MAPBIOMAS PERU

Land use and land cover

General manual

Theoretical basis document on algorithms (ATBD)

Collection 3.0

2025

Team of Specialists

Andrea Bravo

Zuley Cáceres

Kathrin Hopfgartner

Valeria Our country

Efrain Turpo

Sergio Campos

Project Manager MapBiomas Peru

Andrea Bravo

Coordinator of the Common Goods Monitoring Area

Sandra Ríos

Institution

Institute for the Common Good

INSTITUTO DEL BIEN COMÚN

Jr. Mayta Capac 1329
Jesus Maria, Lima 11. Peru
Telephone numbers: (51-1) 3732268 - (51-1) 3732296 - (51-1) 373-2284
www.ibcperu.org

Executive Summary

The Institute for the Common Good (IBC) is a Peruvian non-profit civil association founded in 1998 that works to promote the stewardship of common goods. By common goods, we mean resources and spaces that are jointly owned or used, such as rivers, lakes, forests, fisheries, protected natural areas, and community territories. Because these resources and spaces are crucial for the well-being of Amazonian peoples, particularly in the current era of climate change, our work promoting their conservation and sustainable use contributes to the well-being of these communities and all Peruvians.

The IBC is the Peruvian member of the Amazonian Network of Georeferenced Socio-Environmental Information (RAISG), where this type of information is generated in coordination with other countries in the basin to achieve the same objectives. Since 2009, within the framework of its work with RAISG, the IBC has been developing deforestation maps of the Peruvian Amazon using increasingly advanced satellite data processing tools. Seeking new alternatives for automating processes and generating timely information, in March 2017, RAISG, in agreement with the General Coordination of the MapBiomas Network, created the MapBiomas Amazonia initiative, of which the IBC is a member.

MapBiomas is an initiative of a collaborative network made up of non-governmental organizations, universities and companies in Brazil, organized with the objective of using quality and lower cost technology to produce annual series of land cover and land use maps (from 1985 onwards).

As part of the work with RAISG and MapBiomas, the IBC presents its *Collection 3.0 of Annual Land Cover and Land Use Maps* from all over Peru. Thanks to this collaborative effort, these maps will be available on an interactive platform for the country through the MapBiomas Peru initiative.

The objective of this Theoretical Algorithm Base Document (ATBD) is to provide users with an understanding of the methodological steps and computational algorithms for producing the*Coverage and Use Collection 3.0*, which includes the annual mapping of land cover and land use between 1985 and 2024.

Index

List of Tables

List of Figures

1. Introduction

1.1. Scope and content of the document

The objective of this document is to describe the theoretical basis, justification and methods applied to produce annual land cover and land use maps from 1985 to 2024 of Collection 3 of Annual Land Cover and Land Use Maps of MapBiomas Peru.

This document covers the Landsat image classification methods (L4, L5, L7, L8, L9), the image processing architecture, and the approach to integrating the biomes and regions present in the country. It also presents historical context and background, as well as an overview of the satellite image dataset and the accuracy assessment method applied.

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

1.2. Overview

The MapBiomas Peru project began in July 2021 with the aim of supporting the understanding of land cover and land use (LULC) dynamics across the country. The project is made possible by: i) technological advancements that allow for the cloud-based processing of large amounts of spatial data using algorithms hosted on the Google Earth Engine platform; ii) the implementation of image processing methods focused on monitoring MapBiomas LULC; iii) the multidisciplinary technical team whose expertise enables the mapping of the territory; and iv) the support of visionary institutions and funders who back the project.

MapBiomas Peru's products consist of annual thematic maps with a spatial resolution of 30 meters for the entire country. Their methodology uses annual mosaics of satellite images made up of information layers (spectral bands, derived indices, physical variables). They also obtain statistics derived from the maps by department, province, district, biome, watershed, indigenous territories, conservation units, among others.

MapBiomas Peru's mapping project has now released its first collection of annual maps; this collection will evolve in methodology, analysis period, detail of mapped land cover over time, and an improvement in map quality.

Collection 3: Mapping of land cover and land use between the years **1985 and 2024.**The methodology used was *machine learning (Random Forest)* with 156 layers of information (original Landsat bands, fractional and texture information derived from them, and indices). Landsat C images were used, which present the most up-to-date version of the reprocessed Landsat files. The generated maps have a total of **26 classes**.

The MapBiomas collections aim to contribute to the development of a fast, reliable, collaborative, and low-cost method for processing large-scale datasets and generating historical time series of annual land cover and land use maps. All data, classification maps, statistical codes, and other analyses are freely accessible through the MapBiomas Peru platform (http://peru.mapbiomas.org)

The products in Collection 3.0 are as follows:

- Annual classification rasters of the entire Peruvian territory;
- Rasters of annual transitions between classes and years chosen by the user;
- Preprocessed mosaics generated from Landsat file collections (Landsat 4, Landsat 5, Landsat 7, Landsat 8 and Landsat 9);
- Image processing infrastructure and algorithms (scripts in Google Earth Engine and source code);
- LULC annual and transitional statistics with various units of analysis;
- Landsat mosaic quality assessment. Each scene may have a proportion of clouds and other interference. Thus, each pixel for a given year is rated according to the number of available observations, ranging from 0 to 40 observations per year. The Landsat mosaic quality assessment is available on the MapBiomas website.
- Wall map of Land Cover and Land Use in Peru to 2024;
- National infographic on land cover and land use;
- Document of key findings in the analysis of the results;
- Technical documents for understanding the processes by topic.

1.3. Study Area

The scope of work is the entire territorial extension of Peru, excluding the insular surface (0.01%). This encompasses an approximate area of 1,294,306.15 km2. Within this area, four biomes were defined: the Amazon biome, the Andes biome, the Coastal Desert biome, and the Equatorial Dry Forest biome. (Figure 1).

Figure 1. Limit of identified biomes for Peru

For this purpose, technical criteria regarding ecosystem distribution were used, based on national reference maps and the experience of previous collections. The land cover types used were:

- Vegetation cover map (MINAM, 2015)
- Map of Ecoregions of Peru (SIGMINAM-DGOTA, 2017)
- Physiographic Map of Peru (INRENA, 2002)
- Map of Hydrographic Regions of Peru (MINAM-ANA)
- Map of the Remaining Natural Vegetation of the Northern and Central Andes (Andean Community - CAN)
- SRTM 90m Digital Elevation Model
- Map of wetlands of Peru (MINAM, 2010)

Table 1. Characteristics of land cover and land use in Peruvian biomes

Biome	Area (km2) (% country)	Description	Threats
Equatorial dry forest	46,026.95 (3,55%)	The extent of this biome is defined primarily by the spread of dry forest, both lowland and mountainous, along the country's northwest coast. Approximating Brack's "Equatorial Dry Forest" ecoregion, it is subject to the influence of the Tropical Sea and warm ocean currents, related to the El Niño phenomenon. The biome is characterized by a mixed tropical/subtropical climate with broadleaf dry forest vegetation, and it also contains Peru's only mangrove forests.	Dry forests face significant pressure that has gone largely unnoticed at the national level due to a lack of information. They are subject to logging (the felling of carob trees for firewood and charcoal), overgrazing (primarily by goats), and increasing deforestation to allow for agricultural expansion, especially by the agro-export industry. Pressure on groundwater is also increasing due to the growing number of wells being drilled for agriculture. At the same time, years of drought threaten dry forests, whose regeneration is linked to the El Niño phenomenon and rainfall.
Coastal desert	84,991.20 (6,57%)	Heavily influenced by the cold Humboldt Current from Chile, the arid subtropical climate of the south-central Peruvian coast supports sparse vegetation, with desert predominating. Despite this, fog often forms, fostering unique ecosystems such as the coastal hills (lomas) and tillandsia scrublands. Most of the vegetation and agricultural activity is concentrated in the river valleys, which are fed by rivers originating in the high Andes.	In the desert region, ecosystems such as coastal wetlands, coastal hills, and tillandsia forests face significant pressure from the uncontrolled urban sprawl of cities along the coast. Another constant threat is the lack of water for agriculture in river valleys, due both to decreased rainfall caused by climate change affecting water reserves and to the growing demand resulting from the expansion of agribusiness.
Andes	378,533.71 (29,25%)	This geographic region divides Peru into two watersheds: the Atlantic (eastern) and the Pacific (western). On the western slope, the Andes rise from approximately 750 meters above sea level to 6,788 meters above sea level, then descend along the eastern slope to 3,500 meters above sea level, giving way to the High Jungle, also known as the Yungas. Herbaceous vegetation predominates, with small inclusions of shrublands	It is severely threatened by soil compaction caused by livestock farming, as well as peat extraction from high-altitude Andean wetlands and extensive agriculture that supplies essential goods to the country's main population centers and cities. Agricultural burning and forest fires are frequent occurrences in a biome where the predominant ecosystems are characterized by climates with low relative humidity and vegetation with high fuel potential.

		and small forests. Glaciers are a prominent feature of this biome, serving as the main water source for the Atlantic and Pacific watersheds of Peru. They also create lakes and flooded high-Andean ecosystems such as bofedales (high-altitude wetlands). The inter-Andean valleys, known for their high agricultural productivity, are also noteworthy.	
Amazon	784,754.29 (60,63 %)	According to Brack's ecoregions, this biome mostly encompasses the extensions of the High Jungle and Low Jungle; characterized by a variety of forest landscapes that differ in their composition depending on their location, altitude, relief, climate and vegetation.	Primarily due to extensive agriculture, livestock farming, logging, and open-pit mining. Industrial crops such as oil palm are expanding in the northern and central parts of the biome, leading to the clearing of primary forests. Meanwhile, the southern part of the country is mainly affected by the expansion of gold mining in the large rivers of the Amazonian plain.

Source: Own elaboration

1.4. Applications

Scientific applications can be derived from an annual time series history of the LULC maps produced, including:

MapBiomas Peru's products show potential for the annual monitoring of areas threatened by land cover conversion and at risk of deforestation. Likewise, the time series maps can be useful as a complement to studies estimating greenhouse gas emissions from land cover and land use change in the country. Other application examples include characterizing land use dynamics, quantifying land cover and land use transitions, forest loss and gain, monitoring regeneration, changes in water resources, urban and agricultural expansion, regional planning, and the management of protected areas.

MapBiomas Peru not only complements existing national and global efforts, but also brings additional advantages such as: 1) MapBiomas Peru maps have been constructed using the complete Landsat data collection (40 years) with an annual timeframe; 2) the entire product shares the same methodology, legend, and temporal and spatial resolution, thus allowing comparisons between regions; 3) the product is prepared by experts familiar with the national context, generating a product with a view to local applications; 4) MapBiomas Peru makes its methods, tools, and products available to the public through a public consultation platform on the internet.

2. Basic information and background

2.1 Institutional context

2.1.1. Institute for the Common Good - IBC

The Institute for the Common Good is a Peruvian non-profit civil association founded in 1998 that works to promote the stewardship of common goods. By common goods, we mean resources and spaces that are jointly owned or used, such as rivers, lakes, forests, fisheries, protected natural areas, and community territories. Because these resources and spaces are crucial for the well-being of Amazonian peoples, particularly in the current era of climate change, our work promoting their conservation and sustainable use contributes to the well-being of these communities and all Peruvians.

All information about IBC projects and publications generated since the institution's inception is available on the websitehttps://ibcperu.org/.

2.1.2 MapBiomas

The MapBiomas Global Network currently comprises six initiatives mapping land cover and land use in Brazil, the Amazon, the Chaco, the Trinational Atlantic Forest, the Trinational Pampas, and Indonesia. These initiatives are multi-institutional collaborative networks made up of NGOs, universities, and technology companies that use cloud processing and automated classifiers developed and operated with the Google Earth Engine platform to contribute to the understanding of changes in land cover and land use. All data and methods generated by the project are public, transparent, and available on the platforms.https://mapbiomas.org/.

In 2024, the network expanded to include the initiative in Chile and extended its reach to Argentina, Bolivia, Colombia, Paraguay, Ecuador, Peru, and Venezuela, all involving local institutions. The main objective is to produce annual collections of land cover and land use maps that reflect the dynamics of transformations in different biomes in South America and other tropical and subtropical regions.

The objective of the Red Global MapBiomas is to produce and promote the use of qualified information for land use and land cover stewardship in South America and other tropical and subtropical regions. This Network presents a series of common practices across all its MapBiomas initiatives and products:

- User-friendly data platform, easy to access and use for applications
- Transparency in methodology and technology
- Open and free data
- Local experience and thematic knowledge of Land Use and Land Cover
- Cloud processing (Google Earth Engine platforms)
- Technical knowledge in remote sensing and programming
- Independence in data publication
- Collections that allow for constant evolution and improvement
- Distributed and decentralized networks
- Collaborative spirit
- Committed to technical and scientific rigor
- Promoting capacity building

2.2 Remote Sensing Data

The mapping data for Collection 3 were obtained from satellite images from the period 1985 to 2024 from the Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS) and Operational Land Imager 2 and Thermal Infrared Sensor 2 (OLI-2 -SHOTS2), aboard the Landsat 4 satellites (L4, for coverage of information gaps at the beginning of the series and mainly in 1988), Landsat 5(L5, for the years 1985-2012 of the series), Landsat 7 (L7, for the years 2000-2021),Landsat 8 (L8, 2013 onwards) and Landsat 9 (L9, 2021 onwards).

The images dThe surface reflectance values belong to the Landsat data catalog.[1]C2 with Tier 1 correction level,These images underwent radiometric calibration, orthorectification based on ground control points, and digital elevation modeling to ensure pixel-level recording and atmospheric correction. The catalog of Landsat images with a spatial resolution of 30 meters was accessed through the Google Earth Engine platform, provided by NASA and the United States Geological Survey (USGS).

2.3. Google Earth Engine and MapBiomas Amazonia

Google Earth Engine (GEE) is a cloud-based platform for the scientific analysis of global geospatial datasets. The main components of GEE are: 1) publicly available remote sensing data catalogs, 2) petabyte-scale cloud computing infrastructure, 3) APIs for JavaScript and Python to interact with GEE servers, and 4) an online integrated development environment (IDE) that enables application development using scripts.[2]called the Code Editor[3].

The aforementioned components make GEE the ideal tool for processing the large amounts of data required for classifying satellite images for land cover, land use, and land use change mapping. Additionally, GEE provides an environment that facilitates collaboration among regional teams (as in the case of RAISG) and the application of shared methodologies to the same dataset, as well as the replication of processes by third parties interested in evaluating concepts or methodologies.

