



MAPBIOMAS
ECUADOR

Land Cover and Land Use

Mangrove - Transversal Map

Algorithm Theoretical Basis Document (ATBD)

Collection 4.0

Version 1.0

October 2026

MapBiomias Ecuador Team – Mangrove Transversal Map

General Coordinator of MapBiomias in Ecuador

Wagner Holguín

Mapping Specialists

Katherine Terán

Executive Director, Fundación Ecociencia

Carmen Josse

Institution

Fundación de Estudios Ecológicos Ecociencia



Lizardo García E10-80 y 12 de Octubre.

Edificio Alto Aragón, Oficina 5C

Quito-Ecuador

+593 2 2523 066

<http://ecociencia.org>

How to cite

W. Holguín, K. Terán, F. Garcés, C. Cabrera & S. Cevallos. (2026). Algorithm Theoretical Basis Document (ATBD) MapBiomias Ecuador - Mangrove Transversal Theme, Collection 4.0, Ecuador Appendix

Table of Contents

1. Introduction	3
2. Satellite Image Mosaics	5
2.1. Composition of Mosaics	7
2.2. Selection of classification variables	8
3. Classification	9
3.1. Class Definition	9
3.1.1 Mangrove in the Insular Zone	9
3.1.2 Pacific Mangrove	10
3.2 Background information	11
4. Post-sorting	12
4.1 Gap Fill Filter - Filling Information Gaps	12
4.2 Time Filter	13
4.3 Frequency filter	14
4.3 Spatial Filter	15
4.5 Integration with the other MapBiomass Ecuador classes	15
5. References	17

Figure List

Theme	Page.
Figure 1. Location of the classification regions for the transversal Mangroves Collection 4.0 Mapbiomas Ecuador	4
Figure 2. Methodological diagram for the classification of the cross-sectional map of Mangroves	4
Figure 3. Image of the MMRI (Modular Mangrove Recognition Index) generated from Landsat (Top of atmosphere) data for the coastal and insular zone of Ecuador	5
Figure 4. Method of generating annual mosaics Collection 4.0 MapBiomas Ecuador	7
Figure 5. Reference images for the Mangrove class in the insular zone. (a) Coverage classification (Legend: Mangrove, Non-Mangrove Areas); (b) MMRI Mosaic; (c) Landsat Mosaic (RGB); (d) Google Street View Image	9
Figure 6. Reference images for the Mangrove class on the Ecuadorian Pacific coast. (a) Coverage classification (Legend: Mangrove, Non-Mangrove Areas); (b) MMRI mosaic; (c) Landsat mosaic (RGB); (d) Landscape image	10
Figure 7. a) Mangrove map with referential layers b) Manual training samples of mangrove (dark green) and non-mangrove (gray)	11
Figure 8. Example of the mechanism of action of the void-fill filter. Where: CO: Original classification, CF: Classification with filter	12
Figure 9. Example of the mechanism of action of the temporary filter. Where: CO: Original classification, CF: Classification with filter	12
Figure 10. Effect of the application of the frequency filter. Where: CO: Original classification, CF: Classification with filter	13
Figure 11. Effect of the application of the spatial filter. Where: CO: Original classification, CF: Classification with filter	14

List of tables

Table 1. Scenes, number of satellite images and processed Landsat mosaics used for mangrove mapping in the 4.0 Collection of MapBiomas Ecuador	5
Table 2. Landsat data collections used for mangrove mapping in Collection 4.0. from MapBiomas Ecuador	6
Table 3. Variables for the classification of flood cover in Collection 4.0, MapBiomas Ecuador	8
Table 4. Reference layers for the mangrove class	10

1. Introduction

Mangroves are covers of great importance for coastal ecosystems (Peters et al., 1997), they provide various ecosystem services of provision, regulation, support, and culture (Carvajal-Oses et al., 2019; Marlianingrum et al., 2019). Among the ecosystem services, carbon sequestration stands out, which can capture up to four times the amount of the average of other terrestrial forest covers (Spalding & Leal, 2021). They are also recognized as the "cradle" for various species of fish, mollusks, amphibians and birds, as they provide shelter, feeding and spawning/nesting sites (General Directorate of Ecosystems, 2002). In addition, they serve an important support service as a barrier against marine erosion, stabilizing the coasts and protecting the communities that live there from strong waves.

In order to establish effective measures for mangrove management, mapping and monitoring losses and gains over time is essential. In this sense, Global Mangrove Watch (GMW) is one of the platforms dedicated to providing geospatial information on the extent of mangroves in the world and the changes made since 1996 through remote sensing, although not consecutively. At the national level, it is the Ministry of the Environment, Water and Ecological Transition (MAATE) that is in charge of generating geospatial information of Ecuador through maps of vegetation cover and ecosystems, in which mangroves can be found, it should be noted that this information is for the continental part of the country. Likewise, reference has been taken to the mapping of mangroves in Guayas for the years 2018, 2020 and 2022 of the Ecociencia Foundation. In the case of the Galapagos Archipelago, it does not have state geospatial information, so the layers of the Charles Darwin Function (CDF) and Ecoscience have been taken as a national reference.

One of the challenges of the MapBiomass Ecuador 3.0 Collection was the mapping of mangrove ecosystems consecutively for a time series of 40 years, from 1985 to 2025. Based on the methodology addressed by Diniz et al., 2019 and used by Mapbiomas Brasil in collections for the mapping of mangrove cover, adjustments and adaptations to the method were developed to replicate it, using the tools available and known to the interpretation team, delimiting specific areas of work (Figure 1) and making use of national reference maps for comparisons and validation of the results.

The entire process was divided into three main stages: (I) processing of the satellite mosaics, (II) sample collection and classification from the satellite mosaics, and (III) application of post-classification filters. Each stage consisted of several steps that included reference data collection, definition of sampling areas, and preliminary test classifications. The complete classification process is outlined in Figure 2.

It is important to highlight the use of landsat mosaics that differ from those used for the classification of the general map and the other cross-sectional ones that make up Collection 4 of MapBiomass Ecuador. The data used for mangrove mapping correspond to annual mosaics built from Landsat images with Tier 1 correction level (Top Of the Atmosphere) of Google Earth Engine Collection 4. It was decided to work with TOA data because this allows to preserve the land surface on the coasts as much as possible and at the same time reduce the incidence of clouds as much as possible. Of the total number of available variables, the most representative variables were selected to discriminate the mangrove cover of other classes present in the mask (between Landsat bands, spectral indices and topographic variables, with median and 25th percentile reducers) in order to train the Random Forest

classifier.

Finally, the classification of mangroves proposed by Mapbiomas Ecuador is obtained based on the spectral response of this cover.

