MAPBIOMAS
COLOMBIA

Appendix - Colombia

Algorithm Theoretical Basis Document - ATBD

Collection 3.0

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Coordination of the MapBiomas Colombia
Adriana Rojas Suarez

Technical Lead MapBiomas Colombia
Karen Andrea Huertas

Team of specialists

Laura Urrea
Angie Bustos
Andres Medina
Vanessa Bolivar
Santiago Barreto
Tatiana Losada
Fernanda Betancourt
Natalia Garcia
Santiago Salazar
Luis Medina
Miguel Restrepo
Janner Simbaqueba
Valentina Vera
John Aguilar
Valentina Castellanos

Institution
Fundación Gaia Amazonas

Gaia
Amazonas

Calle 70a # 11- 30
Bogotá, Colombia.
(57-1) 772 35 42 / (57-1) 805 37 68
contacto@gaiaamazonas.org
https://www.gaiaamazonas.org

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EXECUTIVE SUMMARY

MapBiomas Colombia is a country-led initiative coordinated by Fundación Gaia Amazonas, a partner of the MapBiomas Network and the Red Amazónica de Información Socioambiental Georreferenciada (RAISG). MapBiomas Colombia stems from the MapBiomas Amazonia project, launched in 2017 under RAISG to map the Pan-Amazon region across its nine countries. Its purpose is to improve understanding of land-use dynamics in the Amazon by developing and applying a fast, reliable, and low-cost methodology to produce an annual time series of land cover and land use maps from 1985 onward, using artificial intelligence and machine learning algorithms (Rosa, Shimbo & Azevedo, 2019).

The methodology developed and implemented by MapBiomas is based on imagery from Landsat 4, 5, 7, 8, and 9 at 30-meter spatial resolution. For each year, a median composite is built—preferentially using scenes from the final months of the year. Using a supervised machine-learning Random Forest algorithm, a pixel-by-pixel classification is generated by creating multiple decision trees from random samples, combining information from up to 156 variables to produce more robust and accurate predictions. To reduce mapping inconsistencies such as noise, the salt-and-pepper effect, data gaps, and temporal incongruities, a series of temporal filters is applied iteratively. The entire processing chain was implemented with cloud computing on the Google Earth Engine platform.

MapBiomas Colombia is releasing its third collection of 40 years of land-cover maps for the country's land surface; this also constitutes the seventh collection for the Colombian Amazon, which is integrated with collections produced by the other countries to form RAISG's MapBiomas Amazonia. MapBiomas Colombia 3.0 includes a thematic detail of 25 land-cover classes distributed across five biogeographic regions: Andean, Caribbean, Orinoquia, Pacific, and Amazon.

Accordingly, this Algorithm Theoretical Basis Document (ATBD) provides a detailed description of the methodological process and computational algorithms used to produce MapBiomas Colombia Collection 3, which maps land cover and land use annually across the country from 1985 to 2024.

1. Introduction

The transformation of vegetation cover and land use driven by human activities is one of the main issues affecting terrestrial and aquatic ecosystems, directly impacting their functioning and their ability to meet human needs. The effects go beyond biodiversity loss, soil degradation, and regional climate alteration (Lambin et al., 2003), extending to a reduction in the capacity to provide environmental services to the population, thereby threatening food security and even public health (E.G. Leija et al., 2020). Moreover, the complexity of the factors influencing these alterations, together with the rapid pace at which they occur, makes it necessary to implement monitoring tools that enable timely understanding of the dynamics of these changes, in order to inform territorial and natural resource management.

In recent years, remote sensing and geographic information systems have been widely used in land cover and land use change analyses to estimate the loss and/or gain of natural cover and the dynamics derived from these processes, such as deforestation (Pero, 2015). Globally, several initiatives focus on land cover mapping, including The Globcover Project (ESA, 2005) and Global Forest Watch (WRI, 2014). At the national level, institutions such as the *Instituto de Hidrología, Meteorología y Estudios Ambientales* (IDEAM) and the *Instituto Amazónico de Investigaciones Científicas* (SINCHI) are responsible for monitoring land cover through the *Sistema de Monitoreo de Bosques y Carbono* (SMBYC) and the *Sistema de Monitoreo de las Coberturas de la tierra de la Amazonia colombiana* (SIMCOBA), respectively. These acronyms correspond to their names in Spanish.