The MapBiomas processing chain is based entirely on Google technology, and as such, the MapBiomas Peru initiative has relied on GEE to: 1) process satellite images in cloud computing infrastructure, 2) develop code (scripts) in Javascript and Python, 3) store the generated data using cloud storage, and 4) display the results (mosaics, annual land use maps, transition analysis, statistics by class and by transition, methodological information, among others) through a publicly accessible web platform.http://plataforma.peru.mapbiomas.org.

2.4. Other mapping initiatives

In recent years, various tools have been developed for mapping land cover and land use in the Amazon, some of them global in scope, with increasingly robust approaches. They all share a common interest in contributing to one of today's most pressing issues: understanding the current state of land cover types and monitoring changes in them. These initiatives have contributed to detecting deforestation, monitoring terrestrial and aquatic ecosystems, and strengthening the detection of forest degradation, conservation efforts, hotspots, and more. Below, we list the most relevant initiatives.

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

2.4.1. Global Sources

- GLC 2000 - Global Land Cover mapping for the year 2000, the project was an international partnership of some 30 research groups coordinated by the European Commission's Joint Research Centre, with the aim of producing a global land cover database for the year 2000. The database contains land cover maps with detailed and regionally relevant map legends and a global product that combines all regional classes into a coherent legend.
- Intact Forest Landscapes (IFL) is a global spatial database at a scale of 1:1,000,000, showing the extent of intact forest landscapes (IFL) for the years 2000, 2013, and 2016. The first global IFL map, for the year 2000, was prepared in 2005–2006 under the leadership of Greenpeace, with contributions from the Biodiversity Conservation Center, the International Socio-Ecological Union, and Transparent World (Russia), Luonto Liitto (Finnish Nature League), Forest Watch Indonesia, and Global Forest Watch, a network initiated by the World Resources Institute. The 2013 version was subsequently generated, and the map was finally updated to 2016 with support from the University of Maryland, the Wildlife Conservation Society, Greenpeace, and Transparent World.
- Global Forest Watch (GFW) – A collaboration between the GLAD (Global Land Analysis & Discovery) laboratory at the University of Maryland, Google, USGS, and NASA, measures areas of tree cover loss across the Earth (excluding Antarctica and other Arctic islands) at a 30 × 30 meter resolution. Their project focuses on developing global tree cover change data products based on Landsat satellite imagery, available on the Global Forest Watch 3.0 web platform. It includes annual forest cover change (gains and losses) from 2000 to 2020.
- GlobeLand30, is an initiative of the National Geomatics Center of ChinaThis collection comprises spatial datasets compiled at a resolution of 30 meters. It considers ten land cover types, including forests, artificial surfaces, and wetlands, for the years 2000 and 2010. These datasets were extracted from more than 20,000 satellite images from Landsat and the Chinese HJ-1 satellite.
- ESA CCI Land Cover, a joint project of the European Space Agency (ESA) and the Climate Change Initiative (CCI), provides annual global land cover maps, which describe the Earth's surface in 22 classes. The series of annual global land cover maps spans the period from 1992 to 2018.
- The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990). Updates were carried out in 2000, 2006, 2012, and 2018. It consists of a land cover inventory in 44 classes. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for area features and a minimum width of 100 m for linear features. Time series data are supplemented with change layers, which highlight land cover changes with an MMU of 5 ha.
- ESRI 2020 Global Land Use/Land Cover from Sentinel-2: This layer displays a global land use/land cover (LULC) map for 2020. The map is derived from ESA Sentinel-2 imagery with a 10-meter resolution and contains 10 classes. This map was produced by a deep learning model trained on over 5 billion hand-labeled Sentinel-2 pixels sampled from more than 20,000 sites distributed across the world's major biomes.
- ESA WorldCover 2020 and 2021: This is a reference global land cover product with a spatial resolution of 10 m, generated from Sentinel-2 and Sentinel-1 imagery with 10 land cover classes and an overall accuracy of 75%. The legend includes 11 generic classes that adequately describe the land surface: "Tree cover", "Shrubland", "Grassland", "Cropland", "Built-in", "Bare/sparse vegetation", "Snow and ice", "Permanent water bodies", "Herbaceous wetland", "Mangroves", and "Mosses and lichens".
- Dynamic World is a near real-time, 10-meter resolution global land cover dataset generated from Sentinel-2 imagery using deep learning. It is freely available and openly licensed. The legend presents the probabilities per pixel for nine land cover classes: Water, Forest, Shrub and

Bush, Grassland, Floodplain Vegetation, Cropland, Buildings, Bare Soil, Snow, and Ice. This data is the result of a partnership between Google and the World Resources Institute to produce a dynamic dataset of the physical material on Earth's surface.

2.4.2. Sources for the Amazon region

- Ecological Systems of Latin America and the Caribbean presents and outlines the conceptual basis for a classification unit for ecological systems. These systems represent recurring groups of biological communities found in similar physical environments and influenced by similar dynamic ecological processes, such as fires or floods. The goal was to provide a "mesoscale" classification unit that is easily mappable, often from satellite imagery, and readily identifiable in the field. The project was developed by NatureServe and its member programs, with funding from The Nature Conservancy, completing a functional classification of terrestrial ecological systems in Latin America and the Caribbean.
- Land Cover Map of South America. Digital map of land cover in South America based on satellite imagery taken between 1995 and 2000. The mapping scale has a spatial resolution of 1 km. This map was produced as part of the Global Land Cover project.GLC 2000" .
- The Land Cover Map of Latin America and the Caribbean, developed within the framework of the SERENA project, is a land cover map for Latin America and the Caribbean (LAC) for the year 2008. It was developed within the framework of the Latin American Network for Monitoring and Study of Natural Resources (SERENA) project. The SERENA land cover map for LAC integrates: 1) the local experience of SERENA network members in generating training and validation data, 2) a land cover mapping methodology based on decision trees using MODIS time series, and 3) class membership estimates to account for pixel heterogeneity issues.
- Deforestation in the Amazon, a study conducted by RAISG, analyzes historical and recent deforestation trends by five-year period from 2000 to 2015. The deforestation data was produced by RAISG members using their own standardized methodology, which allowed for regional analysis while still accounting for national differences. The study examines the issue at various levels: the entire Amazon region, the Amazon region within each country, Protected Natural Areas, Indigenous Territories, and at the river basin level.
- Mapbiomas Amazonia Land Cover and Land Use Collections is a study based on Landsat satellite imagery that generates annual land cover and land use maps of the Amazon region, with a spatial resolution of 30 meters. The project was developed by the RAISG network and its partners in the Amazonian countries. Currently, it uses the Landsat C2 image catalog and includes a legend of 27 mapped land cover classes.

2.4.3. Sources for the national territory

- Physiographic Map of Peru (2002) by the National Institute of Natural Resources - INRENA. A legend of 21 classes is used. Publication scale: 1:250,000.
- Ecosystem Map of the Northern and Central Andes. Bolivia, Colombia, Ecuador, Peru, and Venezuela (2009) General Secretariat of the Andean Community, ECOBONA Regional Program, CONDESAN-Andean Páramo Project, BioAndes Program, EcoCiencia, NatureServe, LTA-UNALM, IAvH, ICAE-ULA, CDCUNALM, RUMBOL SRL. Lima. Remaining natural vegetation units, transformed areas, and protected natural areas at the national level in the Northern and Central Andes designated by the Andean Community. Publication scale: 1:4,100,000
- Map of wetlands in Peru (2010) from the Ministry of the Environment - MINAM. The map shows national information on the distribution of wetlands in Peru, comprising four main units: 1)

Swamps and marshes; 2) Mangroves; 3) High-altitude wetlands; and 4) Coastal wetlands. The scale is 1:1,000,000.

- Map of the National Forest Heritage (2010) of the Ministry of the Environment - MINAM. The map was prepared by the Ministry of the Environment through the Directorate of Evaluation, Valuation and Financing of Natural Heritage and the General Directorate of Territorial Planning. It has a publication scale of 1:2,000,000.
- The Forest-Non-Forest and Amazon Rainforest Loss Map 2000-2014 (2015), produced by the National Forest Conservation Program for Climate Change Mitigation, shows the areas and percentages of forest-non-forest and forest cover loss at the national level. It features a 4-class legend and a publication scale of 1:6,000,000.
- Vegetation cover map (2015) from the Ministry of the Environment - MINAM, which includes a legend of 76 classes and a publication scale of 1:100,000
- Land Use and Land Use Change Maps 2000-2005, 2005-2011, 2011-2013, 2013-2016, prepared by the National Forest Conservation and Climate Change Mitigation Program. Available on the Ministry of the Environment's GeoBosques platform in raster and vector formats. They use the IPCC classification at a first level and a more detailed level called Subclasses.
- National Ecosystem Map (2018) prepared by the Working Group for the National Ecosystem Map and the Directorate of Monitoring and Evaluation of Natural Resources of the Territory (DMERNT) at a publication scale of 1:2,000,000.
- Map of Seasonally Dry Forest (2018). Baseline of the dry forests of the northern coast of Peru, prepared by Geobosques and the Ministry of the Environment.
- Mapa de Lomas (2020) obtenido de Moat et al., "Seeing through the clouds - Mapping desert fog oasis ecosystems using 20 years of MODIS imagery over Peru and Chile".
- National agricultural area (2020). Prepared by the Ministry of Agrarian Development and Irrigation. GEOMIDAGRI
- Rice crop monitoring (2021). Prepared by the Ministry of Agrarian Development and Irrigation. GEOMIDAGRI.

3. Methodology

The processing chain adopted for the generation of Collection 2 MapBiomas Peru is summarized in Figure 2 (in Spanish) and is detailed in the following sections: Generation of annual mosaics (section 3.1), Classification (section 3.2), Post classification (section 3.3) and Validation (section 3.4).

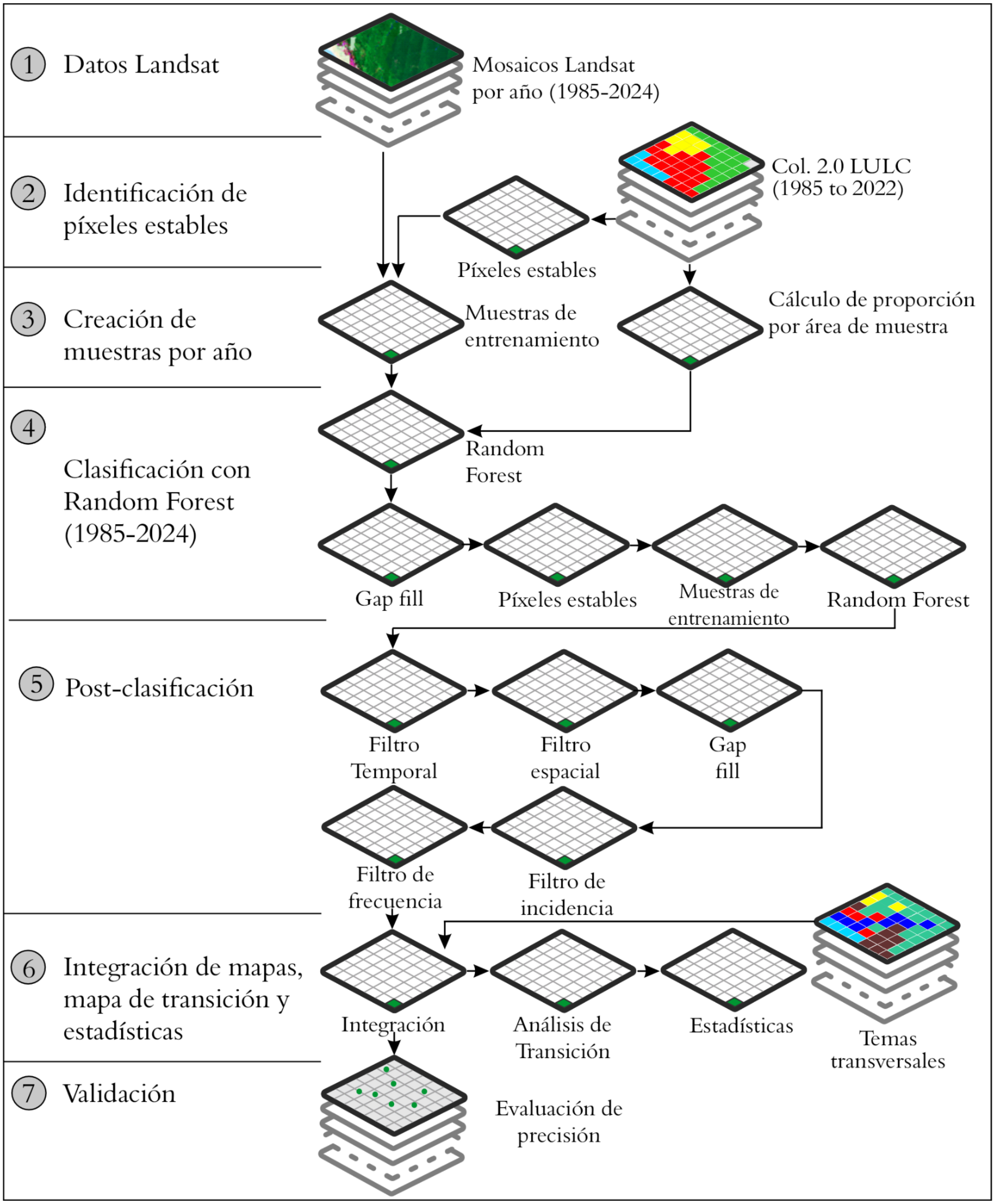

Figure 2. Methodological synthesis of Collection 3.0

3.1 Generation of annual mosaics

3.1.1. Division of the analysis space into charts

The MapBiomas methodology divides the project area into a grid of regular maps defined based on the grid of the International Maps of the World to the Millionth, at a scale of 1:250,000. Each rectangular map covers an area of 1°30' longitude by 1° latitude. A total of 107 maps cover the Peruvian territory.

The regular division of space resulting from the application of the International Charts grid implies that each chart requires a total or partial combination of Landsat images, given that the Landsat image grid is oblique to the MapBiomas chart grid (Figure 3).