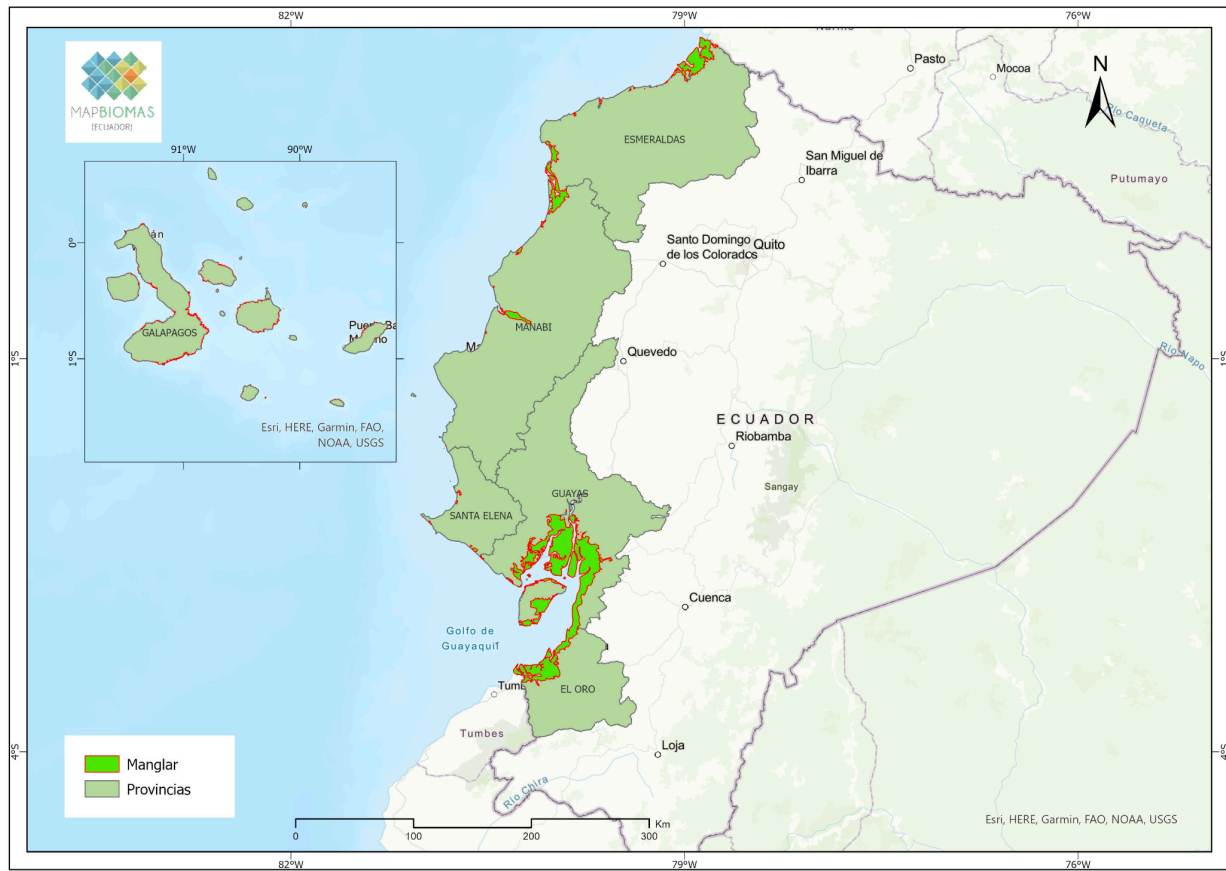


Figure 1. Location of the classification regions for the transversal Mangroves Collection 4.0 Mapbiomas Ecuador. Elaboration: Ecociencia, 2026

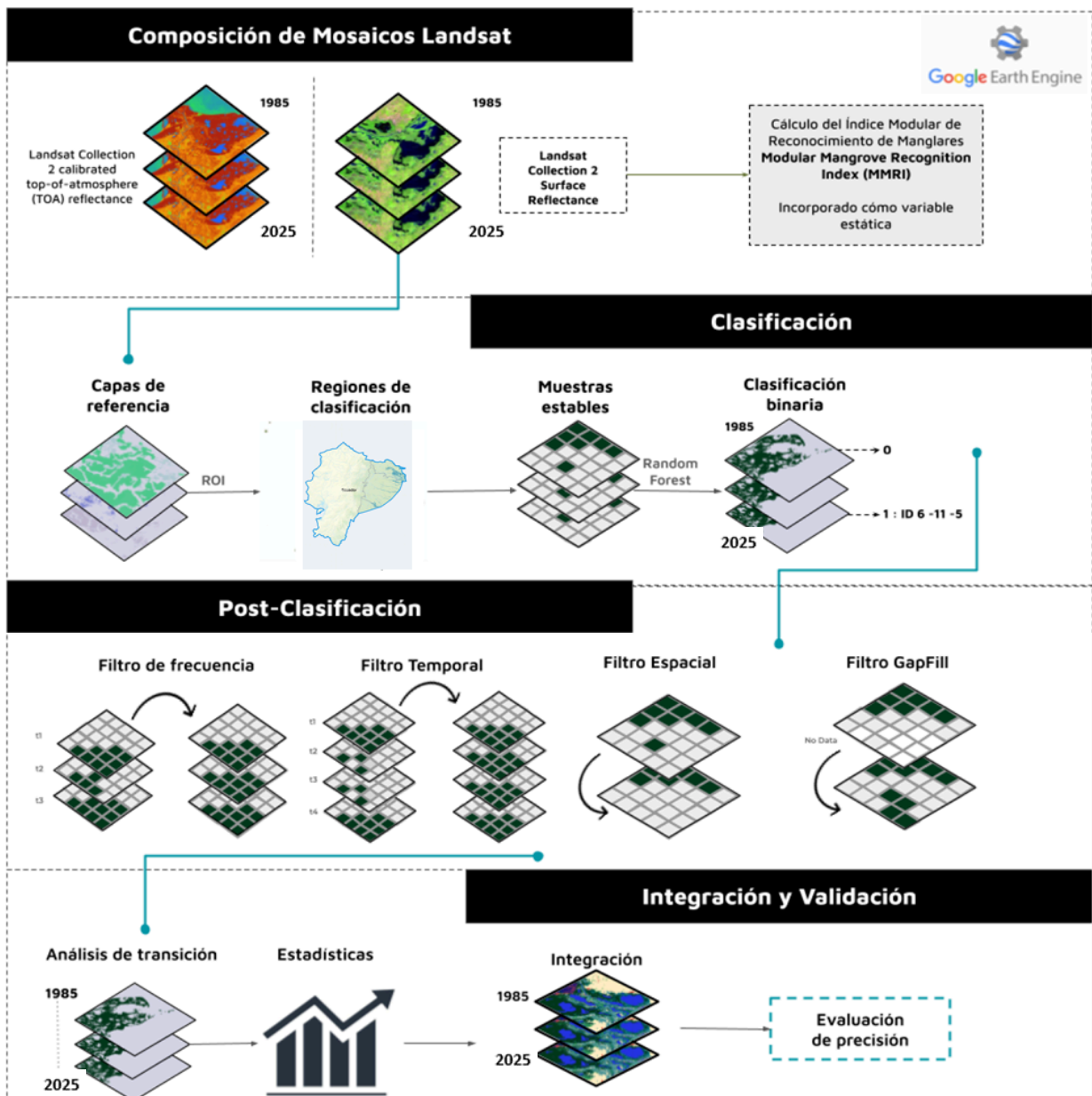


Figure 2. Methodological diagram for the classification of the cross-sectional map of Mangroves. Elaboration: MapBiomias, adapted by Ecociencia, 2026.