In this context, the *Red Amazonica de Informacion Socioambiental Georreferenciada* (RAISG, Spanish acronym), in partnership with the MapBiomas Brazil project, launched *MapBiomas Amazonia* in 2017, an initiative for annual mapping and monitoring of land cover and land use across the entire Amazon region. The project is based on the analysis of satellite imagery, machine learning algorithms, and cloud processing through the Google Earth Engine platform. It emerged from the need for detailed, reliable, and up-to-date information on landscape changes and involves a collaborative network of researchers, academic institutions, and non-governmental organizations from the Amazon countries. Following the release of five Pan-Amazon collections, MapBiomas expanded to the rest of Colombia in 2023 and is currently launching the third collection of annual land cover and land use maps for the Colombian territory.

MapBiomas Colombia Collection 3 covers a 40-year period, from 1985 to 2024, and includes a total of 25 land cover classes. These comprise natural cover types of ecological importance such as glaciers, wetlands, flooded forests, and mangroves, as well as anthropogenic covers such as palm oil, mosaic of agriculture and pasture, mining, and Infrastructure. Fundación Gaia Amazonas, representing RAISG in Colombia, is responsible for the annual mapping of land cover and land use across both the Colombian Amazon and the rest of the country. As part of the network's knowledge-sharing efforts, the foundation presents this document, which outlines the theoretical background, rationale, and methods applied in the production of

annual land cover maps, along with the historical context and background information to facilitate understanding of the procedures and specific considerations for Colombia.

2. General Characteristics of the Country

2.1. Brief Context of Colombia

Colombia is located in the northwestern corner of South America, bordered to the north by the Caribbean Sea, to the east by Venezuela and Brazil, to the south by Peru and Ecuador, and to the west by Panama and the Pacific Ocean. The country's political-administrative division consists of second-level territorial entities known as departments and districts, as well as third-level entities called municipalities and indigenous territories. In addition, legislation allows for the creation of regions and provinces as additional territorial entities. There are also metropolitan areas, *comunas* (urban subdivisions), and *corregimientos* (rural subdivisions) that serve as administrative divisions responsible for implementing state functions and providing services to the population (IGAC, n.d.). Currently, Colombia has 32 departments, 1,103 municipalities, and 18 non-municipalized areas.

Additionally, due to the geographic, climatic, topographic, and ecological diversity across its territory, the country is divided into six natural regions: the Amazon Region, the Andean Region, the Caribbean Region, the Orinoquia Region, the Pacific Region, and the Insular Region, which are shown in **Figure 1** and detailed in **Table 1.** In terms of topography, the country features: (1) the Andean mountain system, divided into three major ranges, the Eastern, Central, and Western Cordilleras, which form the inter-Andean valleys of the Magdalena River (between the Central and Eastern ranges) and the Cauca River (between the Western and Central ranges); (2) the Sierra Nevada de Santa Marta, the highest mountain in the country, reaching 5,775 meters above sea level; (3) the Bogotá Savanna, located in the central-eastern part of the country, west of the Eastern Cordillera; and (4) the plains to the southeast, extending from the Eastern Cordillera to the Orinoco and Amazon river basins (Bell, 2012).

The Colombian Amazon is subdivided into four subregions according to their social, economic, and environmental characteristics. The western Amazon is the most densely populated area and is characterized by an extensive road network connecting its urban centers. The northwestern Amazon comprises 17 municipalities, includes protected areas, and has been the scene of armed conflict and peasant colonization, with predominant extensive cattle ranching and coca cultivation. The eastern Amazon is the largest subregion, dominated by tropical rainforest, with a mostly indigenous, dispersed population and a subsistence economy. Finally, the southern Amazon is primarily covered by tropical rainforest and is strategically important due to its location along the Amazon River; this region is integrated into the global market through extractive and river-based economies, with Leticia serving as its economic hub.