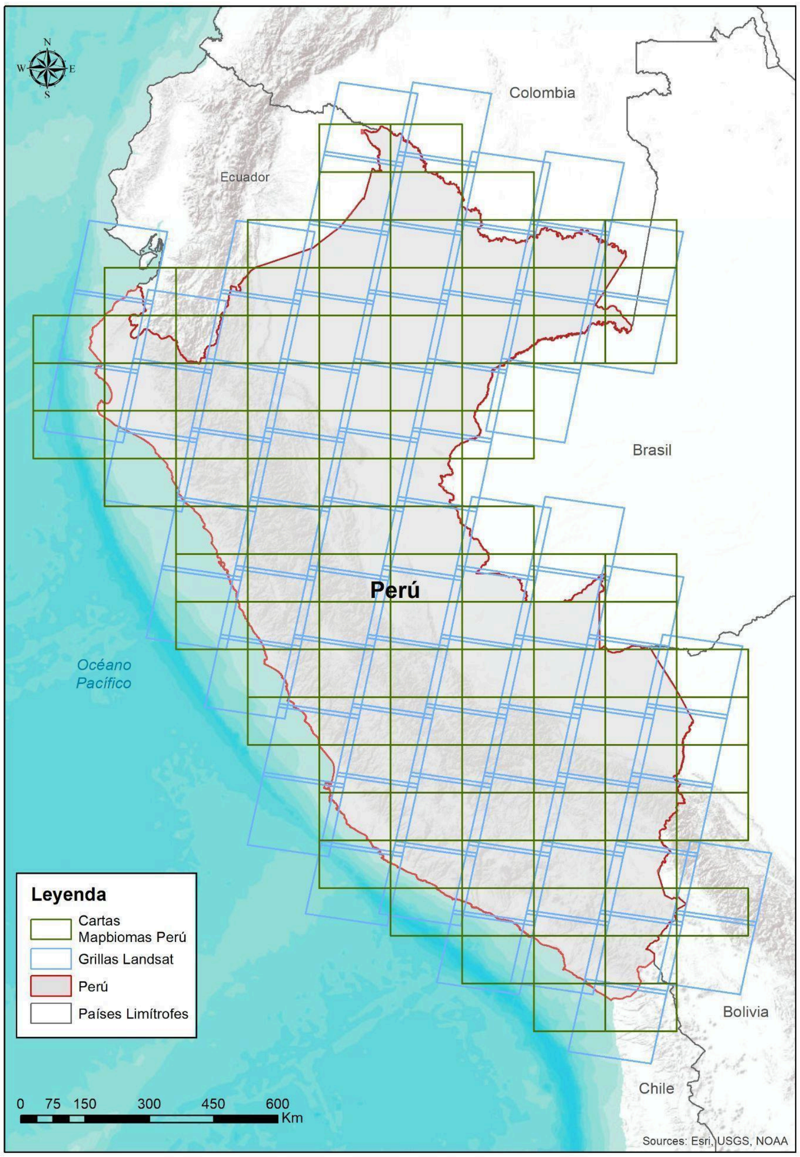

Figure 3. MapBiomas Peru map grid (green) and Landsat image grid (blue) and national boundary (red).

It was essential to subdivide the cards by mosaic regions.[4](Figure 4) to facilitate the construction of the mosaics through parameterization tailored to the specificities of each portion. As a result, annual mosaics of independent Landsat image pixels were generated for each map or subdivision, each of which was processed separately. Table 2 summarizes the number of existing maps at the country level (without subdivision), the final number of subdivisions (maps/region), and the total number of mosaics processed and generated.

Table 2. Summary of the number of MapBiomas Peru maps by region and country

Mosaic region	Biomes that it encompasses	Cards/Mosaic Region	Total number of tiles (x40 years)
Region 701	Amazon (high jungle mountain range)	31	1240
Region 702	Amazonia (lowland rainforest plains area)	59	2360
Region 703	Andes (Atlantic basin)	32	1280
Region 704	Andes (Pacific and Titicaca basins)	35	1400
Region 705	Equatorial dry forest and coastal desert	35	1400
Total		192	7680

Source: Own elaboration

[4] The "**mosaic regions**"are used specifically in the construction of mosaics and are different from the "**classification regions**"that are used specifically for the sorting process."

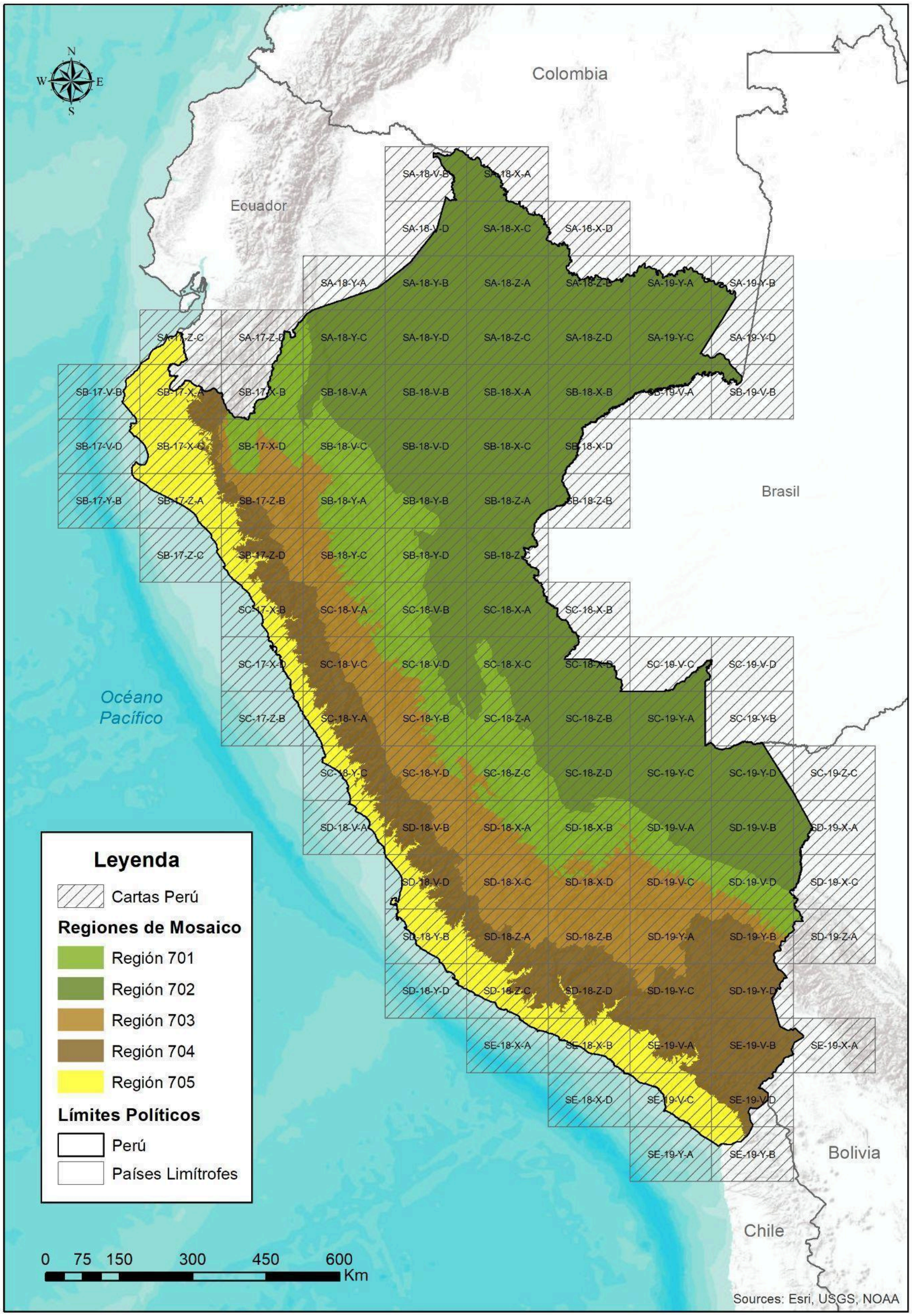

Figure 4. Map of the region-charts for the generation of image mosaics for Peru.

3.1.2. Parameterization of annual mosaics

An annual mosaic is the aggregation of pixels from several Landsat images from which a representative mosaic for a year is generated, constructed from the following parameters:

- ID: Unique identifier of the letter-region unit
- Year: Year of the series (1985 to 2024) to which the mosaic corresponds.
- Letter: Letter identifier code
- Start Date/ End Date: Period of the year (start and end date) for the selection of images from the Google Earth Engine Landsat image data catalog.
- Sensor: The satellite and its respective sensor: Landsat 4 TM, Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI or a combination of Landsat 5 and Landsat 7, Landsat 9 OLI-2 TIRS-2.
- Cloudiness: The maximum percentage of cloud cover accepted for each Landsat image that will be used to construct the image mosaic. This data comes from the Landsat image metadata.
- Probability of clouds:
- shadowSum: This is a TDOM parameter for cloud shadow detection. A lower number masks fewer pixels with cloud.
- cloudThresh: This is a CloudScore parameter for cloud detection. Lower numbers increase masking, while higher numbers decrease it. Decreased masking can be useful in areas of bare ground where high reflectance leads to false cloud detection.
- Blacklist: Images that, due to their quality, are excluded from the mosaic construction. Some quality issues are related to snow pixels in non-glacial regions and clouds that have not been masked.

The parameters for constructing annual mosaics are defined by the interpreter and represent the criteria for selecting images available in the Landsat data catalog from which the annual mosaic is constructed. The images selected for each year were *reduced* to an individual image, or annual mosaic, using operators called *reducers* existing in Google Earth Engine, as illustrated in Figure 5.

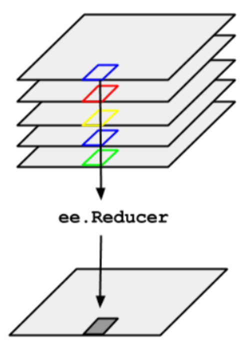

Figure 5. Schematic of the application of a reducer to a set of images (Google, 2020)[5]).

When parameterizing the mosaics, it was considered that higher accuracy values could be achieved by using satellite image mosaics with minimal noise. Therefore, each mosaic was designed to have the least possible cloud cover and interference, as well as the largest possible coverage of available Landsat data within the defined period. In exceptional cases where images were unavailable for the selected period, the image search period was extended.

[5]Taken from: https://developers.google.com/earth-engine/guides/reducers_image_collection

Clouds and cloud shadows are pre-masked so that only pixels free of clouds and cloud shadows are selected from the available images. The cloud and cloud shadow masking methods used were Cfmask and CloudScore.

Table 3 presents a summary of the most frequently used parameters for each region by biome.

Table 3. Summary of the parameters used in the construction of the mosaics

Region	Satellite	Year	Period	Max % cloud
Region 701	L5	1985-1999, 2003-2011	June 15 - November 15	20 - 90
	L7	2002, 2012		
Amazon (zone mountainous high jungle)	L5/L7	2000-2001		
	L8	2013-2021		
	L9	2022-2024		
Region 702	L5	1985-1999, 2000, 2003-2011	June 1 - October 31	10 - 80
	L7	2002, 2012		
Amazon (zone of plains lowland jungle)	L5/L7	2001		
	L8	2013-2021		
	L9	2022-2024		
Region 703	L5	1985-2001,2003-2011	April 1 - August 30	30 - 95
	L7	2002,2009,2010,2012		
Andes (basin) of the Atlantic)	L8	2013-2021		
	L9	2022-2024		
Region 704	L5	1985-2001,2003-2011	April 1 - August 30	30 - 95
Andes (basin) of the Pacific and Titicaca)	L7	2002,2009,2010,2012		
	L8	2013-2021		
	L9	2022-2024		
Region 705	L5	1985-1999	January 1 - December 31	20-90
	L7	2000-2012		
(Equatorial B.S. and coastal desert)	L8	2013-2021		
	L9	2022-2024		

Source: Own elaboration

3.2. Classification variables or feature space

Variables were calculated (*feature space*) from the annual mosaic representing the inputs of the classification process. The Landsat bands, along with the classification variables, are consolidated into raster files composed of 156 bands in total.[6] which include: spectral landsat bands, spectral indices, fractional and texture information derived from them, and indices of spectral fractions.

Additionally, 7 static variables were used: HAND, shademask2, slppost, altitude, slope, latitude and longitude; which helped to classify classes that are spectrally very similar but are differentiated by these topographic aspects.

The calculation was applied to the images available each year. Statistical reducers are used to generate the values for each pixel. The process is represented in Figure 6. These reducers are:

- Median: Median[7]of all available values in the annual mosaic for that location (pixel).
- Median dry season: Calculation of the statistical median applied to the pixels of the 25th quartile (with the lowest values) of NDVI (proxy of dry season).
- Median wet season: Calculation of statistical median applied to the pixels of the 75th quartile (with the highest values) of NDVI (proxy of rainy season).
- Amplitude: Extent of variation between all available pixels in the annual mosaic.
- Standard deviation: Standard deviation of the values of all available pixels in the annual mosaic for a given location.
- Minimum: Lowest value of all available pixels in the annual mosaic in a location determined.
- Maximum: Highest value of all available pixels in the annual mosaic in a location determined.
- Minimum of the dry period: Calculation of the lowest value of all available pixels from the images in the quartile with the lowest NDVI values (dry season proxy).
- Minimum of the wet period: Calculation of the lowest value of all available pixels from the images of the quartile with the highest NDVI values (rainy season proxy).
- Maximum of the dry period: Calculation of the highest value of all available pixels from the images of the quartile with the lowest NDVI values (dry season proxy).
- Maximum of the wet period: Calculation of the highest value of all available pixels from the images in the quartile with the highest NDVI values (rainy season proxy).
- QMO of the dry period: The highest value that the band has in the evi2 index in the dry season.
- QMO of the rainy period: The highest value that the band has in the evi2 index in the wet season.

[6]Available for download on the MapBiomas Peru platform.
[7] The median is the value that separates the upper half from the lower half of a data sample or population.Documentationof the tool in Google Earth Engine.