2. Satellite Image Mosaics

In the identification and classification of the mangrove class, Landsat TOA (Top of Atmosphere) data were used, which use radiometric re-scaling coefficients to produce annual cloud-free mosaics, which were constructed from the Landsat images available in the Google Earth Engine collections (Diniz et al., 2019). In this sense, the annual mosaics of the area covered by the 13 Landsat scenes corresponding to

the coastal zone of the Ecuadorian Pacific and the island areas where there is a presence of mangroves were generated (Table 1).

Table 1. Scenes, number of satellite images and processed Landsat mosaics used for mangrove mapping in the 4.0 Collection of MapBiomass Ecuador.

Country	Class	Scenes	Number of satellite images used for mosaic parameterization	Parameterized and processed mosaics for the time series 1985-2023
Ecuador	Mangrove	13	5459	36

Source: Ecociencia, 2026

These tiles significantly improve the integrity of the data by identifying those pixels that could be affected by the albedo of the presence of clouds (Chander et al., 2009). In short, during processing, the average pixel value of a set of temporary images is taken, rejecting values that are too bright, in this case clouds, or too dark, such as shadows (Diniz et al., 2019).

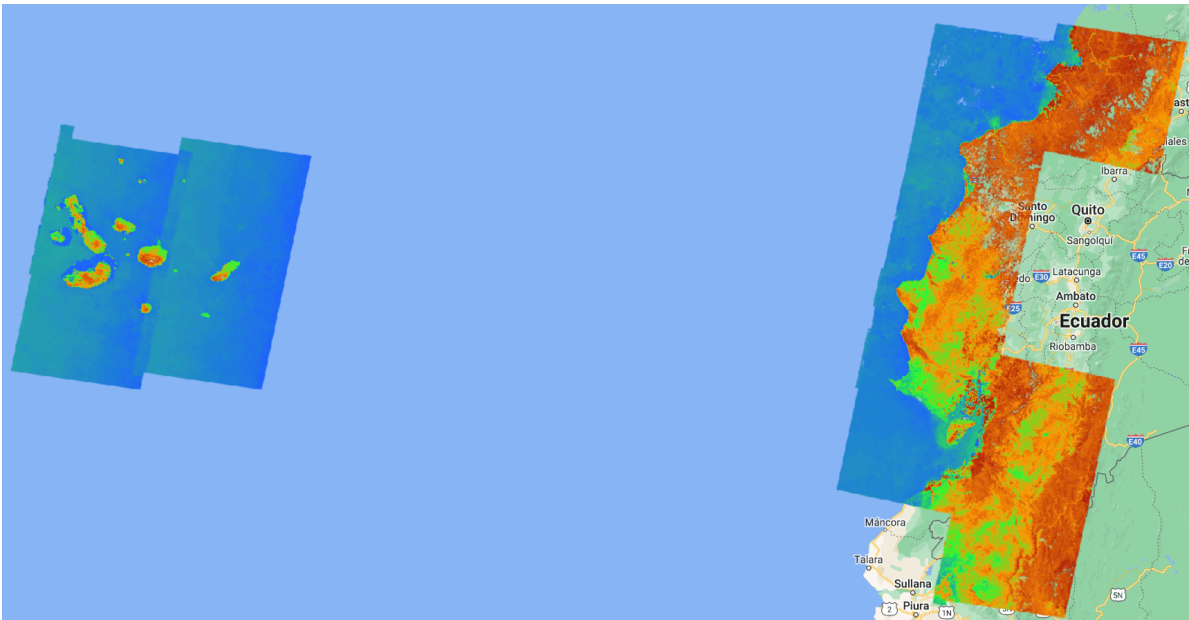


Figure 3. Image of the MMRI (Modular Mangrove Recognition Index) generated from Landsat (Top of atmosphere) data for the coastal and insular area of Ecuador. Elaboration: Ecociencia, 2026.

In addition, stable sampling was used as a complementary visual aid to the parameterized mosaics used in the general map, these have 151 bands each (detailed in the General ATBD) that contemplate, in addition to the satellite's own bands, derived spectral indices that use the following aggregation methods¹:

- **Median (_median):** The value of the pixel that separates the top half of the pixel set from the bottom half, and includes all cloud-free pixels in the images available for each year.
- **Median dry season (_dry):** The value of the pixel that separates the top half of the pixel set from the bottom half, only from NDVI 25% percentile annual imagery.
- **Medium wet epoch (_wet):** The value of the pixel that separates the top half of the pixel set from the bottom half, only from images that are located in the 75% percentile per year of NDVI.
- **Amplitude (_amp):** The difference between the two ends of an annual range per pixel.

¹ These aggregation methods were applied to the chart-selected Landsat imagery and all spectral indices derived from them.

- **Standard deviation (_stdDev):** A measure of dispersion obtained as the square root of the variance of annual pixels.
- **Minimum (_min):** The lowest pixel value within the dataset for a given year.
- **Maximum (_max):** The highest pixel value within the dataset for a given year.

The selection of scenes and construction of the final tiles was made using the following parameters as a reference, stored as metadata in each asset built:

- **ID:** Unique identifier for the region.
- **Year:** Year (1985 to 2024) to which the mosaic corresponds.
- **Path Row:** Landsat Scene Identifier
- **Start and end date:** Dates used to define the time range for the selection of imagery from collections available in Google Earth Engine.
- **Sensor:** Sensor identifier (L5: Landsat 5 TM, L7: Landsat 7 ETM+, L8: Landsat 8 OLI, LX: Combination of Landsat 5 and Landsat 7 scenes.)
- **Cloud Cover:** Maximum allowable percentage of cloud cover. Scenes that exceed that percentage were excluded from tile creation.
- **Blacklist:** List of scenes considered to be of poor quality, which are excluded from the construction of the mosaic.

All generated mosaics are stored as a collection of Google Earth Engine imagery and are available at the path: projects/mapbiomas-raisg/MOSAICOS/mangrove-5.

2.1. Composition of Mosaics

The composition of mosaics for the cross-sectional classification of Mangroves was carried out through satellite images without atmospheric correction (TOA) from the Landsat 4, 5, 7, and 8 sensors that cover the surface associated with the area of interest (Pacific region and insular zone), generated annually within a time series of 44 years from 1985 to 2025. The processing and analysis of the data was produced using Google Earth Engine, Table 2 shows the collections of images that are hosted on the aforementioned platform.

Table 2. Landsat data collections used for mangrove mapping in the 4.0. Collection of MapBiomias Ecuador.