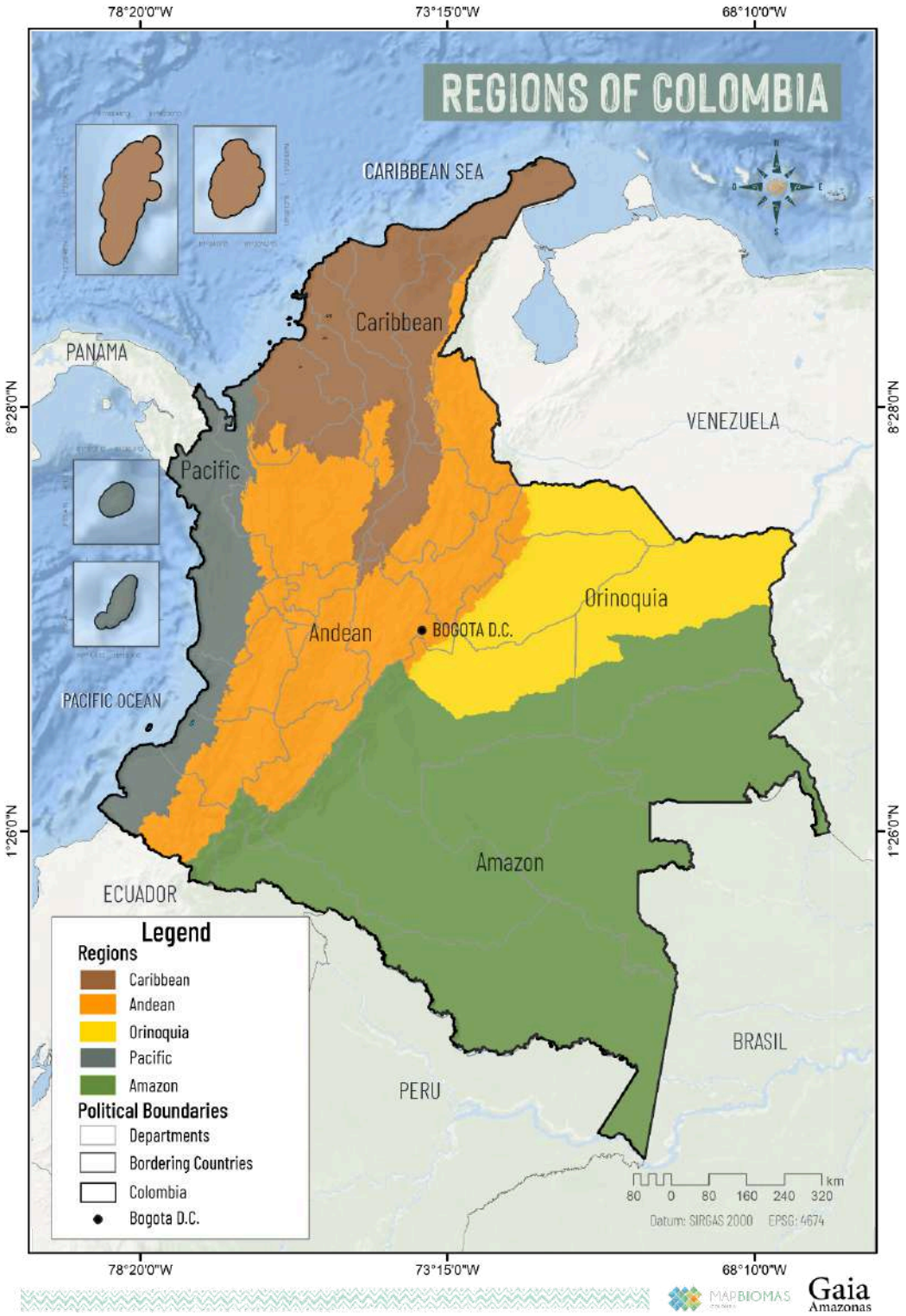


Figure 1 Location and Natural Regions of Colombia

Because of its highly rugged terrain, Colombia exhibits great climatic diversity. According to the Caldas-Lang climate classification, the predominant climate type is warm, with varying levels of humidity. The upper Guajira region features a desert climate, while arid and semi-arid conditions dominate much of the coastal strip, as well as parts of Magdalena, northern Bolivar,

Sucre, and Cordoba. Semi-humid and humid zones prevail across large portions of the Orinoquia, Amazon, Middle Magdalena Valley, southern Caribbean region, and eastern Norte de Santander. In contrast, the Pacific region is characterized by a super-humid climate (IDEAM, n.d.). These areas host diverse strategic ecosystems such as wetlands, among which the Ciénaga Grande de Santa Marta (Magdalena), the Ciénaga de Zapatosa (Cesar and Magdalena), the Ciénaga Grande del Bajo Sinú (Córdoba), and the Ciénaga de Ayapel (Córdoba) stand out. In addition, mangrove ecosystems are distributed along both the Caribbean and Pacific coasts.