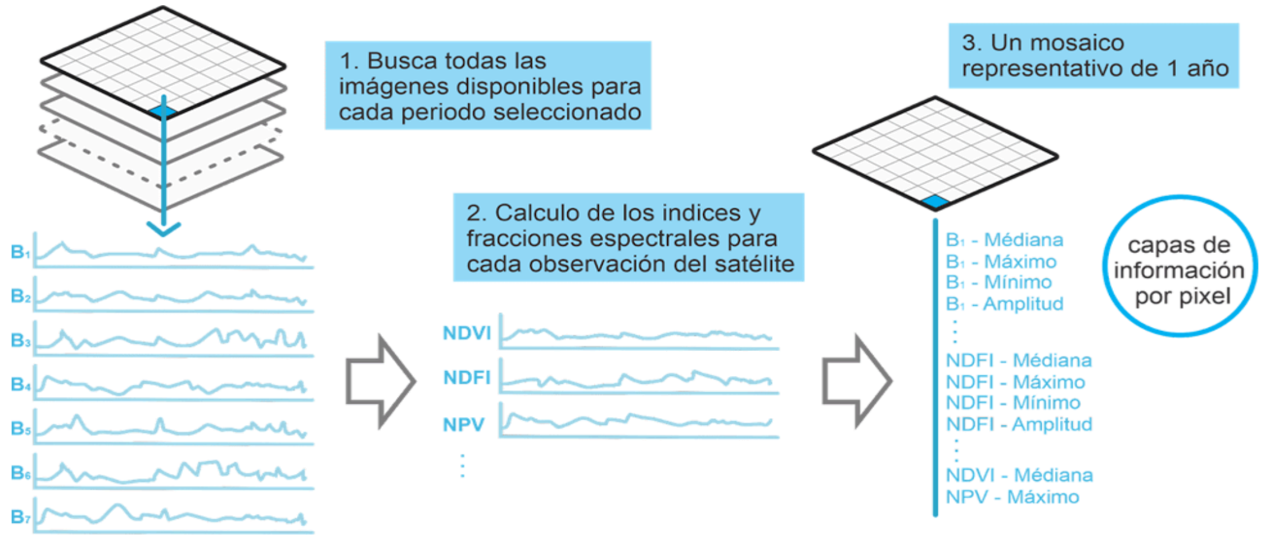

Figure 6. Process of calculating bands that make up the annual Landsat image mosaics.

Table 4 shows the complete list of bands for the final mosaics or feature *space*Each band represents a training variable of the classifier.

Table 4. Description of bands and variables used for Collection 2 MapBiomas Peru.

Type	Name	Formula	Description	Reducer[8]											Quality Band*[9]	
				Median	Median_dry	Median_wet	amp	stdDev	Min	Max	Dry_min	Dry_max	Wet_min	Wet_max	Dry_qmo	Wet_qmo
Band	blue	B1 (L5 y L7); B2 (L8)	Blue visible spectrum	X												
	green	B2 (L5 y L7); B3 (L8)	Green visible spectrum	X	X				X				X		X	X
	red	B3 (L5 y L7); B4 (L8)	Red visible spectrum	X	X	X			X		X	X		X	X	
	nir	B4 (L5 and L7); B5 (L8	Near infrared	X	X	X		X	X						X	X
	swir1	B5 (L5 y L7); B6 (L8)	Shortwave infrared 1	X	X	X			X			X	X	X	X	X
	swir2	B7 (L5); B8 (L7); B7(L8)	Shortwave infrared 2	X	X	X			X		X			X	X	X
Indices	ndvi	(nir - red)/(nir + red)	Normalized Difference Vegetation Index	X	X	X	X	X								
	evi2	(2.5 * (nir - red)/(nir + 2.4 * red + 1)	Modification of the Enhanced Vegetation	X	X	X	X	X								

[8] Each product calculated with the statistical reducers makes up a band of the integrated product.
[9]It combines all the images in a collection, using a quality band (evi2) as the pixel sorting function.

			Index (EVI) that only uses NIR and Red, ignoring the blue band.													
	ndwi_gao	(nir - swir)/(nir + swir)	Normalized difference water index (GAO)	X	X	X	X				X		X	X		X
	ndwi_mcfeeters	(green - nir)/(green+ nir)	Normalized difference water index (mcfeeters)	X			X									
	ccv	(nir/green) - 1	Relationships between near-infrared and green bands	X	X	X										
	hallcover	(-red * 0.017) - (nir * 0.007) - (swir2 * 0.079) + 5.22	Land cover spectral index	X												
	at	(blue - green)/(blue + green)	Photochemical reflectance index (*Photochemical Reflectance Index*)	X	X											
	clay	(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}))	Entropy in the Blue band	X												
	nuance	$UNTL*(1-\sqrt{(NDWIi-aNDWI)2+(NDVIi-aNDVI)2+(NDBIi-aNDBI)2})$	Normalized Composite Index of Urban Areas	X												
	ndsi	(green-swir1)/(green+swir1)	Normalized Differential Snow Index	X					X							
	water	(swir2 / swir1)	Color Alteration Index	X					X	X			X			
	The	((2 * green) - red - blue) / ((2 * green) + red + blue)	Green leaf index	X	X				X	X						

	man	(green - nir) / (green + nir)	Normalized Difference Water Index	X	X	X				X						
	ndbi	(swir1 - nir) / (swir1 + nir)	Cumulative normalized difference index	X	X				X	X						
	ndgb	(green - blue) / (green + blue)	Normalized difference Green Blue	X	X	X		X		X						
	ndmi	(nir - swir1) / (nir + swir1)	Normalized Humidity Difference Index	X	X					X						
	mdmir	(swir1 - swir2) / (swir1 + swir2)	Normalized difference mean infrared index	X		X		X	X	X						
	ndrb	(red - blue) / (red + blue)	Normalized Difference Red Blue			X		X	X							
	ndsi2	(swir1 - nir) / (swir1 + nir)	Normalized Soil Difference 1	X	X	X			X	X						
Fraction MOTHE R[10]	teacher		Fractional abundance of green vegetation within the pixel	X			X	X								
	npv		Fractional abundance of non-photos ynthetic vegetation within the pixel	X				X								
	soil		Fractional abundance of soil within the pixel	X			X	X								
	shade	100 - (gv + npv + soil +cloud)	Fractional abundance of shadow within the pixel	X												
	snow		Fractional abundance of snow within the pixel	X					X							

[10]MME = Spectral Mixture Model

	cloud		Fractional abundance of clouds within the pixel	X												
MEM Index	gvs	gv / (gv + npv + soil + cloud)	Green vegetation normalized by shade	X	X	X		X								
	money	(gvs - (npv + soil)) /(gvs + (npv + soil))	Normalized difference fraction index	X	X	X	X	X								
	heads	(gv+npv -soil) /(gv+npv + soil)	Savanna ecosystem fraction index	X	X			X								
	wefi	((gv+npv)-(soil+shade))/(gv+npv)+(soil+shade)	Wetland ecosystem fraction index			X	X	X								
	UN	((gv+shade) - soil) / ((gv+shade) + soil)	Index based on gv, shade, and soil fractions		X			X								
	ndfib	GV-(NPV+Soil+Snow)/ GV+(NPV+Soil+Snow)	Adaptation of the NDFI for the Andes	X			X									
Static and/or topographic variables	shademask2		Shadow map	---												
	slppost		Stratified Slope													
	altitude		Altitude													
	slope		Earring													
	latitude		Latitude													
	longitude		Length													
	HAND (Height Above the Nearest Drainage)	hand30_100 hand30_1000 hand30_5000 hand90_1000 water_HAND_0m water_HAND_10m water_HAND_1m water_HAND_2m water_HAND_5m	Index - Height above the nearest drain													

3.3 Classification

3.3.1. Legend

The semi-automated classification was developed using a random forest methodology. The collection specifically maps 26 classes: 1.1. Forest (ID 3), 1.2. Dry forest (ID 4), 1.3. Mangrove (ID 5), 1.4. Floodplain forest (ID 6), 2.1. Swamp or floodplain grassland (ID 11), 2.2. Grassland / herbaceous vegetation (ID 12), 2.3. Rocky outcrop (ID 29), 2.4. Scrubland (ID 66), 2.5. Coastal hill (ID 70), 2.6. Other non-forest formation (ID 13), 3.1. Pasture (ID 15), 3.2. Agriculture (ID 18), 3.2.1. Oil palm (ID 35), 3.2.2. Rice (ID 40), 3.2.3. Other crops (ID 72), 3.3. Forest plantation (ID 9), 3.4. Agricultural mosaic (ID 21), 4.1. Beach (ID 23), 4.2. Urban infrastructure (ID 24), 4.3. Mining (ID 30), 4.4. Coastal saltworks (ID 32), 4.5. Salt flat (ID 61), 4.6. Other natural area without vegetation (ID 68), 4.7. Other anthropogenic area without vegetation (ID 25), 5.1. River, lake or ocean (ID 33), 5.2. Aquaculture (I9D 31), 5.3. Glacier (ID 34).

Table 5. General legend of land cover and land use in Collection 3

ID	Class	Hexadecimal code	Color	Natural/anthropogenic
1	1. Forest formation	#1f8d49		
3	1.1. Forest	#1f8d49		Natural
4	1.2. Dry forest	#7dc975		Natural
5	1.3. Mangrove	#04381d		Natural
6	1.4. Flooded forest	#026975		Natural
10	2. Non-forested natural formation	#d6bc74		
11	2.1. Swamp or flooded Grassland	#519799		Natural
12	2.2. Grassland / Herbaceous	#d6bc74		Natural
29	2.3. Rock outcrop	#ffaa5f		Natural
66	2.4. Scrubland	#a89358		Natural
70	2.5. Fog oasis	#be9e00		Natural
13	2.6. Other non-forest formation	#d89f5c		Natural
14	3. Agricultural area	#ffefc3		
15	3.1. Pasture	#edde8e		Anthropogenic
18	3.2. Agriculture	#e974ed		Anthropogenic
35	3.2.1. Oil palm	#9065d0		Anthropogenic
40	3.2.2. Rice	#c71585		Anthropogenic
72	3.2.3. Other crops	#910046		Anthropogenic
9	3.3. Planted forest	#7a5900		Anthropogenic
21	3.4. Mosaic of agriculture and pasture	#ffefc3		Anthropogenic
22	4. Non vegetated area	#d4271e		
23	4.1. Beach	#ffa07a		Natural
24	4.2. Urban infrastructure	#d4271e		Anthropogenic
30	4.3. Mining	#9c0027		Anthropic
32	4.4. Coastal salt flat	#fc8114		Natural
61	4.5. Salt flat	#f5d5d5		Natural
68	4.6. Other natural non vegetated area	#E97A7A		Natural
25	4.7. Other non vegetated area	#db4d4f		Anthropogenic
26	5. Water body	#2532e4		
33	5.1. River, lake or ocean	#2532e4		Natural
31	5.2. Aquaculture	#091077		Anthropogenic
34	5.3. Glacier	#93dfe6		Natural
27	6. Not observed	#ffffff		Not defined

Source: Own elaboration

As part of the process of describing the land cover classes for each country, a table was created to correlate the MapBiomas legend classes with the Vegetation Cover Map (MINAM, 2015). A workshop was also held with various state and/or educational entities to facilitate the exchange of information and the approval of the legend. The following descriptive report and interpretation criteria (Table 6) for each class in the MapBiomas Peru legend, within the context of Peru's land cover, are presented.

Table 6. Descriptive report for the MapBiomas Peru legend

	MapBiomas CLASS (ID)	Biome	Approval VEGETATION COVER MAP (MINAM, 2015)	Class description	Interpretation criteria (RGB 543)
1	Forest (ID:3)	Amazon	Lowland and montane forests; Forest plantation Low and high terrace forests; White sand sclerophyllous vegetation (varillal); High and low hill forests; Pacales; Forest plantation	Dense tree cover with evergreen foliage, predominantly arboreal in form, reaching up to 45 m in height in the Lower Amazon region (up to 500 m above sea level) and decreasing in height as the altitude reaches 3800 m above sea level in the Upper Amazon region. Located on terraces, hills, and mountains. Includes forests with pure paca and paca stands, as well as forest plantations. Excludes dense forests subject to permanent or seasonal flooding established on poorly drained soils.	- In dense forests: high roughness; dark green hue; - In sparse forests: low roughness; light green tone;
		Andes	Relict forests; Dry mountain forests; Subhumid mountain forests;	Tree cover is of two types: the very humid forests of the northern part of the country and the relict forests of the central and southern regions. The former are evergreen, dense, and with trees that reach up to 20 m in height. The relict forests are characterized by scattered, low-growing trees (up to 10 m) and are located on almost inaccessible mountain slopes between 2800 and 3800 meters above sea level or in areas bordering agricultural activity.	- In sparse forests: low roughness; light green tone; - In semi-deciduous forests: medium roughness; green-purple tones.
		B. S. Ecuatorial	subhumid mountain forest	Small tree cover in the upper part of Tumbes between 600 and 1200 meters above sea level. The vegetation is made up of a mixture of species typical of the dry forest with the inclusion of some species typical of the Amazon rainforest, where evergreen species predominate over deciduous ones.	- High roughness; dark green hue in wet periods or dark purple in dry periods;
	Dry forest (ID: 4)	Amazon	Semi-deciduous mountain forests, mountain forest	This type of forest is characterized by tree and shrub vegetation adapted to markedly seasonal climatic conditions. It may have a discontinuous canopy, with deciduous species that lose their leaves seasonally. It harbors high biodiversity and endemic species.	- Sparse forests, of medium roughness, when they lose their leaves tend to have a fuchsia-orange hue.
		Andes	Inter-Andean xeric savannas; Inter-Andean xeric forests;	Dry inter-Andean tree cover of scattered trees, distributed in deep inter-Andean valleys and on their slopes. It includes low shrubby trees (< 8 m tall) with deciduous foliage during the dry season.	- Sparse forests, varying in texture and color according to latitude. To the north they tend towards a brownish-green tone, towards the center and south, brownish-pink tones.

