoons at elevations above 2800 m.a.s.l.
	3.1. Pasture / Fallow lands	Amazon	Pasture area where natural vegetative cover has been altered or replaced through the cultivation of grasses and legumes used for livestock feed.This class includes fallow lands.

3. Agricultural areas

Level 1	Level 2	Region	Description
	3.2. Agriculture / Fallow lands	Amazon	Cultivation of plants with the aim of utilizing various parts, which can be fruits, leaves, stems, roots, tubers, etc. It encompasses a wide variety of production systems, ranging from extensive to intensive, including dryland farming, irrigated farming, and conucos (small traditional plots). This class also includes fallow land. In the Amazon, it includes the conucos of indigenous peoples, where it is common to produce crops such as yam (Dioscorea spp.), corn (Zea mays), cassava (Manihot esculenta), plantain (Musa spp.), among others.
	3.3. Cropland / Pasture / Fallow lands	North / Amazon	It encompasses pasture cultivation and agriculture, which includes a wide variety of plant crops in a diverse range of production systems. It is not possible to distinguish the boundaries between pastures and agriculture. This class includes fallow lands. This class is present north of the Orinoco River and in the state of Guayana Esequiba.
	3.4. Forest plantation	North / Amazon	Monospecific cultivation of standing trees, generally pine species (Pinus spp.) or eucalyptus species (Eucalyptus spp.), for the production of saw timber, wood chips, or pulp for papermaking.
4. Non-vegetated areas	4.1. Beach or dune	North	Sandy plains in coastal areas, accumulation areas in river floodplains, and the edges of bodies of water. It also includes dunes, which consist of rounded or elongated accumulations of sand of aeolian origin.
	4.2. Urban	North / Amazon	Area of human settlement with built environment infrastructure, including buildings and roadways. It also encompasses urban peripheries that are in constant expansion. In the Amazon, it includes indigenous communities.
	4.3. Mining	North / Amazon	Areas for mineral extraction, typically involving soil removal and exposure of lithological material. It includes various types of industrial mining. In northern Venezuela, it mainly involves the extraction of non-metallic minerals. In the Amazon, there are typically operations for metallic minerals, primarily gold. This includes artisanal, riverbank, or illegal extraction that results in the loss of vegetative cover, as well as soil removal and erosion.
	4.4. Other non-vegetated natural areas	North / Amazon	Surface with little or no natural vegetation cover, with less than 10% ground cover. It can be found in floodplains, arid zones, and a variety of landscapes such as hills, mountains, slopes, and ridges; it can also include landslides and mass movements.

Level 1	Level 2	Region	Description
	4.5. Other non-vegetated anthropic areas	North / Amazon	Areas without vegetation cover, composed of various infrastructures such as industrial yards, ports, airports, dams, airstrips, main roads, and other infrastructures outside urban areas.
5. Water bodies	5.1. River, lake or ocean	North / Amazon	Area covered by natural or artificial surface water. It includes rivers, lakes, reservoirs, and other water bodies, as well as marine-coastal areas.
	5.2 Glacier	North	Permanent ice cover, resulting from processes of snow accumulation and compaction. In the Venezuelan Andes, it occurs at summits at elevations around 4,800 meters above sea level. Venezuela's glaciers are the first to disappear in South America due to the effects of climate change, with a small glacial surface reported until 2020.
	5.3. Aquaculture	North	Infrastructure composed of artificial ponds for the cultivation of fish, shrimp, and other aquatic invertebrates of commercial interest.

Table 3: Description of Bands and Variables Used in MapBiomas Venezuela Classifications. In the columns corresponding to reducers and quality band, the cells marked with an “x” indicate the bands or variables that include those reducers or quality band.

Type	Name	Formula	Description	Reducer											Quality Band *	
				Median	Median_dry	Median_wet	amp	stdDev	Mín	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
BANDS	Blue	B1 (L5 and L7) B2 (L8 and L9)	Blue visible spectrum	X												
	Green	B2 (L5 and L7) B3 (L8 and L9)	Green visible spectrum	X	X				X				X		X	X
	Red	B3 (L5 and L7) B4 (L8 and L9)	Red visible spectrum	X	X	X			X		X	X		X	X	
	NIR	B4 (L5 and L7) B5 (L8 and L9)	Near-Infrared	X	X	X		X	X						X	X
	SWIR1	B5 (L5 and L7) B6 (L8 and L9)	Shortwave Infrared 1	X	X	X			X			X	X	X	X	X
	SWIR2	B7 (L5, L7, L8 and L9)	Shortwave Infrared 2	X	X	X			X		X			X	X	X
BAND INDICES	NDVI	(nir - red)/ (nir + red)	Normalized Difference Vegetation Index	X	X	X	X	X								
	EVI2	(2.5 * (nir ed)/ (nir + 2.4 * red + 1)	Modified Enhanced Vegetation Index (EVI2). A modification of the Enhanced Vegetation Index (EVI) that uses only NIR and Red, excluding the Blue band	X	X	X	X	X								
	NDWI_GAO	(nir -swir)/ (nir + swir)	Normalized Difference Water Index (Gao)	X	X	X	X				X		X	X		X