This climatic pattern supports the formation of tropical rainforest, an ecosystem of exceptional ecological value and biodiversity, found primarily in the Amazon region. It harbors an extraordinary variety of plant and animal species adapted to high humidity and constant rainfall. This ecosystem plays a crucial role in regulating the water cycle, carbon sequestration, and biodiversity conservation, making it one of the most diverse and valuable ecosystems on the planet (Rincon Lopez, 2019).

Along the slopes of the three mountain ranges, up to elevations of 1.800–1.900 meters above sea level, temperate climates predominate. The driest zones are located in the Cauca Valley and parts of Santander, whereas humid and sub-humid climates occur in the central range of Antioquia, the western range in Cauca, and along the piedmonts of the Orinoquia and Amazon regions (IDEAM, n.d.).

Above 2.000 meters in the three cordilleras and the Sierra Nevada de Santa Marta, cold climates prevail, home to numerous moorlands that occupy about 1,2% of the national territory. Prominent examples include Sumapaz, Chingaza, Iguaque, Puracé, El Cocuy, and the Sierra Nevada de Santa Marta. Glaciers are found above 4.850 meters and are distributed across six zones: Sierra Nevada de Santa Marta, Sierra Nevada del Cocuy, Nevado del Ruiz, Nevado Santa Isabel, Nevado del Tolima, and Nevado del Huila. Conversely, dry climates characterize the Cundiboyacense high plateau and parts of Nariño, while more humid conditions occur along the slopes of the Eastern Cordillera (IDEAM, n.d.).

Colombia has a diverse population totaling 48.258.494 inhabitants. Most people live in municipal capitals (77,2%), while 7,1% reside in populated centers and 15,8% in dispersed rural areas. Regarding ethnic and cultural diversity, the 2018 National Population and Housing Census identified 1.905.617 people who self-identify as Indigenous, belonging to 115 Indigenous groups, 62 of which are located in the Amazon region, mainly in the departments of Amazonas and Putumayo (Escobar Gutiérrez et al., 2020). This population represents approximately 4,4% of the national total. The departments of La Guajira, Cauca, Nariño, Cordoba, Sucre, and Choco host more than half of Colombia's Indigenous population; however, the most significant growth in Indigenous populations has been observed in Guaviare, followed by Guainia, Vaupés, and Vichada (DANE, 2019).

These communities have established settlements that sustainably use local resources through ancestral knowledge and traditional ecological understanding, enriching Colombia's cultural and linguistic diversity while playing a vital role in natural resource conservation and regional ecological connectivity. Nevertheless, recent years have seen a worrying increase in deforestation, leading to the dispossession of Indigenous lands and the degradation and

destruction of ancestral forests (Lopez Rozo, 2020). According to IDEAM's Deforestation Early Warning Bulletin No. 38 (2024), during the first quarter of 2024, 13 deforestation hotspots were identified. These were driven by large-scale conversion to pasture, land grabbing, poor extensive cattle ranching practices, unplanned transport infrastructure, illicit crop cultivation, illegal logging, agricultural expansion into restricted areas, burning, and illegal mineral extraction. The Amazon region was the most affected, followed by the Andean, Caribbean, Pacific, and Orinoquia regions.

Livestock farming stands out as one of the most significant agricultural activities in Colombia and is one of the main drivers of agricultural frontier expansion. In 2019, the national herd reached approximately 27.239.767 head of cattle distributed across about 39 million hectares. The activity is most concentrated in the Andean region (35,6%), followed by the Caribbean (27,6%), Orinoquia (21,8%), Amazon (9,8%), and Pacific (5,3%) regions, with the departments of Antioquia, Casanare, Meta, Cordoba, and Caqueta showing the highest livestock inventories (DANE, 2020).

In the agricultural sector, according to the 2019 National Agricultural Survey (ENA) conducted by DANE, more than 5 million hectares were under cultivation, with the greatest share held by agro-industrial crops, followed by cereals and forest plantations. Among agro-industrial crops, coffee accounted for 38,4% of cultivated area, palm oil for 25%, and sugarcane for 13,7% (DANE, 2020). Although these crops play a key role in national production and the economy, they have also been associated with increasing deforestation. This dynamic stems from competition between forest cover and the demand for agricultural land: when land productivity fails to meet profit expectations, deforestation becomes an incentive to expand production and maximize economic returns (Gonzalez Arenas et al., 2011).