		B. S. Ecuatorial	Dry savanna forest; Riparian dry forest; Piedmont dry forest; Hillside dry forest; Low hill dry forest; High hill dry forest; Mountain dry forest	Tree cover of small stature, generally deciduous with a shrubby-herbaceous understory. It includes a) dry savanna-type forests dominated by "algarrobo" type trees (5-8m high), located from near sea level up to 800 m above sea level; b) dry hill and mountain forests, of semi-dense formation with a canopy height up to 12 m, and which cover an altitude between 400 and 2000 m above sea level; and c) dry riparian forests dominated by "algarrobo" type trees (up to 12 m high) in a dense form due to the better humidity conditions due to their location in the areas adjacent to watercourses.	- In sparse savanna forests: low roughness; pinkish-purple hue; - In semi-dense hill and mountain forests: high roughness; green hue in wet periods or dark purple in dry periods:
		Coastal desert	Riparian dry forest	Tree cover located in the areas adjacent to watercourses, dominated by "algarrobo" type trees (up to 12 m high) in a dense manner due to the better humidity conditions.	- Areas near the water with a deep green to dark green-purple hue.
	Mangrove (ID: 5)	B. S. Ecuatorial	Mangrove	Dense evergreen tree cover that grows in saline or brackish coastal waters.	- Uniform texture and color characteristics, from dark green to light green.
	Flooded forest (ID:6)	Amazon	Floodplain palm forest (aguajal); Basimontan and flood terrace forests; Meandering plain forest	Tree cover located on the large alluvial plain and terraces that are periodically or permanently flooded. It grows in poorly drained soils with abundant, slowly decomposing organic matter. Palm trees dominate this forest, accompanied by trees such as "renacales" and "pungales".	- They have uniform texture and color characteristics, tending towards green-purple.
2	Swamp or flooded grassland (ID: 11)	Amazon	Hydrophytic grassland; Hydrophytic palm savanna	Vegetation cover located in the floodplain, such as grasslands and hydrophytic savannas. Characterized by soils with hydromorphic substrates, which are flooded for a long period of the year, and where, as the flood level recedes, a dense carpet of low-growing herbaceous vegetation emerges. It also includes the hydrophytic palm savannas in the Pampas de Heath.	- Natural wetlands with variations in edge and color (presence of sediments); Proximity to watercourses.
		Andes	Bofedal	Evergreen, compact, cushion-like vegetation cover found in the bottoms of fluvio-glacial valleys, volcanic cones, and high Andean plains or terraces. These areas are found above 3800 meters above sea level, on permanently flooded and poorly drained soils. Also known as bofedales.	- Natural wetlands near bodies of water (lagoons). - Annual variations in extent. - They tend towards green-purple.
		B. S. Ecuatorial Coastal desert	Lagoon; Estuary; Virillá Estuary; Coastal Wetland	Vegetation cover where herbaceous vegetation predominates, subject to periodic flooding by fresh, brackish, or salt water. Includes marshy areas temporarily flooded by the El Niño phenomenon.	- Annual variations in extent; colors vary according to humidity between bright green-purple-brown.

Grassland / Herbaceous (ID: 12)	Amazon	Jalca;Páramo;Pajonal andino	In the Upper Amazon region, the vegetation is considered herbaceous. At the transitional boundary with the Andes, it includes high-Andean grass vegetation in jalca and páramo ecosystems.	- Bright pink color - Low roughness - Color difference per period (dry: fuchsia / wet: green).
	Andes	Andean grassland	Grasslands composed of vigorous, low-growing grasses and puna turf, almost at ground level. This vegetation is found approximately between 3000 and 4800 meters above sea level.	- Intense pink, it blends in with bare soil (dry grass). - Near the wetland area it is a very light green or yellow.
Rocky outcrop (ID:29)	Andes	Area with little or no vegetation;	Naturally exposed rocks without soil cover, with rock-dwelling vegetation and steep slopes. They are found mainly in periglacial zones or stone forests.	-Pinkish-purple in different shades, strong presence of shadows due to the slopes
Scrubland (ID:66)	Andes	Shrubby scrubland; High-altitude shrubby scrubland; Montane sclerophyllous scrubland	Vegetation cover with a predominance of shrubs (scrubland) and the presence of herbaceous plants, from approximately 1500 to 3800 meters above sea level, up to the limit of the natural grasslands. Three subtypes of scrubland are distinguished according to climatic conditions: Scrublands above 1500 meters above sea level (northern part of the country) are influenced by the moisture conditions of the arid soil; those of the middle and upper levels, between 2500 and 3800 meters above sea level, are dominated by deciduous and evergreen shrubs in sub-humid conditions; and those of the upper level, between 2000 and 3500 meters above sea level (central part of the country and inter-Andean valleys), 3500 and 3800 meters above sea level (western central part of the country), and between 3600 and 3800 meters above sea level (southern part of the country), where in all of them there is better moisture conditions and lower temperatures.	-Low to medium roughness. Intense pink color. May have color differences in dry and rainy periods. Low density of trees or only small shrubs.
	Equatorial dry forest	Shrubby scrub	The predominant vegetation is xerophytic scrubland, composed of shrub communities interspersed with columnar cacti and ephemeral grasslands. The vegetation is sparse (30-60%), isolated, xerophytic, thorny, and stunted, with a relatively undiversified flora but high endemism. Shrubs and cacti reach up to 4 meters in height. It is found primarily in the interior of valleys, on steep terrain between 300 and 2000 meters above sea level.	
	Coastal Desert	Cardonal	Two types of vegetation cover are distinguished: a) xeric scrubland in the southern zone, a sparse xerophytic cover made up of shrub associations interspersed with columnar cacti and ephemeral herbaceous vegetation, located on steep terrain up to 2000 meters above sea	- Low to medium roughness. Intense pink color. May have color differences between dry and rainy periods. Low tree density or only small

					level; b) tillandsia vegetation, which is scattered along the entire coastline, with a higher concentration in the south. It is a single-species plant formation, composed of creeping plants of the genus Tillandsia.	shrubs. - Tillandsial displays purple colors in desert areas.
	Fog oasis (ID:70)		Coastal desert	Lomas	The hills form a special type of seasonal vegetation (developed due to dense winter fogs) with different types of cover: trees, shrubs, and herbaceous plants. They are located at altitudes ranging from 100 to 1000 meters above sea level. The tillandsia scrubland is found scattered along the entire coastline, with a higher concentration in the south. It is a single-species plant formation, composed of creeping plants of the genus Tillandsia.	- The hills have dark colors of purple-burgundy-brown-green tones with medium roughness. - Tillandsial displays purple colors in desert areas.
	Other non-forest formation (ID: 13)		Amazon	Area without Amazon rainforest	Vegetation cover with a predominance of shrubs and some dwarf trees with leathery leaves, located on the plateaus at the top of the Cordillera El Cóndor, above 1800 meters above sea level. They are also found in high mountain areas, above 3500 meters above sea level, in contact with the Andean grassland.	- Low to medium roughness. Intense pink color. May have color differences between dry and rainy periods. Low tree density or only small shrubs.
			Andes	Cardonal; Sclerophyllous and shrubby scrublands;	Areas dominated by shrubs, with the presence of herbs, grasses, or low-growing vegetation. Scattered shrubs may be found. This category also includes areas with specialized flora not classified in other categories.	- Low to medium roughness. Intense pink color. May have color differences between dry and rainy periods. Low tree density or only small shrubs.
3	Pasto (ID: 15)		Amazon Andes	Area without Amazon rainforest Coastal and Andean agriculture	Areas of pasture, planted or natural, linked to livestock activity.	- In the lower Amazon region, it displays intense orange and yellow colors. - In the high Amazon and Andes it presents low green colors and shades of yellow, melon.
	Agriculture (ID: 18)	Oil palm (ID: 35)	Amazon	Area without Amazon rainforest	Areas where the original cover has been modified or replaced by permanent oil palm crops, mainly of the species Elaeis guineensis.	- Intense light green colors of delimited geometric structures.
		Rice (ID:40)	Amazon Coastal desert	Area without Amazon rainforest Coastal and Andean agriculture	Areas where the original cover has been modified or replaced by permanent rice crops, mainly of the species Oryza sativa.	- Delimited geometric structures, intermittency between light greens and bodies of water.
		Other crops (ID: 72)	Coastal desert	Coastal agriculture	Area of annual, temporary and perennial crops.	- Intense purple and light green colors

	Planted forest (ID: 9)	Andes	Forest plantation	This coverage corresponds to all areas forested with exotic species (Pinus sp. and Eucalyptus sp.) located on lands suitable for forestry in the Andean region, from approximately 3000 to 3800 meters above sea level. Trees have been established in these areas, forming a forest stand with a defined design, size, and species to meet specific objectives such as productive plantation, etc.	- Light green color.
	Mosaic of agriculture and pasture (ID: 21)	Amazon Andes B.S. Ecuatorial Coastal desert	Area without Amazon rainforest Coastal and Andean agriculture	Areas of agricultural use, where it was not possible to distinguish between agriculture and pastureland. In the Equatorial and Coastal Desert biomes, cereal, vegetable, and fruit crops predominate. It also includes green areas in urban zones. In the Amazon biome, land use is predominantly changing towards livestock farming and the cultivation of cereals and oil palm. In the Andes biome, livestock farming and the cultivation of cereals, tubers, and vegetables predominate, located in the valley bottoms and on the slopes of inter-Andean valleys.	- They feature mixed colors of fuchsia, burgundy and green with light tones. - Agro-industrial plantations of light green color similar to the fallow land and young secondary forests. - Small size.
	Beach (ID: 23)	Amazon Andes	Sandbar	Areas with sandy cover or no vegetation that is transported by rivers.	- Pink-purple in different shades
	Urban infrastructure (ID: 24)	Amazon Andes B.S. Ecuatorial Coastal desert	Urban area; Infrastructure	This unit consists of the spaces covered by Urban infrastructure and all associated green areas and communication routes. Excludes small-scale rural infrastructure that is not visible at the resolution of Landsat images.	- Intense pink. In some cases white (reflective infrastructure).
4	Mining (ID: 30)	Amazon Andes B.S. Ecuatorial Coastal desert	Mining center; area without Amazon rainforest	It includes the areas where materials are extracted or accumulated from open-pit mining and river mining.	They feature intense fuchsia, burgundy, and purple colors, as well as turquoise bodies of water (salt extraction).
	Coastal Saltflat (ID: 32)	Coastal desert	Coastal Wetland	Stationary natural areas and product of the accumulation of salts due to evaporation processes and/or infiltration of seawater on the coast.	- Light blue or turquoise tones
	Salt flat (ID:61)	Andes	Not applicable	A high-altitude Andean wetland located more than 3,000 meters above sea level where the rate of evaporation exceeds that of precipitation. Salts are transported primarily by surface runoff, wind, or groundwater, and are then deposited and accumulate. Occasionally, lagoons or even springs may form within the salt flats.	- Light blue and blue coloration with the presence or absence of water respectively

	Other natural non vegetated area (ID:68)	Amazon	Areas outside the Amazon rainforest	Natural areas with little or no vegetation. This includes landslides on hillsides caused by tectonic activity, heavy rains, etc.	- Pinkish-purple in different shades, including white areas in drier zones
		Andes	Areas without Amazon rainforest	Natural areas with little or no vegetation not mapped in other classes. Includes exposed soils, alluvial fans, riverbanks, volcanic deposits, etc.	- Pinkish-purple in different shades, including white areas in drier zones
		B.S. Ecuatorial	Arena benches	Natural areas with little or no vegetation not mapped in other classes. This includes deserts, alluvial fans, arid hills, etc.	- Pinkish-purple in different shades, including white areas in drier zones
		Coastal desert	Arena benches Coastal Desert	Natural areas with little or no vegetation not mapped in other classes. On the coast, this includes sandbanks, alluvial fans, dunes, desert, foothills located in the transition between the coastal and Andean biomes, etc.	- Pinkish-purple in different shades, including white areas in drier zones
	Other non vegetated area (ID: 25)	Amazon Andes B.S. Ecuatorial	Area without Amazon rainforest	Anthropogenic areas with little or no vegetation. This includes crop transition areas, clearing, exposed rock/soil in areas of anthropogenic intervention, urban and road expansion areas, and dirt roads.	- Pinkish-purple in different shades, including white areas in drier zones. Variation in roughness.
5	River, lake or ocean (ID: 33)	Amazon Andes B.S. Ecuatorial Coastal desert	Lagoons, lakes and oxbow lakes River	It is any body of water found on the Earth's surface, whether natural or artificial. It includes rivers, lakes, dams, reservoirs, and other bodies of water.	- Depending on the sediment content and the depth of the source, they could be black, dark blue, or light blue.
	Aquaculture (ID: 31)	B.S. Ecuatorial	Lagoons, lakes and oxbow lakes	Artificial bodies of water intended for shrimp farming using seawater. This structure consists of a series of adjacent pools and is therefore characterized by a regular geometric pattern.	- Typically black, but depending on the time of use they could also present different shades of blue or, in years without use, pink.
	Glacier (ID: 34)	Andes	Glacier	The ice and/or snow cover that forms in the Andes Mountains from 4,800 to 6,768 meters above sea level. It is a large mass of ice resulting from the accumulation, compaction, and recrystallization of snow over thousands of years. It is the main source of water resources for the country's river basins.	- Light blue and turquoise tones

Source: Own elaboration

3.3.2. Classification Regions

To facilitate the mapping of the diversity of landscapes within the study area, sixty-one (61) mapping or classification regions were defined. Each region was mapped independently for each year of the time series.

The regions were defined following ecosystem criteria and the occurrence of anthropogenic intervention, based on reference maps such as those mentioned in the section '*Other national mapping initiatives*The resulting regions are shown in Figure 7 and detailed in Table 7.

Table 7. Classification regions defined within the framework of the MapBiomas Peru project

	Mosaic region	Codes	Reason for separation
1	Region 701	70101	Northern transition zone with medium intervention, around Cajamarca
2		70102	Northern area of medium intervention around Amazonas
3		70103	Northern low-intervention zone around the Amazon
4		70104	Northern zone of little intervention around Alto Mayo and Colán
5		70105	Central zone of high intervention along San Martín, Huánuco, Pasco and Junín
6		70106	Central transition zone with little intervention. San Martín, Huánuco and Pasco
7		70107	Central zone with little intervention and many landslides
8		70108	Central transition zone with little intervention in Junín
9		70109	Central zone of high intervention in Junín
10		70110	Central area of medium intervention in Pasco
11		70111	Central transition zone with high intervention
12		70112	Central transition zone with little intervention around Otishi
13		70113	Southern high-intervention zone around Quincemil y Pillcopata
14		70114	Southern zone of little intervention around Manu and Bahuaja Sonene
15		70115	Southern transition zone with high intervention in Puno
16	Region 702	70201	Northern low-intervention zone around the Putumayo River
17		70202	Northern area of medium intervention around the Amazon and Nanay rivers
18		70203	Northern zone of little intervention around the Pastaza and Pacaya Samiria rivers
19		70204	Northern high intervention zone in Yurimaguas
20		70205	Central zone with little intervention due to Sierra del Divisor
21		70206	Central zone with little intervention and many landslides
22		70207	Pachitea high intervention central zone
23		70208	Central zone of minor intervention around the Imiria
24		70209	Central zone of high intervention in Ucayali
25		70210	Southern area of low intervention near Purús
26		70211	Southern zone of high intervention around Tambopata
27		70212	Northern zone of non-forested vegetation in continuity with Ecuador.
28	Region 703	70301	North-central area of the Atlantic slope above approximately 3800 meters above sea level, presence of glaciers and wetlands.
29		70302	Central zone of the Atlantic slope at approximately 3800 meters above sea level, presence of glaciers and wetlands.
30		70303	South-central area of the Atlantic slope above approximately 3800 meters above sea level, presence of glaciers and wetlands.
31		70304	Southern zone on the slope of Lake Titicaca (east) at approximately 3800 meters above sea level, presence of glaciers and wetlands.
32		70305	Northern area of the Atlantic slope, humid forests with intervention.
33		70306	North-central area of the Atlantic slope below approximately 3800 meters above sea level.
34		70307	Central zone of the Atlantic slope below approximately 3800 meters above sea level.
35		70308	Southern zone of the Atlantic slope below approximately 3800 meters above sea level.
36		70309	Southern zone of the Atlantic slope below approximately 3800 meters above sea level.
37		70310	Northern area of the Atlantic slope of dry forests and thorny mountains
38		70311	Northern area of the Atlantic slope that combines humid forests, scrubland and heavy human

			intervention
39		70312	Central-southern area of the Atlantic slope, dry forests and scrubland
40		70313	Southern area of the Atlantic slope, dry forests and thorny steppes
41		70314	Northern zone of the Atlantic slope, Andean humid forests in continuity with Ecuador

42	Region 704	70401	North-central zone on the Pacific slope, at approximately 800 meters above sea level, with glaciers and wetlands.
43		70402	Central zone of the Pacific slope at approximately 3800 meters above sea level, presence of glaciers and wetlands.
44		70403	Southern zone on the Titicaca slope (west) at approximately 3800 meters above sea level, with high levels of human intervention
45		70404	Southern zone of the Pacific slope below approximately 3800 meters above sea level. It borders the coast (Tacna, Moquegua, Arequipa).
46		70405	Northern area of the Pacific slope, presence of dry forests, borders the Equatorial Dry Forest.
47		70406	Northern area of the Pacific slope, area of regular agricultural intervention.
48		70407	Central zone of the Pacific slope below approximately 3800 meters above sea level.
49		70408	South-central area of the Pacific slope below approximately 3800 meters above sea level.
50		70409	Southern area of the Titicaca slope (west) at approximately 3800 meters above sea level. Presence of grasslands and wetlands
51		70410	Southern area of the Titicaca slope (west) at approximately 3800 meters above sea level. Presence of grasslands, wetlands, and glaciers.