Sensor	GEE Collection ID
Landsat 4 TM	LANDSAT/LT04/C02/T1_TOA
Landsat 5 TM	LANDSAT/LT05/C02/T1_TOA
Landsat 7 ETM+	LANDSAT/LE07/C02/T1_TOA
Landsat 8 OLI /TIRS	LANDSAT/LC08/C02/T1_TOA

Likewise, in Figure 4, the general methodology for the production of mosaics is graphically described, that first, the composition of mosaics was carried out according to the availability of the Landsat image collections year by year from 1985 to 2025 hosted in the Google Earth Engine repositories. The composition of images used the grid of millionths of a world card where an ideal parameterization was developed to produce each mosaic according to criteria associated with the temporality for each country (start date and end date), sensor, cloud cover and exclusion scenes that interfere with the quality of the median image.

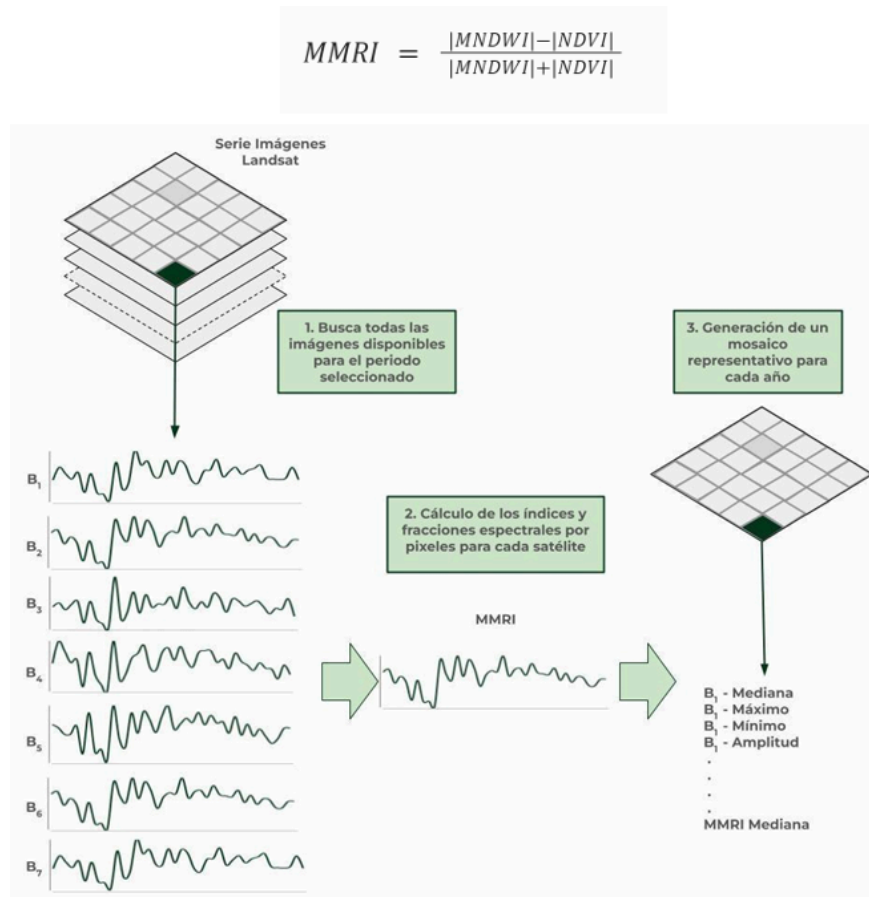


Figure 4. Method of generating annual mosaics Collection 4.0 MapBiomass Ecuador. Elaboration: MapBiomass, 2026

From the parameterization, the preprocessing included the application of the *Cfmask* and *CloudScore* algorithms that for Landsat 4, 5 and 7 (mosaics from 1985 to 2024) used two bands, *pixel_qa* - Pixel quality attributes generated from the *CFMASK algorithm* and *sr_atmos_opacity* - Atmospheric opacity; <0.1 = clear; 0.1 - 0.3 = average; > 0.3 = hazy. The above, if the cloud bit (5) and cloud confidence (7) is set to be high, or if the cloud shadow bit (3) is set, it is considered an incorrect pixel and therefore the edge pixels that do not occur in all bands are removed. For Landsat 8 (tiles from 2013 to 2025), the *band pixel_qa* was used, considering that bits 3 and 5 are clouds and shadows. After deletion, the median calculation of the collection of cloudless images generated by the annual tile was performed.

2.2. Selection of classification variables

From the generated mosaics, preliminary classification tests were carried out that allowed reducing the number of variables necessary to generate the final classification. Based on the results of these tests, the topographic bands (altitude, slope and slppost), derived from the DEM SRTM STRM (Shuttle Radar Topography Mission - V03) elevation model, were also included in the classification process. In total, 14 variables were used to implement the classification. The details of each one are shown in table 1 below.

Table 3. Variables for the classification of flood cover in Collection 4.0, MapBiomass Ecuador

Band	Description	Reducer
Green	Green band value	Medium
Network	Red Band Value	Medium
nir	Near-infrared (NIR) band value	Medium
SWIR1	SWIR1 Band Value	Medium
Swir2	SWIR2 Band Value	Medium
CAI	Cellulose absorption index	Medium
GCVI	Green Chlorophyll Index of Vegetation	Medium

NDFI	Normalized Difference Fraction Index	Medium
SAVI	Soil-Adjusted Vegetation Index	Medium
NDVI	Normalized vegetation difference index	Medium
EVI	Improved vegetation index	Medium
NDWI	Normalized Water Difference Index	Medium
MNDWi	Modified Normalized Water Difference Index	Medium
NDSI	Normalized Soil Difference Index	Medium
MMRI	Modular Mangrove Recognition Index	Medium
slope	Pending	
SLPpost	Stratified Slope	
altitude	Altitude	

Source: Ecociencia, 2026

3. Classification

From the selected mosaics, a supervised classification was carried out based on the Random Forest algorithm available in Google Earth Engine (GEE). The processing was carried out entirely on the GEE platform and the results were stored as a collection of images on the same platform. The detection of coverage focused on the identification of the mangrove class (ID 5 in the legend Collection 4.0 Mapbiomas Ecuador). The classification process was carried out considering only two possible classes; the class of interest (mangrove) and the class Not Observed (everything different from the class of interest).

3.1. Class Definition

Mangroves (ID 5) are natural formations of dense and evergreen forests located in coastal areas, occupying a transitional zone between the continent and the ocean (García Murcia & Cortes Castillo, 2018; MapBiomas, 2023). They develop on sandy soils or clay silt that may be permanently or occasionally flooded due to the influence of the tides. They form strips in estuarine areas, bays, inlets, coastal lagoons, river mouths, estuaries, among others, where they receive the contributions of continental runoff waters and the influence of marine or brackish waters (Díaz Gaxiola, 2011).

MapBiomas Ecuador defines the class "mangroves" as: Area with dense and evergreen forest cover dominated by mangrove species that occur in intertidal zones, river mouths and estuaries, adapted to shallow brackish waters, with adaptations to grow on flat and muddy soils. Mangroves of genera *Rhizophora spp.*, *Avicennia spp.*, *Conocarpus spp.* and *Laguncularia spp.* predominate.