Regarding mining activity, by 2024 approximately 3% of the national territory was under mining titles, with a predominant concentration in the department of Antioquia. During the first quarter of 2024, the most exploited mineral resources included gold and other precious metals, followed by coal; stone, sand, and clay; and emeralds and other gemstones (National Mining Agency, 2024). However, numerous areas are affected by illegal mining, which causes environmental degradation, deforestation, and social conflicts that directly impact local communities. This underscores the urgent need for effective policies and measures to protect the country's biological and cultural heritage.

To "ensure the continuity of natural ecological and evolutionary processes to maintain biological diversity; guarantee the supply of environmental goods and services for human well-being; and ensure the permanence of the natural environment or its components as the foundation for maintaining the country's cultural diversity and the social value of nature" (Parques Nacionales Naturales de Colombia, n.d.), the National System of Protected Areas (SINAP, or its acronym in Spanish) was established. This system includes several protection categories: National Natural Parks, Protective Forest Reserves, Regional Natural Parks, Integrated Management Districts, Soil Conservation Districts, and Recreation Areas, as well as private protected areas such as Civil Society Nature Reserves. In total, Colombia has 1.700 protected areas covering 49.885.068,36 hectares—representing 16,7% of the country's land surface and 26,3% of its marine area (Parques Nacionales Naturales de Colombia, 2023).

Among these protected areas, the Andean region stand out for housing Los Nevados National Natural Park, Chingaza National Natural Park, and the Rio Blanco Nature Reserve. In the Caribbean region, notable sites include Tayrona National Natural Park, Sierra Nevada de Santa Marta National Natural Park, Los Colorados Flora and Fauna Sanctuary, and the Ciénaga Grande de Santa Marta. In the Orinoquia region, El Tuparro National Natural Park, the Nukak Nature Reserve, and Sierra de la Macarena National Natural Park are prominent. In the Pacific region, Utria and Sanquianga National Natural Parks, the Tribuga Gulf and Bajo Calima Forest Reserves, and the Gorgona Island Flora and Fauna Sanctuary are key areas. In the Amazon, the Serranía de Chiribiquete National Natural Park, the largest in the country, spanning over 4 million hectares (Castaño Uribe, 2019), stands out, along with the Apaporis Park-Reserve, an intercultural co-management model, and the Rio Puré National Natural Park, home to Indigenous peoples with minimal contact with the outside world.

2.2 Biogeography of Colombia

Colombia is categorically divided into nine biogeographic units according to Hernandez et al. (1992). These are: Caribbean oceanic insular territories (Archipelago of San Andrés and Providencia), Pacific oceanic insular territories (Malpelo), the Peri-Caribbean arid belt (La Guajira, Santa Marta, and Cartagena), the Sierra Nevada de Santa Marta Massif, the Chocó–Magdalena biogeographic province (Acandi, Utria, Baudo, Tumaco, Lebrija, Gorgona), the Orinoquia biogeographic province (Casanare, Arauca, Maipures, among others), the Guayana biogeographic province (Ariari, Vaupés, Guaviare, Macarena), the Amazon biogeographic province (Florencia, Putumayo, Caguán, among others), and the Northern Andean biogeographic province (Tolima, Cauca, Huila, among others) (Camacho et al., 1992).

Similarly, the country is composed of seven major biomes. One of them is the biome known as “Seas and Oceans.” In this case, this coverage was not classified, since the priority for Collection 3 is terrestrial cover. Nonetheless, it is important to mention it due to its significant area within Colombian territory; however, it is not the focus of this document as it is not located on the continental landmass. For this reason, it is acknowledged but not analyzed in depth.

The major terrestrial biomes are composed of six zonal and azonal biomes, according to the classification proposed by Walter (1985), who defines a biome as a homogeneous biophysical area framed within a zonobiome, orobiome, or pedobiome that encompasses a group of specific ecosystems. These can be summarized as large, uniform environments of the geobiosphere (Walter, 1985).

According to this classification, the Zonobiome of Tropical Humid Forest contains the largest percentage of area among Colombia’s natural ecosystems, representing 45,4% of the total area of major biomes. The second largest biome is the Pedobiome of the Tropical Humid Zonobiome, with 27,3%, followed by the Orobiome of the Tropical Humid Zonobiome with 18,7%. In fourth place is the Tropical Alternohygric Zonobiome, covering 6,5% of the total biome area. Fifth is the Azonal Orobiome of the Tropical Humid Zonobiome with 1,7%, and finally, the Caribbean Insular Pedobiome with 0,00007% (IDEAM et al., 2017; Walter, 1985). It

is worth noting that the remaining percentage corresponds to seas and oceans, which, as previously mentioned, will not be examined in this document.