52	Region 705	70501	Northern coastal area bordering Ecuador with mangroves and dry forests.
53		70502	Northern zone bordering Ecuador with the presence of tropical rainforest of Tumbes.
54		70503	Northern coastal area with dry forests and high urban and agricultural intervention.
55		70504	Sechura Desert with the presence of lagoons, salt flats and wetlands that emerge seasonally from the temporary impacts of the El Niño phenomenon on the area.
56		70505	Border area with Ecuador with the presence of dry forests and regular agricultural intervention.
57		70506	Transition zone from dry forest to the Andean region, with regular agricultural intervention.
58		70507	Central-northern coastal area, sporadic presence of dry forests and high agricultural intervention
59		70508	Central coastal area, little natural vegetation but high urban and agricultural intervention.
60		70509	Southern coastal area, little natural vegetation but high agricultural intervention. Presence of scrubland in transition zones towards the Andean region.
61		70510	Southern coastal area: little natural vegetation but high urban and agricultural development. Presence of scrubland in transition zones towards the Andean region.

Source: Own elaboration

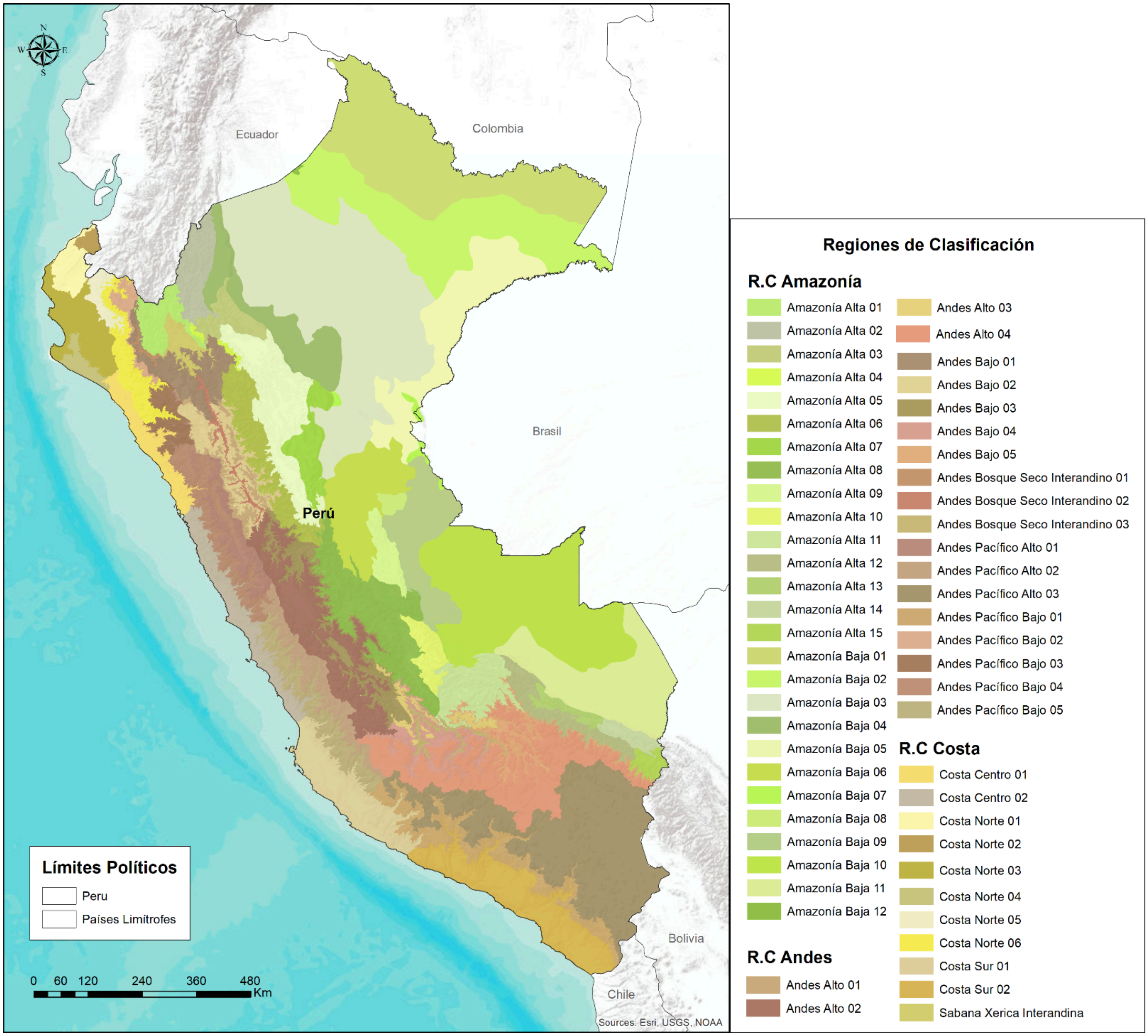

Figure 7. Map of regions of classification for Collection 3.0

3.3.3. Random Forest

Random forest[11]It is a classification method that uses a machine learning algorithm (*machine learning*and which reports high accuracy values, even in complex scenarios due to their heterogeneity. The conceptual basis of Random Forest is based on what Turner and Ghosh (1996) found when demonstrating that the product resulting from the combination of multiple classifiers achieves high accuracy. Random Forest uses training data to build multiple decision trees from which a class is assigned to each pixel. Random Forest has gained importance in recent years due to its robustness against noise and outliers. The Random Forest algorithm is part of the classifier package of *machine learning* available on the Google EE platform.The methodology applies a pixel-based classification criterion.

One of the parameters that Random Forest requires is a defined number of trees. It also requires a list of variables (see the "Variables" section) and training data (see the "Spectral Collection" section). For Collection 3.0, the number of trees varied according to the needs and characteristics of each classification subregion.

3.3.4. Sample collection

The classification method used was random forest and used different sample sources depending on the region to be classified.

For mosaic regions 701, 702 and 703, a collection of stable samples (same class throughout the time series) was carried out for each of the categories of the legend that was being sought mThe data was extracted from the MapBiomas Amazonia products. A preliminary classification for the 40-year period was then generated. Stable samples (for 40 years) were extracted from this data to be used as input for a new classification. The interpreter contributes by excluding and/or including samples to improve the classification.

For mosaic regions 704 and 705, available national references were used. The process began with the homologation of MapBiomas classes with the classes of the national ecosystem map. Then, a random selection of samples per class was made within each classification region, assuming a false stability of these points over the years of analysis, to obtain a preliminary classification. Based on this preliminary result, and with the participation of the interpreter, unstable samples were excluded. As in the first case, the random selection of points was balanced according to the extent of each class within that classification region. Optionally, additional samples were manually included and designated supplementary *samples,*using the geometry creation tools directly in Google EE.
Table 8 presents the summary of stable samples used by region as input for the 40 to 60 trees applied to the classifier.

Table 8. Parameters used in the Random Forest classifier

[11] Leo Breiman, “Random Forests,” *Machine Learning* 45, no. 1 (October 1, 2001): 5–32, https://doi.org/10.1023/A:1010933404324

Mosaic region	Classification region	Number of stable samples exported		Number of trees Random Forest
		Minimum	Maximum	
Region 701	70101 a 70115	Between 800 and 3000	Between 4000 and 5000	50
Region 702	70201 a 70211	Between 500 and 2500	Between 3000 and 5000	50
Region 703	70301 a 70314	Between 300 and 500	Between 4000 and 5000	50 and 60
Region 704	70401 a 70408	Between 300 and 500	Between 4000 and 5000	60
Region 705	70501 a 70510	Between 100 and 500	Between 3000 and 5000	50

Source: Own elaboration

3.3.5. Cross-cutting themes

The various classification tests revealed a limitation in differentiating certain classes, so the decision was made to classify them separately. These classes are called Cross-Cutting Themes and are mapped using binary classification algorithms (class of interest and "Not Observed" class).

This strategy was applied, within the context of Peru, for the following classes:

- Mangrove (ID = 5);
- Flooded forest (ID = 6);
- Planted forest (ID = 9);
- Swamp or Flooded Grassland (ID = 11);
- Pasture (ID = 15);
- Agriculture (ID = 18);
- Mosaic of agriculture and pasture (ID = 21);
- Beach(ID = 23)
- Infrastructure (ID = 24);
- Mining (ID = 30);
- Aquaculture (ID = 31);
- Coastal Salt flat (ID = 32);
- Oil palm (ID = 35);
- River, Lake and Ocean (ID = 33)*
- Glacier (ID = 34)*
- Rice = (ID = 40)
- Salt flat (ID = 61)
- Fog oasis (ID = 70)

The details of each methodology can be found in the appendices of each cross-cutting theme.

*Cross-cutting classes that have been mapped in other initiatives such as MapBiomas Agua

3.4. Post-classification

The preliminary classification result was subjected to the application of a sequence of filters in order to reduce temporal inconsistencies and reduce classification noise smaller than the minimum mapping unit.[12]and fill information gaps. The post-classification process in this collection does not follow a

[12] 5 pixels = approximately half a hectare

specific order in the application of filters; their sequence was determined by the needs of each classification region, and repeated use of filters was even facilitated. Exceptions were also included within each filter, such as excluding certain years and classes. All these tools were implemented on the Google EE platform using scripts written in JavaScript. Each of these tools is presented in greater detail below. A description of how these filters were adapted by country can be found in the national appendices.

3.4.1 Gap Fill

Certain areas of Peruvian territory are characterized by atmospheric and climatic conditions that result in an almost permanent presence of clouds throughout the year in various parts of the territory. As a result, the composition of annual mosaics contains pixels without observations or data (*No data*).

The gap fill filter has the ability to reduce these residual gaps by assigning values to pixels without data due to absences of satellite observation ("gaps").

Pixels in classifications with no data ("gaps") are replaced with the nearest temporally available value. When a "future" pixel lacks a value (no data), the Gap Fill filter assigns it the value of the year closest to it (Figure 8). This filter reviews the series, first filling gaps by scanning from "back to front," where gaps are filled with data from the years immediately preceding the year with no data. If any gaps remain, they are filled with data from the immediately preceding year. For each pixel whose value was filled using this filter, the change is recorded in a metadata file, which records the pixel's year (history).

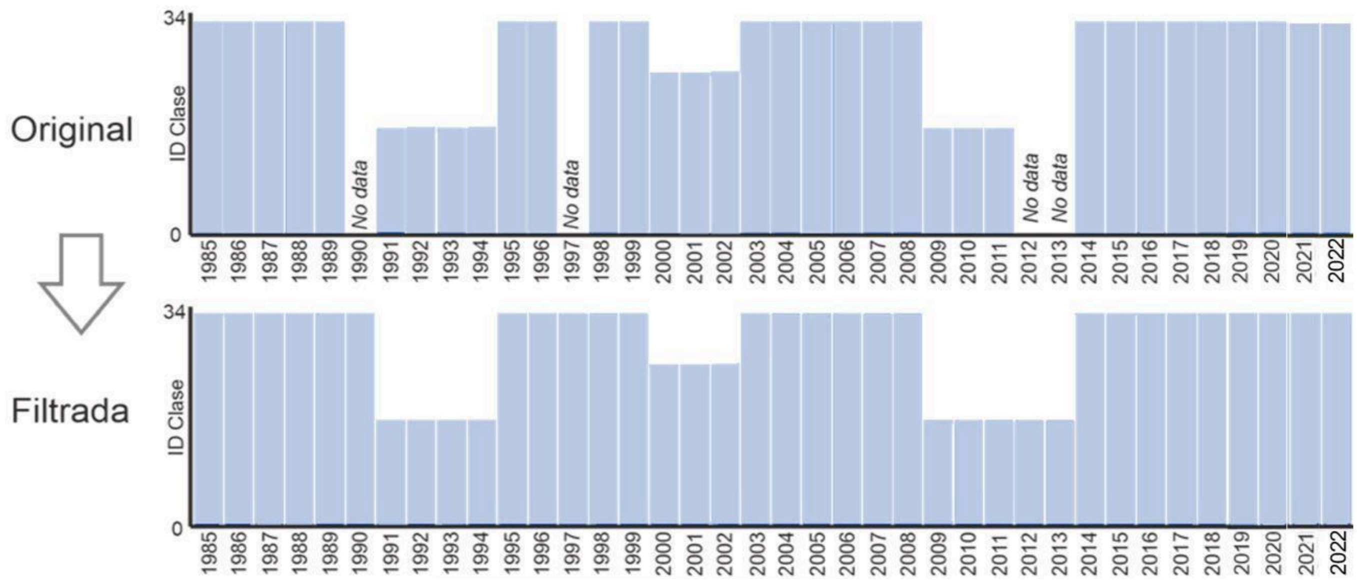

Figure 8. Functionality of the Gap Fill filter

3.4.2 Temporal Filter

The temporal filter examines the value of each classified pixel in relation to its value in consecutive temporal classifications. It does this using a one-way moving window that considers classification sequences of 3 to 5 years and identifies disallowed temporal transitions. The temporal filter is applied to every pixel in every year of the collection.