Due to climatic and edaphic conditions, oceanographic and fluvial variables, vegetation has a set of particular morphological and physiological characteristics that allow it to grow in unstable, anaerobic and floodable terrain, with soils with low oxygen concentrations and high levels of salinity, such as: Elongated and flexible roots to colonize unstable substrates, anatomical structures called "lenticels" and pneumatophores that allow the exchange of gases with the atmosphere and reproductive strategies such as the presence of seeds that can float for long periods of time (Villalba Malaver, 2006). In Ecuador, mangroves are

They are located on the Pacific coast.

3.1.1 Mangrove in the Insular Zone

In the Insular region, the Galapagos Islands are the only volcanic islands in the Pacific where mangroves are found naturally, covering 35% of the coast, where 4 species of mangroves are distributed: White Mangrove (*Laguncularia racemosa*), Black Mangrove (*Avicennia germinans*), Red Mangrove (*Rhizophora mangle*) and Button Mangrove (*Conocarpus erecta*), on different islands and islets. Depending on the species, it can be found from the intertidal part to the linear part of the coast. Depending on the species, they can grow between 3-30 meters in height (Moity & Grijalva, 2020).

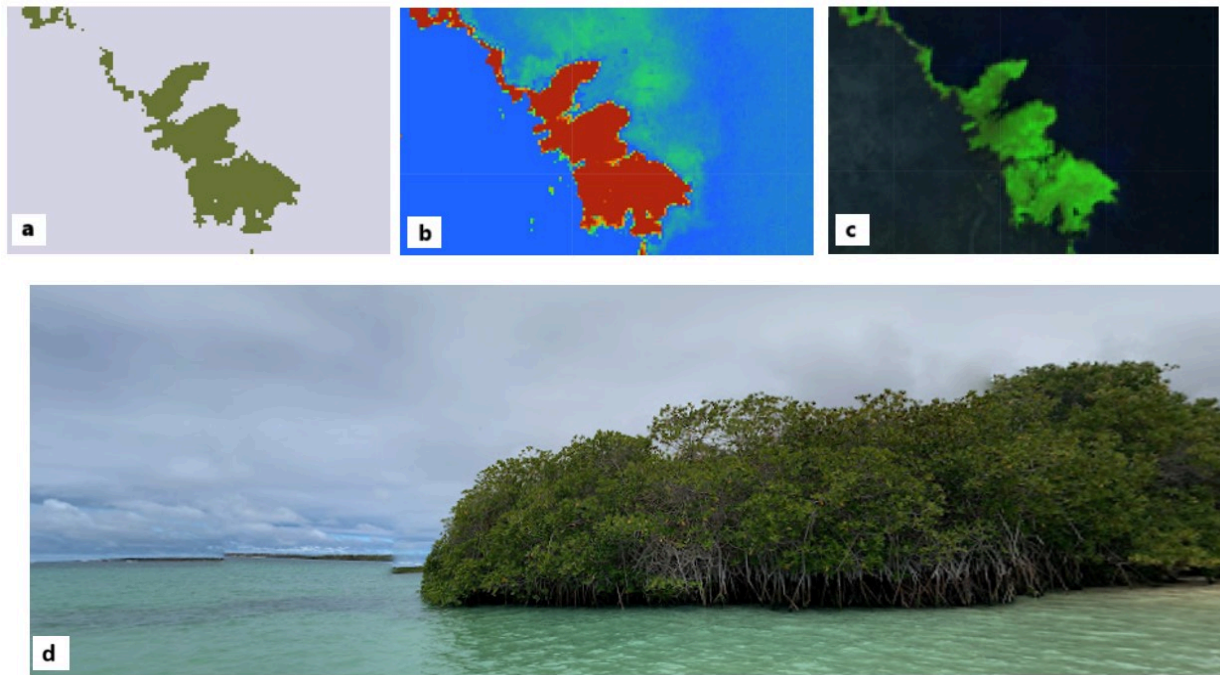


Figure 5. Reference images for the Mangrove class in the insular zone. (a) Coverage classification (Legend: Mangrove, Non-Mangrove Areas); (b) MMRI Mosaic; (c) Landsat Mosaic (RGB); (d) Google Street View Image

3.1.2 Pacific Mangrove

The mangroves of the Ecuadorian Pacific are conditioned by the presence of i) the mangroves of Chocó, and ii) the mangroves of the equatorial Pacific.

The mangroves of Chocó are located in the northwest of the province of Manabí, distributed from the Mataje River to the Cojimíes estuary, in the humid forest and very humid tropical life zones, with an average annual rainfall of 1 500 to 4 000 mm.l (Cornejo & PMV, 2013). The high levels of rainfall in Chocó produce abundant discharges of fresh water rich in organic matter and nutrients that are carried downstream through the rivers to the estuarine zones, producing large extensions of mangroves with developed tree representatives, up to 40 meters high, distributed from Darién in Panama to northwestern Ecuador (Cuatrecasas, 1958a, 1958b; Little, 1969; Cintrón et al., 1981, 1985; Alvarez León, 1993; Cornejo, 1994). In the province of Esmeraldas, some individuals of *Rhizophora spp* reach giant sizes up to 50 m tall and trunks of more than one meter in diameter, these have been reported as the tallest in the American continent and the world (Little, 1969).

To the south of the mangroves of Chocó are the mangroves of the equatorial Pacific, these are distributed from near latitude 0° in the area of Pedernales in the province of Manabí, and extend discontinuously to the mangroves of San Pedro de Vice in Piura, Peru, this portion of Ecuador is called the mangrove of Jama-Zapotillo (Cornejo et al, 2013), and they are found in the life zones of dry forest, very dry tropical, and thorny scrub, whose average annual rainfall is less than 600 mm (Cornejo, 2013, 7).

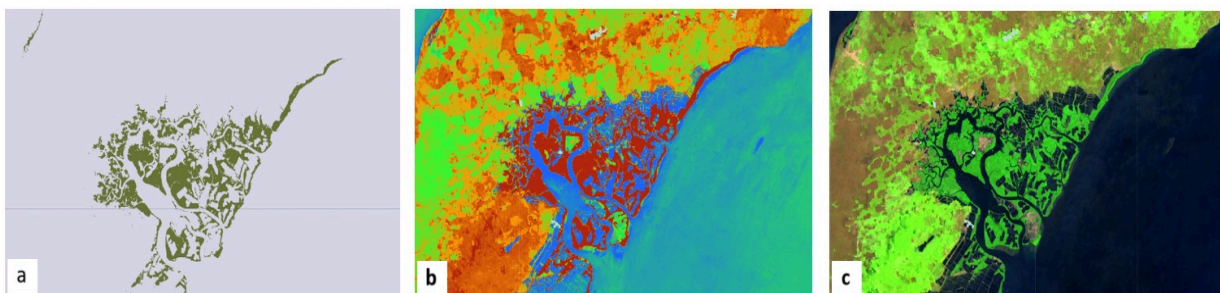




Figure 6. Reference images for the Mangrove class on the Ecuadorian Pacific coast. (a) Cover classification (Legend: Mangrove, Non-Mangrove Areas); (b) MMRI mosaic; (c) Landsat mosaic (RGB); (d) Landscape image (Ecoscience, 2026)

3.2 Background information

To generate the mangrove reference layer, geospatial information was collected from state, private and international institutions, of different temporality as the case may be, and in vector or raster format. Subsequently, all the collected references were joined (Table 4) into a single vector file and finally a visual analysis was carried out by adding polygons in the places that could find mangroves on the Pacific coasts and in the Galapagos Archipelago. The resulting data (Figure 7) served to guide the inspection and manual sample collection.