For this document, these biogeographic units are recognized and used as references to approach the interpretation of actual land cover. These major and preliminary biomes can be observed in **Figures 2** and **3**, respectively, and are described in **Table 1**. However, the natural regions of Colombia are used for regional division and subsequent classification, dividing the territory into five subregions as shown in **Figure 1.**

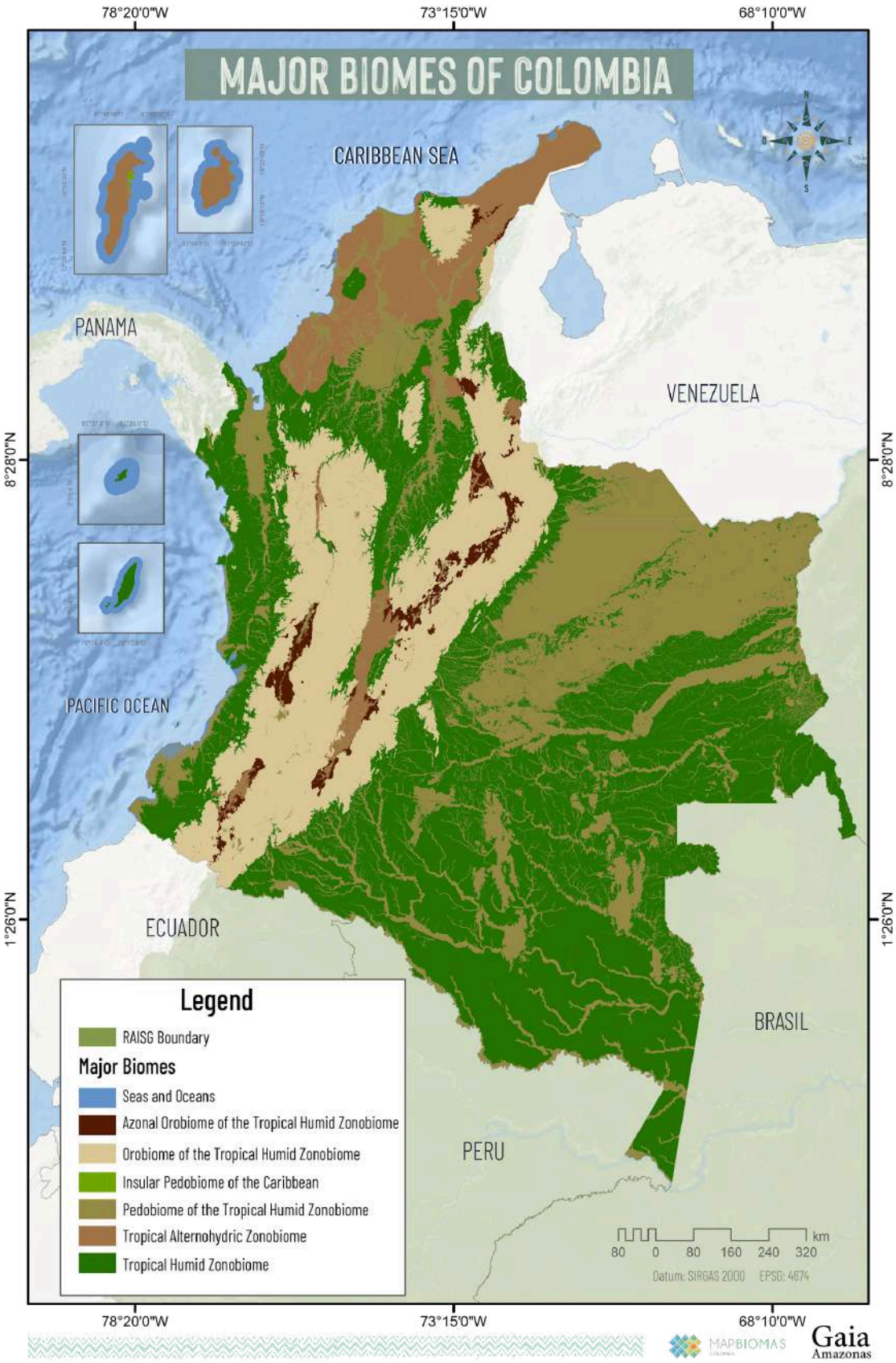


Figure 2 Biogeography Map of Colombia. Major Biomes

Source: Extracted and adapted from the Continental and Marine Ecosystems Layer of Colombia (IDEAM et al., 2017).