Depending on the year the rule will modify, there are three types of rules:

- General Rules (GR). Applied to pixels in intermediate positions within 3- to 5-year sequences. This rule applies only in cases of temporal inconsistency; for example, when sequences of consecutive years have identical values except for the central pixel. In these cases, the filter will modify the value of the central pixel to maintain consistency with the preceding and following pixels. For 3-year sequences, there is only one central position or intermediate year option. For 4- or 5-year sequences, there are two or three central position alternatives. This rule modifies the classification values for the years 1986 to 2023.
- First-year rules (PR). Applied only to the first year of the time series. This rule modifies the classification values for the year 1985.
- Last-Year Rules (RU). Applied to the last year of the ranking. This rule modifies the ranking values for the year 2024.

In this way, temporal filters reduce information gaps and temporal inconsistencies or changes that are not possible or permitted (Figure 9). For example, if in three consecutive years a pixel has the following values: Forest Formation > Non-Vegetated Area > Forest Formation, the filter will correct the intervening year. This case is a typical classification error due to the presence of cloud haze in the mosaic of the intervening year.

The decision to choose the size of the time window was made by each country according to the needs and characteristics of its land cover and land use by subregion and/or cross-cutting theme. See more details in the respective country appendices.

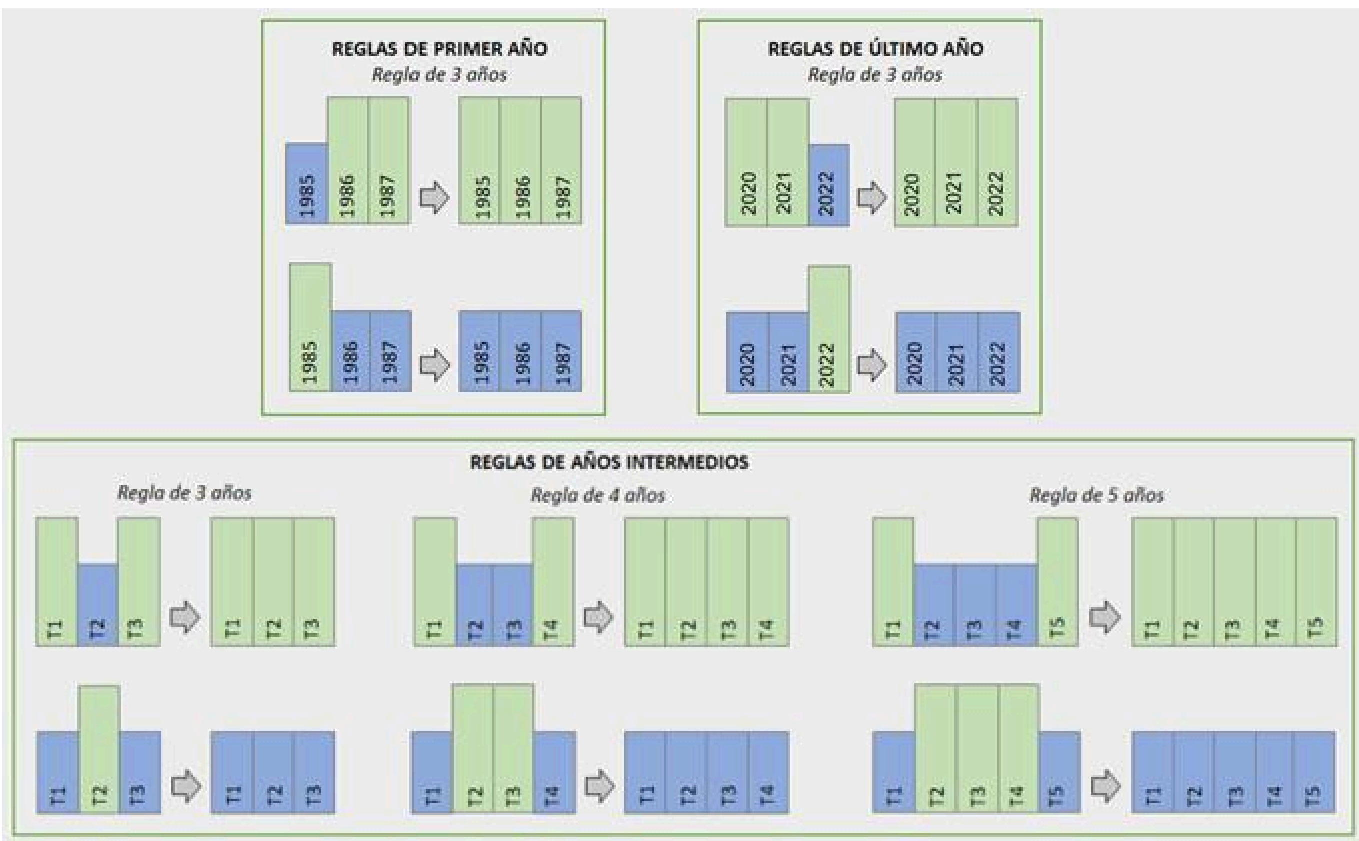

Figure 9. Functionality of the time filter

3.4.3 Spatial Filter

The spatial filter is based on the GEE's native "connectedPixelCount" function. This function locates connected pixels (neighbors) that share the same value using a moving window. Only pixels that do not share a connection with a predefined number of identical neighbors are considered isolated pixels. In the case of MapBiomas Amazonia, the minimum mapping unit was defined as 0.5 ha (5 pixels). Consequently, at least five connected pixels were required to meet the minimum connection criterion. Thus, the spatial filter smooths out local differences by eliminating isolated or edge pixels smaller than 0.5 ha, increasing the spatial consistency of the ratings (Figure 10). It should be noted that some classification regions had exceptions to the 3-pixel minimum unit.

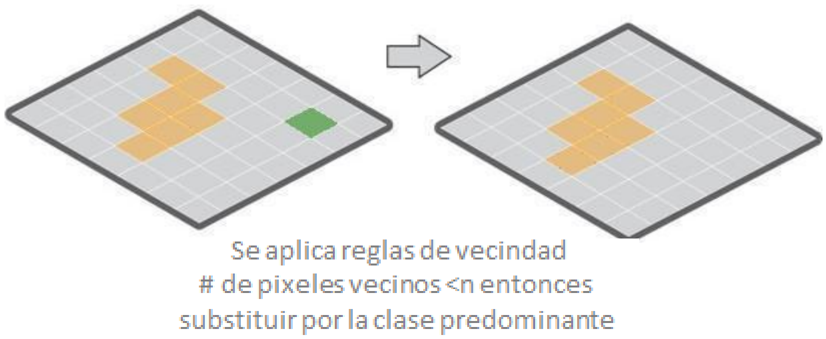

Figure 10. Functionality of the spatial filter

3.4.4 Frequency Filter

This filter takes into account the frequency of occurrence of natural classes throughout the time series. Therefore, classes with occurrences below a percentage defined by the interpreter are replaced by the value of the most frequent class. This mechanism helps reduce the temporal oscillation associated with a natural class, decreasing the frequency of false positives and preserving established trends (Figure 11). The filter criteria were adapted by classification region according to the needs of each subregion and/or cross-cutting theme. Its application was ruled out in several subregions and/or countries. See the respective country appendices for more details.

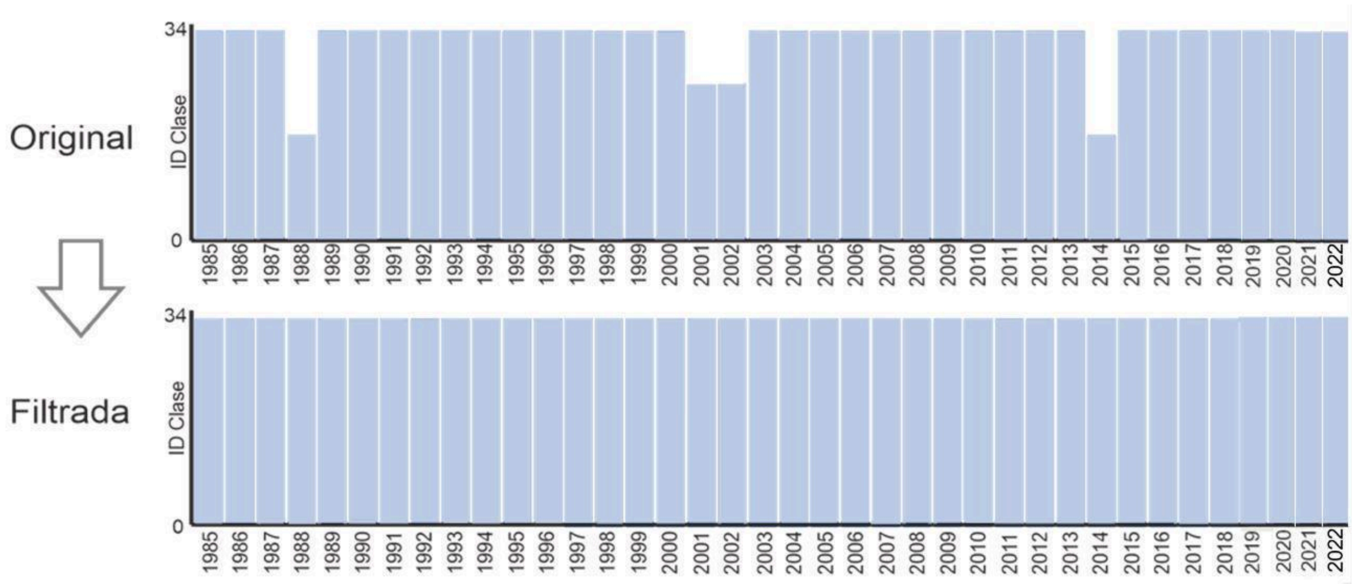

Figure 11. Functionality of the frequency filter

3.4.5 Incident Filter

The incidence filter stabilizes the value of natural-class pixels that changed class too many times over the 40-year time series. All pixels that change more than a user-defined number of times and are connected to at least *n* Pixels were replaced by the mode class value for that pixel. This reduces changes along class edges and helps stabilize transitions disrupted by noise. The filter criteria were adapted to the needs of each subregion and/or cross-cutting theme (Figure 12). Its application was ruled out in several subregions and/or countries. See the respective country appendices for more details.

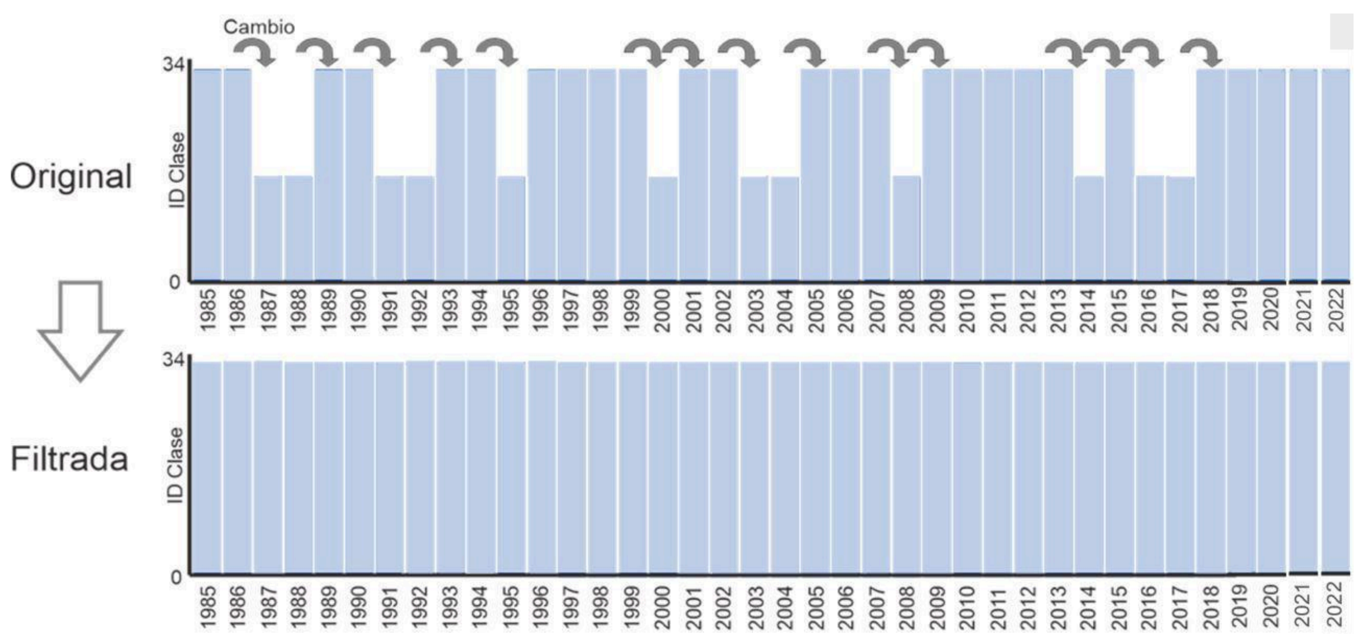

Figure 12. Functionality of the incidence filter

3.4.6. Reclassification

In very particular cases, where there was no class continuity between countries, it was decided to verify with reference layers or secondary information which country had the correct classification and thus reclassify the erroneous class and obtain a correct continuity between biomes or countries.

3.5. Integration

The results of the annual classifications obtained for each of the classification regions constitute sectors of the general base map, which need to be integrated into a single annual regional map with the cross-cutting themes; following rules of prevalence or order of integration that define the prevalence of classes where overlap of different values occurs.

The integration for Peru was carried out by classification region with specific prevalence rules for each region, as shown in Table 9. Layers with a lower prevalence order (numbers close to one (1)) are those with a smaller classification area and will be the top layer in the integration. These prevalence orders vary according to the biome. The product consists of annual land cover and land use maps by country.