Table 4. Reference layers for the mangrove class

Reference	Global	Ecuador
Global Mangrove Watch (GMW) years 1996,2007-2010, 2015-2020	Yes	Yes
Global Tropical and Subtropical Wetlands Map (SWAMP)	Yes	Yes
ESA World Cover	Yes	Yes
Manglee (Servir Amazonía/Ecociencia, 2022)	no	Yes
Map of Land Cover and Use and Agricultural Production Systems of the Mainland Ecuador (MAG)	no	Yes
Map of Land Cover and Use and Agricultural Production Systems of Continental Ecuador (MAG)	no	Yes
Map of Vegetation Cover of Continental Ecuador 1982	no	Yes
Map of Vegetation Cover of Continental Ecuador 1990	no	Yes
Map of Ecosystems of Continental Ecuador (MAATE) 2013	no	Yes
Charles Darwin Foundation (CDF)	no	Yes
Mangroves (Ecoscience)	no	Yes

3.3 Training Samples

Once the mangrove reference layer for the country was generated, stable samples of the mangrove class (id 5) and non-mangrove or those coverages that do not correspond to mangrove (id 27) were taken visually and manually, in such a way that in the entire time series from 1985 to 2025 the pixels were stable according to each mosaic and respective class (Figure 7b).

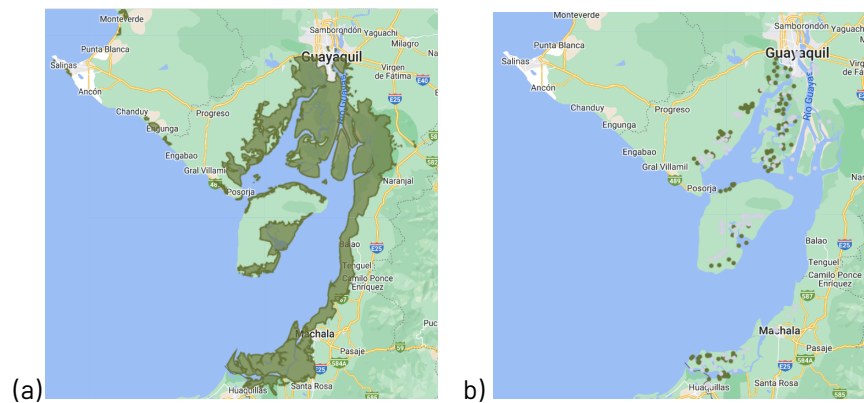


Figure 7. a) Mangrove map with referential layers b) Manual training samples of mangroves (dark green) and non-mangroves (gray).
Elaboration: Ecociencia, 2026

4. Post-sorting

The presence of some inconsistencies in the mapping is common, such as noise, salt and pepper effect, information gaps and temporal inconsistencies, for which a series of post-classification filters were applied; gapfill, temporal, frequency and spatial filters.

4.1 Gap Fill Filter - Filling Information Gaps

The sequence of filters begins with the filling of information gaps. In certain years, partial or total absence of the mosaic is common, either due to sensor defects, and/or because some regions are severely affected by the constant presence of clouds, especially in the Pacific region, impacting the completeness of the classified data in places for which there are no useful observations. This filter allows the replacement of pixels that do not present information with the closest temporal classification (Figure 8). If there is no availability of a value in the immediately preceding year, then the space is filled with the value of the following year. Thus, the remaining gaps should only exist if a given pixel has been permanently classified as having no information in the entire time series.

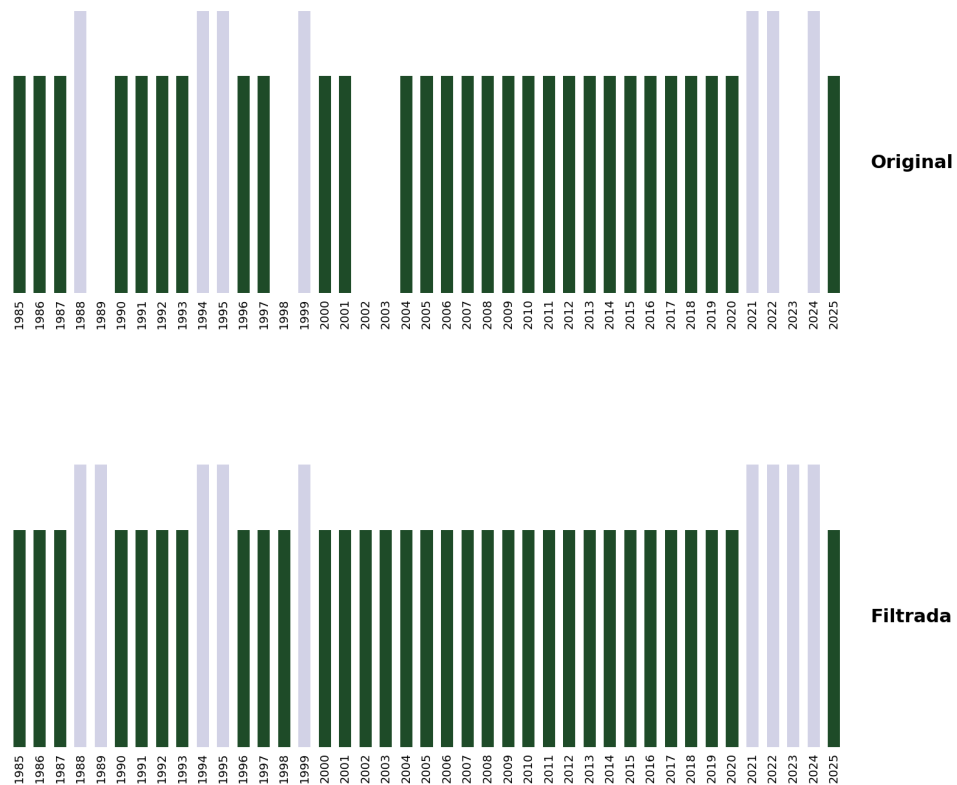


Figure 8. Example of the mechanism of action of the void-filling filter. Elaboration: MapBiomass, 2026.

4.2 Time Filter

The temporal filter uses sequential classifications in a one-way moving window of 3, 4 or 5 years over the entire time series. The functionality of the filter consists of identifying temporarily disallowed transitions, that is, abrupt changes that are not consistent with the behavior of the mapped coverage. The execution of the temporal filter contemplates 3 rules:

- First year rule (PR): Applied only to the classification of the first year of the time series (1985) where there is an abrupt change with respect to the continuity of the series.
- Last year rule (RU): Applied only to the classification of the last year of the time series (2025) where there is an abrupt change with respect to previous years.
- General rule or middle years (RG) rule: Applied to all intermediate years of the series (1986-2024), replacing the value of pixels located in the intermediate zone where there is a temporal inconsistency with the value of the extremes. In the 3-year sequences, there is only one option for a central position or intermediate year, while in the 4- or 5-year sequences, there are two or three alternatives for central positions (Figure 9).