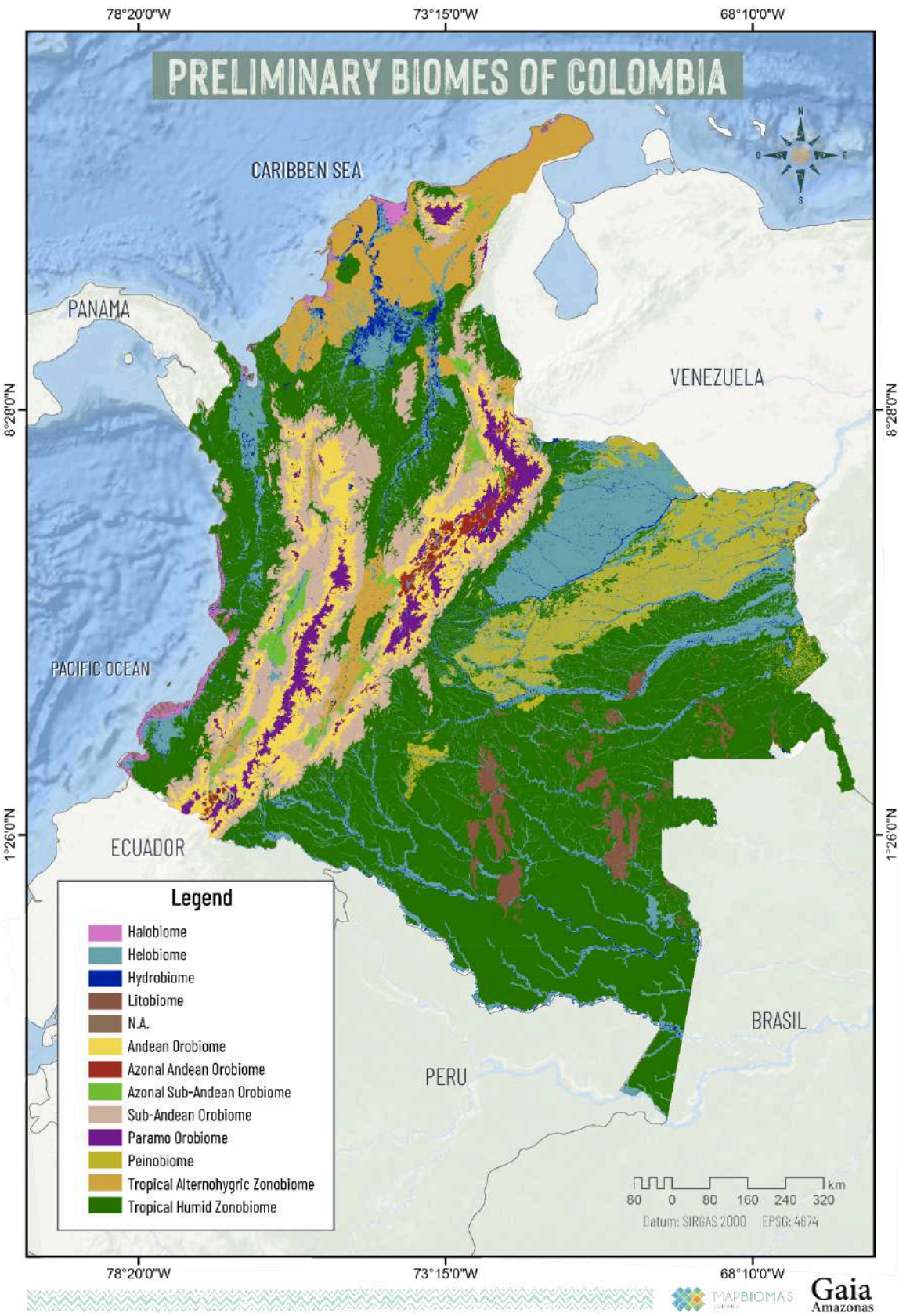


Figure 3 Biogeography Map of Colombia. Preliminary Biomes

Source: Extracted and adapted from the Continental and Marine Ecosystems Layer of Colombia (IDEAM et al., 2017).