Table 9. Prevalence rules by biome for the integration phaseration

COLLECTION 3	CLASS ID	FOUNTAIN	ORDER OF PREVALENCE			
			AMAZONIA	ANDES	EQUATORIAL DRY FOREST	COASTAL DESERT
Glacier(MAPBIOMES WATER)	34	Transversal	-	1	-	-
Planted forest	9	General	-	2	-	-
Planted forest	9	Transversal	-	3	-	-
Beach	23	Transversal	1	4	-	7
Aquaculture	31	Transversal	-	-	15	-
Water	33	General	2	5	16	8
Water(MAPBIOMES WATER)	33	Transversal	21	6	17	9
Mining	30	Transversal	3	7	1	1
Urban Infrastructure	24	Transversal	4	9	2	2
Fog Oasis	70	Transversal	-	-	18	18
Coastal Salt flat	32	Transversal	-	-	7	10
Salt flat	61	Transversal	-	8	-	-
Rock outcrop	29	General	-	10	-	-
Other natural non vegetated area	68	General	5	11	25	25
Other non vegetated area	25	General	6	12	14	17
Grasslands / herbaceous	12	General	7	21	24	24
Swamp or Flooded Grassland	11	General	8	16	3	3
Swamp or Flooded Grassland	11	Transversal	9	-	4	4
Scrubland	66	General	-	19	19	19

Oil palm	35	Transversal	10	-	-	-
Rice	18	Transversal	11	-	8	11
Pasture	15	Transversal	12	-	10	13
Pasture	15	General	13	17	11	14
Mosaic of agriculture and pasture	21	Transversal	14	-	12	15
Agricultural mosaic	21	General	15	18	13	16
Other non-forest formations	13	General	17	20	23	23
Other crops	72	General	-	-	9	12
Flooded forest	6	Transversal	18	-	-	-
Flooded forest	6	General	19	-	-	-
Mangrove	5	General	-	-	5	5
Mangrove	5	Transversal	-	-	6	6
Dry forest	4	General	-	15	20	20
Dry forest	4	Transversal	16	14	21	21
Forest	3	General	20	13	22	22

Source: Own elaboration

3.6 Transition Maps

Based on the integrated annual land cover and land use maps, transitions are calculated. These represent the changes between pairs (2) of maps, that is, between two periods. The results are available on the MapBiomas Amazonia platform. Transitions are calculated for different periods, such as:

- (A) consecutive years, annual (for example, from 2001 to 2002, or from 2013 to 2014, etc.)
- (B) five-year periods (for example, 2000-2005)
- (C) ten-year periods (e.g., 2000-2010)
- (D) complete time series (1985 - 2024)
- (E) special periods (for example, 2000-2024)

3.7 Statistics

Based on the integrated annual land cover and land use maps, area statistics in hectares (Ha) are calculated for both zonal and annual areas of the mapped classes. The spatial units considered for the calculation of the statistics are:

- Country
- Biome
- Department
- Province
- District
- River basin
- Indigenous territories
- Protected natural areas
- Geographic region

4. Validation

Map validation is performed every three collections. The validation process for collection 1.0 of annual land cover and land use maps of Peru, which only covers the period 1985–2021, is detailed below.

The accuracy analysis evaluates the quality of the resulting maps. This analysis was conducted by an institution external to the map's authors and includes results on the overall map accuracy by class and year, as well as errors of omission and commission for each of the classified categories.

The accuracy analysis considered a sampling method in which the population (i.e., the total number of pixels) was divided into two domains in Peru, inside and outside the RAISG boundary. Within the RAISG boundary, subdomains were created by constructing maps.[13]grouped (ATBD link). Nineteen maps were constructed, grouped by region of Peru (Figure 14), each with an area of approximately 70,000 km[22]For each domain, a one-stage proportional stratified random sampling was carried out, where stratification was defined by division into six slope levels, and within each stratum, a simple random sampling of the primary sampling units (pixel) was carried out.

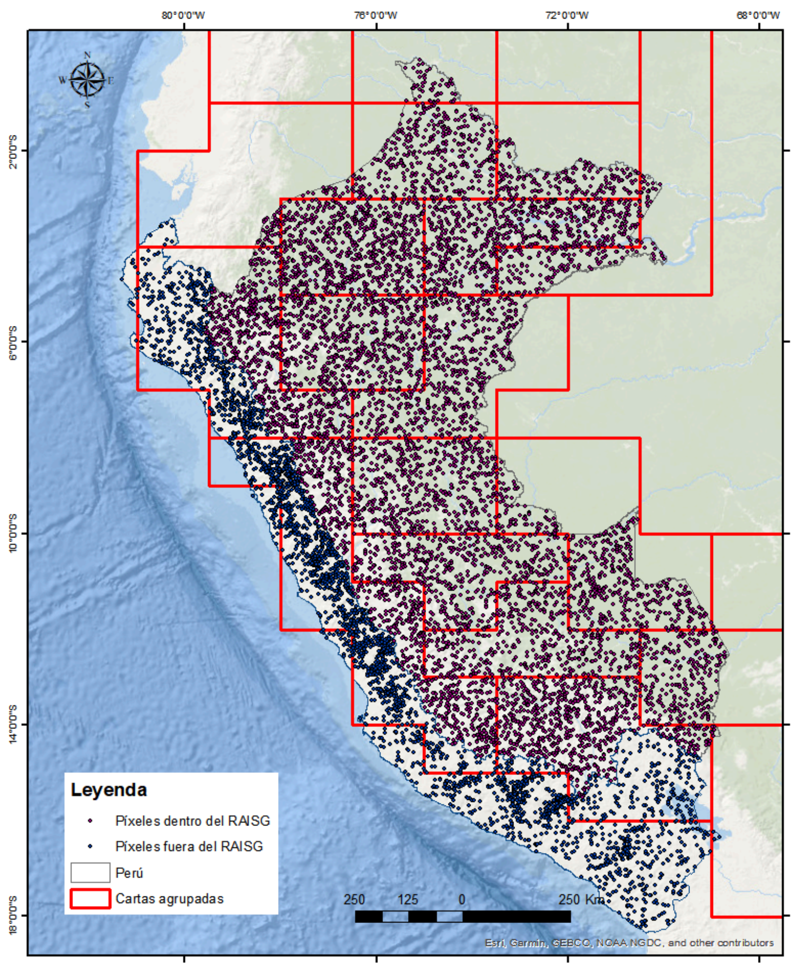

Figure 14. Distribution of sample points in domains inside and outside the RAISG boundary.

[13]Corresponding to the charts of the International Map of the World to the Million (CIM) at scales of 1:250,000. See section 3.1.1.

In each domain, the precision and reliability of the estimates were controlled so that the sample size would guarantee a maximum standard error of 5% in the grouped maps and 2.5% in the rest of Peru, with a 95% confidence level. From this perspective, the maximum expected error for the entire study area is 0.5%. Considering the feasibility of time and interpreters for the inspection process, a minimum of 500 points was defined for each domain. The sample size calculation also considered information on variability and the number of classes in each grouped map. Thus, the sample size was established as an increasing function in relation to the number of classes and/or the variability. The variability information was derived from the maximum variance of the land cover classes, and the Bonferroni correction (Dunn, 1959) was applied to account for the information on the number of classes.[14]which corrects the quantile value of the standard normal distribution. The total number of samples extracted for the entire study area corresponded to 7,839 pixels within the RAISG boundary and 3,450 outside of RAISG.

The formula for calculating the sample size for each domain is shown below.

$$n = \max_{p \cdot q} \left(\frac{N z_{\gamma}^2 pq}{(N-1)E^2 + z_{\gamma}^2 pq} \right),$$

where *n*is the sample size; N is the total number of points; E is the maximum margin of error; p = 1-q is the proportion to be estimated (for outside RAISG, the maximum proportion of 0.25 was used); and z is the factor of the standard normal distribution corresponding to the adjusted confidence level 1-g calculated by the Bonferroni correction, where g = k - 1 and 1− is the desired confidence level; k is the number of land use and land cover classes (Cochran, 1977).[15].

Each sample was classified annually (i.e., 1985–2021) by three independent interpreters. In this study, we considered the class with the most votes in each observation. This process involved a group of 14 people and the validation of 18 classes present in Collection 1.0.

Visual inspections were conducted using the Temporal Visual Inspection (TVI - tvi.lapig.iesa.ufg.br) tool, developed by the Image Processing and Geoprocessing Laboratory (Lapig) at the Federal University of Goiás (UFG). Each year under evaluation, the interpreter had access to two Landsat images (SWIR-NIR-RED composite). Auxiliary information, such as coordinates and region, was also provided, along with the option to view high-resolution images using Google Earth. It is worth noting that Google Earth was used to enhance understanding of the landscape context and its spectral response in Landsat images.

Meetings were also held between the group of interpreters and a group of experts from each country. These meetings led to the creation of an interpretation key with different criteria for interpreting Landsat images (e.g., color, tone, texture, homogeneity, shape, and context). This action enhanced the understanding of different land cover types in the region.

Accuracy was assessed using metrics that compare the assigned class with the class evaluated by the validating technicians on the reference data. The metrics used were: User accuracy (commission error), which is associated with the reliability of each assigned class; Producer accuracy (omission error), which is associated with the classifier's sensitivity, i.e., its ability to correctly distinguish one

[14] Olive Jean Dunn "Estimation of the Medians for Dependent Variables," The Annals of Mathematical Statistics, Ann. Math. Statist. 30(1), 192-197, (March, 1959)
[15] William Gemmell Cochran, *Sampling Techniques*, 3d ed, Wiley Series in Probability and Mathematical Statistics (New York: Wiley, 1977).

class from others; and finally, overall accuracy, which is the estimate of the classifiers' overall accuracy rate.

The validation results are available on the MapBiomas platform.

5. Practical considerations and challenges

The 3.0 collection of annual land cover and land use maps for Peru is a strategic monitoring tool that reflects the country's history over more than three decades. The production of this volume of multi-year information has led to applications for estimating trends in land cover change, as well as for understanding the factors that modify land cover dynamics.

For the development of this project, with its unprecedented spatial and temporal scope, a standardized methodology was used that can be replicated in other areas of the world. The use of Google Earth Engine's cloud-based work platforms and open-source technology has shown promise for large-scale data accessibility and processing.

Through the learning and experience gained from producing the previous collection, along with the exchange of ideas with the teams from the various MapBiomas initiatives, it was possible to achieve greater efficiency in terms of time and processes. Through the collaborative and networked work of a multidisciplinary team, it was possible to develop a methodology tailored to the specific needs of each region.

The use of the Random Forest algorithm as a classifier, combined with a flexible mapping protocol, allows each country in the various initiatives to define its feature space and samples.

Applying post-classification filters reduced the effects associated with the low quality and limited availability of satellite imagery, which were most prevalent at the beginning of the time series. Furthermore, the inclusion of new, hierarchically integrated cross-cutting themes made it possible to provide greater thematic detail in the land use and land cover maps.

The next step in this project is to expand the level of detail in the legend, increase the accuracy of the mapping, and use new remote sensing technologies and tools to obtain a higher quality product.

6. References

- National Water Authority. n.d. Map of Hydrographic Units. Lima, Peru. https://sinia.minam.gob.pe/repositorio-de-mapas?page=11
- Andean Community. Map of Ecosystems of the Northern and Central Andes. 2009 https://sinia.minam.gob.pe/mapas/mapa-vegetacion-natural-remanente-andes-norte-centro
- DGOTA-MINAM. National Ecosystem Map. 2018http://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/
- DGOTA-MINAM. Map of Ecoregions of Peru. 2017http://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/
- 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.

- Google (2019, March 1). Landat Collections. Accessed athttps://developers.google.com/earth-engine/datasets/catalog/landsat/
- Google (2019, March 1). Google Earth Engine API. Retrieved from https://developers.google.com/earth-engine/
- 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.
- National Institute of Natural Resources - Office of Intersectoral Environmental Management, Evaluation and Information of Natural Resources. 2000. Map of natural regions of Peru. Lima. Peru.
- National Institute of Natural Resources. 2002. Physiographic map of Peru. Lima, Peru.
- Kalliola, R., Puhakka, M. and Danjoy, W. (ed.) (1993). Peruvian Amazon: Tropical humid vegetation in the sub-Andean plain. Amazon Project University of Turku-National Office of Natural Resources Assessment.
- LAMPRECHT, H. 1990. Silviculture in the tropics. Forest ecosystems in tropical forests and their tree species; possibilities and methods for sustainable use. Translated by Antonio Carrillo. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). 335 pp.
- Ministry of Agrarian Development and Irrigation. 2020. Official National Agricultural Area.https://siea.midagri.gob.pe/portal/index.php/normas
- Ministry of Agrarian Development and Irrigation. 2021. Rice crop monitoring. GEOMIDAGRI.https://minagri-geoespacial.users.earthengine.app/view/monitoreoarrozv1
- Ministry of the Environment. 2009. Map of wetlands of Peru. Lima, Peru. https://sinia.minam.gob.pe/repositorio-de-mapas?page=11
- Ministry of the Environment. 2015. Map of Vegetation Cover of Peru. Descriptive Report - Peru. 108p.https://sinia.minam.gob.pe/repositorio-de-mapas?page=11
- Ministry of the Environment. 2022. Forest Conservation and Climate Change Mitigation Program. Map of Forest and Non-Forest 2000. Forest Loss 2001-2021. Lima, Peru.
- Ministry of the Environment. 2018. Forest Conservation and Climate Change Mitigation Program. Mapping of seasonally dry and non-seasonally dry forests on the northern coast of Peru. Tumbes • Piura • Lambayeque. Descriptive Report.http://www.bosques.gob.pe/archivo/Memoria-descriptiva_Bosques-secos-interiores-final.pdf
- Moat et al. 2020. Seeing through the clouds - Mapping desert fog oasis ecosystems using 20 years of MODIS imagery over Peru and Chile. Consulte el mapa en Earth Engine: https://gistin.users.earthengine.app/view/fogoasisSee the article at:https://www.sciencedirect.com/science/article/pii/S0303243421001756
- Nature Server, IIAP, CDC-UNALM (2007). Ecological systems of the Amazon basin of Peru and Bolivia. Classification and mapping. Lima: Nature Server, IIAP, CDC-UNALM.
- Olson, David; Dinerstein, Eric; Wickramanayake, Eric; Burgess, Neil; VN Powell, George; C. Underwood, Emma; A. D'Amico, Jennifer; Itoua, Illanga; E. Strand, Holly; Morrison, John; J. Loucks, Colby; F. Allnutt, Thomas; Ricketts, Taylor; New, 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.

- National Program for Forest Conservation and Climate Change Mitigation. 2016.GridsLand use and change in the Amazon. Peru.
- 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.
- Souza, Carlos; Siqueira, J.V.(2013). ImgTools: a software for optically remotely sensed data analysis. Proceedings of the XVI Brazilian Symposium on Remote Sensing. 1571-1578.