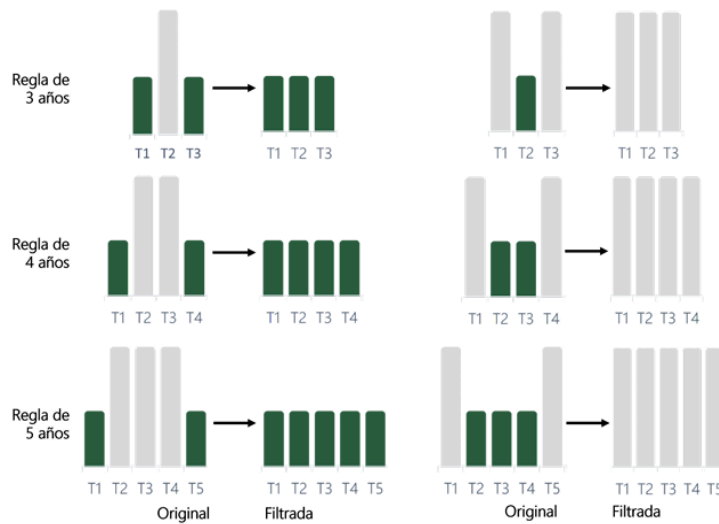


Figure 9. Example of the mechanism of action of the temporal filter. Where: CO: Original classification, CF: Classification with filter. Elaboration: MapBiomass, 2026.

4.3 Frequency filter

Finally, the fourth filter available in the post-classification sequence was the frequency filter. As shown in Figure 10, this filter considers the percentage of occurrence of the class throughout the time series to clean up the classification result, so that from 1985 to 2025 the pixel is assigned the value of the same coverage class.

This filter was applied differentially for class 5 (mangrove) and class 27 (Not observed), the latter being the grouping of all the classes that do not correspond to the cross-sectional in question present in the classification mask. First, the filter allowed to complete the classifications of the mangrove cover in areas where, due to a defect in the mosaic or due to errors in the classification process, there were underestimates that could not be corrected by means of the temporal filter.

Secondly, the filter contributed to eliminating the remaining noises, a particularly frequent case in the Ecuadorian Pacific due to the high rainfall conditions that characterize the region and cause the regular presence of clouds in the mosaics. Figure 10 exemplifies the effect of this filter.

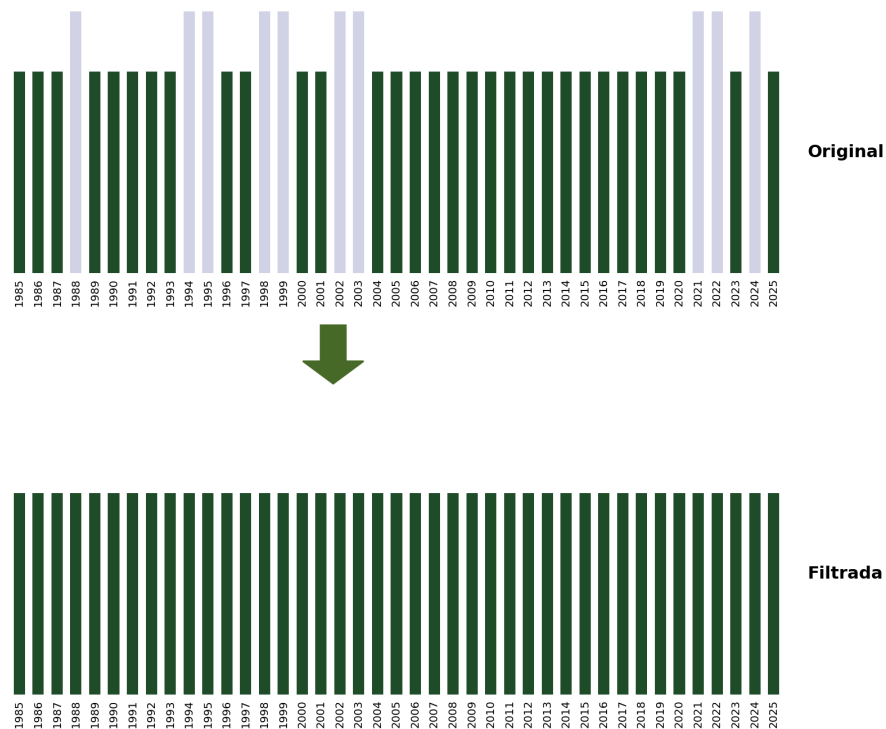


Figure 10. Effect of the application of the spatial filter.

4.3 Spatial Filter

The spatial filter is based on the "connectedPixelCount" function of Google Earth Engine, which allows reducing the "salt and pepper" effect or isolated pixels, homogenizing the classification. To do this, it assigns to scattered pixels the value of the class in which they are immersed and/or that predominates around them if they do not meet a minimum area criterion (0.5 hectares, equivalent to 5 pixels) and connectivity with other pixels of the same class. In this way, those isolated pixels that do not meet this condition are reclassified to the most abundant surrounding class, eliminating noise in the classification and unifying the tile coverages. Figure 11 shows an input image (CO) that shows an isolated pixel, which, once the filter (CF) has been applied, is replaced by the predominant class that surrounds it

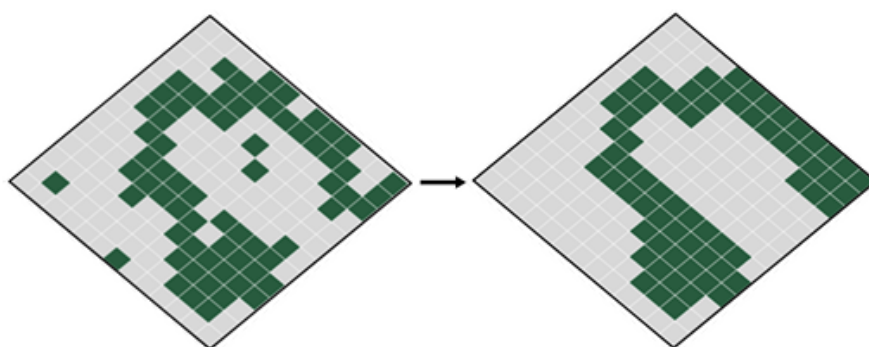


Figure 11. Effect of the application of the spatial filter. Where: CO: Original classification, CF: Classification with filter

4.5 Integration with the other MapBiomás Ecuador classes

After the application of the sequence of filters in the Post-classification stage, the resulting images (Figure 12) of mangroves are integrated into the general maps of each biome. This integration

depends on a series of specific hierarchical rules that assign an order of prevalence to each class. As a result of this stage, the annual maps of land cover and use for all of Ecuador are obtained (Figure 13).



Figure 12. Multitemporal classification, Guayaquil. Elaboration: Ecociencia, 2026.