Type	Name	Formula	Description	Reducer											Quality Band *	
				Median	Median_dry	Median_wet	amp	stdDev	Mín	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
	NDWI_MCFEETERS	(green - nir)/(green+nir)	Normalized Difference Water Index (Mcfeeters)	X			X									
	GCVI	(nir/green) - 1	Near-Infrared and Green Band Ratios	X	X	X										
	HALLCOVER	(-red * 0.017) - (nir * 0.007) - (swir2 * 0.079) + 5.22	Spectral Land Cover Index	X												
	PRI	(blue - green)/(blue + green)	Photochemical Reflectance Index	X	X											
	SAVI	(1 + L) * (nir - red)/(nir + red + 0,5)	Soil-Adjusted Vegetation Index	X	X	X		X								
	TEXTG	('median_green').entropy(ee.Kernel.square({radius: 5}))	Texture Green Index	X												
	NUACI	$UNTL*(1-\sqrt{}(NDWIi-aNDWI)2+(NDVIi-aNDVI)2+(NDBIi-aNDBI)2)$	Normalized Urban Area Composite Index	X												
	NDSI	(green-swir1)/(green+swir1)	Normalized Difference Snow Index	X					X							
	CAI	(swir2 / swir1)	Color Alteration Index	X					X	X			X			
	GLI	((2 * green) - red - blue) / ((2 * green) + red + blue)	Green Leaf Index	X	X				X	X						
	MNDWI	(green - nir) / (green + nir)	Modified Normalized	X	X	X				X						

Type	Name	Formula	Description	Reducer											Quality Band *	
				Median	Median_dry	Median_wet	amp	stdDev	Mín	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
			Difference Water Index													
	NDBI	(swir1 - nir) / (swir1 + nir)	Normalized Difference Built-up Index	X	X				X	X						
	NDGB	(green - blue) / (green + blue)	Normalized Difference Green-Blue Index	X	X	X		X		X						
	NDMI	(nir - swir1) / (nir + swir1)	Normalized Difference Moisture Index	X	X					X						
	MDMIR	(swir1 - swir2) / (swir1 + swir2)	Normalized Difference Mid-Infrared Index	X		X		X	X	X						
	NDRB	(red - blue) / (red + blue)	Normalized Difference Red-Blue Index			X		X	X							
	NDSI2	(swir1 - nir) / (swir1 + nir)	Normalized Difference Snow Index 2	X	X	X			X	X						
FRACTIONS (SPECTRAL MIXTURE ANALYSIS)	GV		Fractional abundance of green vegetation within the pixel													
	NPV		Fractional abundance of Non-Photosynthetic Vegetation													
	SOIL		Fractional abundance of bare soil within the pixel													
	SHADE	100 - (gv + npv + soil +cloud)	Fractional abundance of shadow within the pixel													

Type	Name	Formula	Description	Reducer											Quality Band *	
				Median	Median_dry	Median_wet	amp	stdDev	Mín	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
	SNOW		Fractional abundance of snow and ice within the pixel													
	CLOUD		Fractional abundance of cloud cover within the pixel													
	GVS	gv / (gv + npv + soil + cloud)	Green Vegetation Normalized by Shade													
	NDFI	(gvs - (npv + soil)) /(gvs + (npv + soil))	Normalized Difference Fraction Index													
	SEFI	(gv+npv -soil) /(gv+npv + soil)	Savanna Ecosystem Fraction Index													
	WEFI	((gv+npv)-(soil+shade))/(gv+npv)+(soil+shade)	Wetland Ecosystem Fraction Index													
	FNS	((gv+shade) - soil) / ((gv+shade) + soil)	fractions of green vegetation (GV), shade, and soil													
	NDFIB	GV-(NPV+Soil+Snow)/ GV+(NPV+Soil+Snow)	Normalized Difference Fraction Index for the Andes													
STATIC AND/OR TOPOGRAPHIC VARIABLES	SHADEMASK2		Shadow Map													
	SLPPOST		Stratified Slope													
	ALTITUDE		Altitude													
	SLOPE		Slope													
	LATITUDE		Latitude													
	LONGITUDE		Longitude													

Type	Name	Formula	Description	Reducer											Quality Band *	
				Median	Median_dry	Median_wet	amp	stdDev	Mín	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
	HAND	hand30_100 hand30_1000 hand30_5000 hand90_1000 water_HAND_0m water_HAND_10m water_HAND_1m water_HAND_2m water_HAND_5m	Height Above Nearest Drainage													