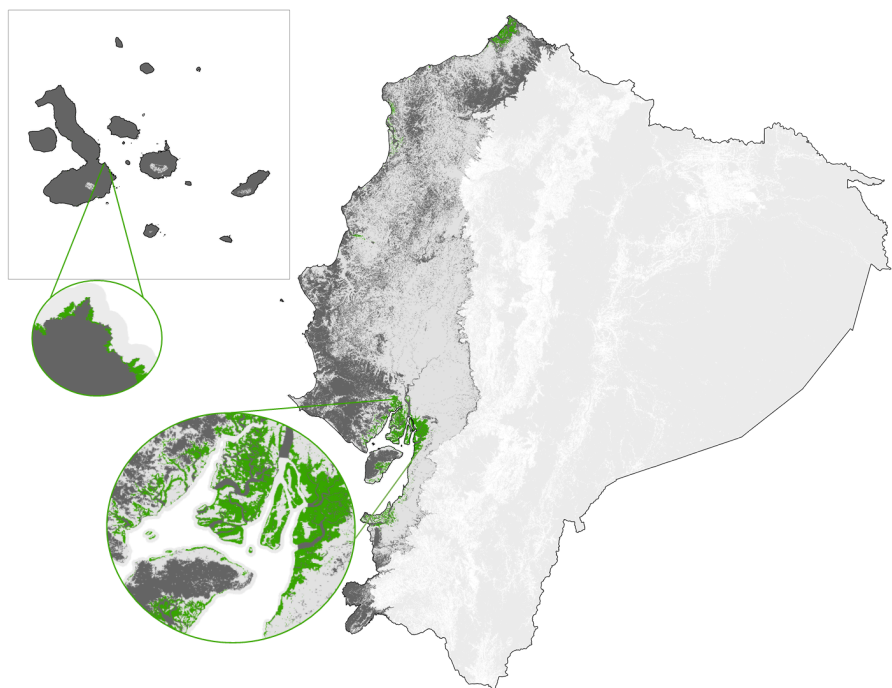


Figure 13. Map of mangroves year 2025. Elaboration: Ecociencia, 2026

5. References

- Alvarez-León, A. 1993. Mangrove Ecosystems of Colombia. In: L. D. Lacerda (ed.), Conservation and Sustainable utilization of mangrove forest in Latin America and Africa Regions. Part I-Latin America. International Society for Mangrove Ecosystems. Yokohama, Japan.
- Carvajal-Oses, M., Herrera-Ulloa, A., Valdés-Rodríguez, B., & Campos-Rodríguez, R. (2019). Mangroves and their Ecosystem Services: Towards Sustainable Development. *Management and Environment*, 22, 277-290. <https://doi.org/10.15446/ga.v22n2.80639>
- Chander, G., Markham, B. L., & Helder, D. L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, 113(5), 893-903. <https://doi.org/10.1016/j.rse.2009.01.007>
- Cintrón, G., R. Horna, R. Paredes, I. Solís, C. Bonifaz. 1981. Some observations on the development of the mangrove swamp on the continental coast of Ecuador and Peru. ESPOL. Guayaquil, Ecuador.
- Cintrón, G., A. E. Lugo, & R. Martínez. 1985. Structural and Functional Properties of Mangrove Forests, In: W. G. D'Arcy and M. D. Correa (eds.), The Botany and Natural History of Panama. Missouri Botanical Garden Press, St. Louis.
- Cornejo, X. (2013). . Lectotypification and a new status for *Rhizophora x harrisonii* (Rhizophoraceae), a natural hybrid between *R. mangle* and *R. racemosa*. *Harvard Papers in Botany* 18, 1(1), 37. <https://doi.org/10.3100/025.018.0106>
- Cornejo, X. 1994. Botanical-Ecological Analysis of Mangroves in the Province of Esmeraldas. Herbarium, Herbarium Dissemination Organ, University of Guayaquil, Faculty of Natural Sciences. Guayaquil, Ecuador.
- Cuatrecasas, J. 1958a. Aspects of the natural vegetation of Colombia. *Journal of the Colombian Academy of Exact, Physical and Natural Sciences* 10: 221-269.
- Cuatrecasas, J. 1958b. Introduction to the study of mangroves. *Bulletin of the Botanical Society of Mexico* 23: 84-98
- Díaz Gaxiola, J. M. (2011). A review of mangroves: Characteristics, problems and their legal framework. Importance of mangroves, the damage of anthropogenic effects and their legal framework: case of the Topolobampo lagoon system. *Ra Ximhai*, 355-370. <https://doi.org/10.35197/rx.07.03.2011.05.jd>
- Diniz, C., Cortinhas, L., Nerino de Souza Jr, G., Rodrigues, J., Sadeck, L., Adami, M., Souza Filho, P. W., & Souza-Filho, M. (2019). Brazilian Mangrove Status: Three Decades of Satellite Data Analysis. *Remote Sensing*, 11, 808. <https://doi.org/10.3390/rs11070808>
- General Directorate of Ecosystems. (2002). *Sustainable use, management and conservation of mangrove ecosystems in Colombia*. <https://par-manglares.net/images/docs/publicaciones/colombia/PNM-2002.pdf>
- García Murcia, Y., & Cortes Castillo, D. V. (2018). Conservation status of the mangroves of the Colombian Caribbean and their potential in non-timber forest products. *CITAS: Science, Innovation, Technology, Environment and Society*, 4(1), 8.
- Little, L.E. (1969). *Common Trees of the Province of Esmeraldas*. (VOLUME IV ed.). FAO.
- MapBiomias. (2022). *Theoretical Basis of Algorithm Document (ATDB) RAISG MapBiomias Amazon Collection 5—General Appendix – Collection 5 of Annual Maps of Land Cover and Use of the Amazon*. https://s3.amazonaws.com/amazonia.mapbiomas.org/atbd/atbd%20general/ATBD_General_MapBiomias_Amazonia_4.0.pdf
- Marlianingrum, P., Kusumastanto, T., Adrianto, L., & Fahrudin, A. (2019). Economic analysis of management option for sustainable mangrove ecosystem in Tangerang District, Banten Province, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 241(1), 012026. <https://doi.org/10.1088/1755-1315/241/1/012026>

- Moity, N., & Grijalva, I. (2020, December 30). *Charles Darwin Foundation - Creativity in Science: Studying Mangroves in Galapagos*. Charles Darwin Foundation. Retrieved November 20, 2023, from <https://www.darwinfoundation.org/es/articulos-blog/670-creatividad-en-la-ciencia-estudiando-manglares-en-galapagos>
- Peters, E. C., Gassman, N. J., Firman, J. C., Richmond, R. H., & Power, E. A. (1997). Ecotoxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry*, 16(1), 12-40. <https://doi.org/10.1002/etc.5620160103>
- Spalding, M. D., & Leal, M. (2021). *The State of the World's Mangroves 2021*. Global Mangrove Alliance. <https://www.mangrovealliance.org/wp-content/uploads/2022/02/The-State-of-the-Worlds-Mangroves-Spanish.pdf>
- Villalba Malaver, J. (2006). *Mangroves in the world and in Colombia: A basic descriptive study*.