Table 1. Preliminary biomes of Colombia.An: Andean. Am: Amazon. Ca: Caribbean. Ori: Orinoquia. Pa: Pacific.

Preliminary biome	Description	An	Am	Ca	Ori	Pa
Halobiome	Areas with poor drainage, permanent waterlogging, or prolonged flooding influenced by marine formation. These areas are identified by discriminating edaphogenetic environments 1 and 2, and their combinations within marine plain landscapes, in addition to the CLC cover corresponding to mangroves, *guandales*, exposed sediments at low tide, and coastal swamps.			●		●
Helobiome	Areas with poor drainage, subject to permanent waterlogging or prolonged flooding. They are differentiated based on edaphogenetic environments 1 and 2, including their respective combinations. The corresponding CLC cover includes peatlands and swampy areas, provided that the landscape is different from a marine plain.	●	●	●	●	●
Hidrobiome	Permanent water bodies within the continental area of the country. They were identified based on the CLC land cover, including the classes corresponding to lagoons, lakes, and swamps (ciénagas), aquatic vegetation over water bodies, rivers, and the edaphogenetic environment class associated with water bodies.	●	●	●	●	●
Litobiome	Rock outcrops located in the Amazon and Orinoquia regions, mostly presenting two climate types: Very Humid Warm (76%) and Humid Warm (24%). The entire area (100%) lies over the geomorphological unit of planation surfaces (plateaus or mountains with flattened summits), predominantly covered by natural forests (90%) and grasslands (7%). They are found over the Guiana Shield and along the Orinoco River, the Serrania de la Macarena, and in the basins of the Guaviare, Inirida, Negro, Vaupés, Yari, and Caqueta rivers (Hernandez & Sanchez, 1992).		●		●	
Andean Orobiome	Located in the altitudinal range between 1800 and 2800 m.a.s.l., these are hygrophytic or sub-hygrophytic forests influenced by a high frequency of fog, with temperatures ranging from 14–15°C to 5–6°C. It corresponds to the Cold climatic belt and to the humidity provinces of Caldas-Lang: humid, semi-humid, and super-humid. According to the Holdridge life zone classification (1964), it includes montane humid forest, montane very humid forest, and montane pluvial forest (Hernandez & Sanchez, 1992; IDEAM et al., 2017).	●	●	●		

Sub-Andean Orobiome	Found in the altitudinal range between 800 and 1800 m.a.s.l., these are hygrophytic or sub-hygrophytic forests of thermal floors ranging from 22–24°C down to 14–15°C. It is characterized by a high frequency of fog, which increases relative humidity and is inversely proportional to evapotranspiration. It corresponds to humid, very humid, and pluvial forests of premontane and montane life zones (Holdridge, 1964), and to the temperate climatic belt and the Caldas-Lang humidity provinces: humid, semi-humid, and super-humid (Hernandez & Sanchez, 1992; IDEAM et al., 2017).	●	●	●	●	●
Azonal Andean Orobiome	Located between 2500 and 3000 m.a.s.l., with mean temperatures between 10 and 13°C and annual precipitation ranging from 500 to 900 mm. Vegetation varies from open grasslands to shrublands 1,5–3,5 m tall and low, relatively dense, and spiny forests that develop on soils derived from volcanic ash, where critical erosive processes occur. These ecosystems harbor species of significant anthropic use, such as various forage and ornamental leguminous plants (Rodriguez & Armenteras, 2006).	●				
Azonal Sub-Andean Orobiome	The best-conserved habitat block of this biome is found in the middle basin of the Chicamocha River, between 400 and 2,200 m a.s.l., within the municipalities of Boavita, Covarachía, Soatá, Tipacoque (Boyacá), and Capitanejo, Cepita, Molagavita, Onzaga, San Joaquin, and San José de Miranda (Santander). Two additional remnants are recorded in the Sogamoso River basin. The natural landscape in this biome has been altered by the introduction of crops and pastures for cattle ranching (Rodriguez & Armenteras, 2006). Like the Azonal Andean Orobiome, it consists of communities with xeromorphic physiognomy, developed over incipiently evolved edaphic units.	●	●			
Páramo Orobiome	This formation occurs above 2.800 m.a.s.l. and corresponds to the Very Cold and Extremely Cold climatic belts, with high humidity levels that may range from humid to semi-humid or super-humid. This orobiome lies above the upper limit of Andean forest formations and below the lower limit of perpetual snow (Hernandez & Sanchez, 1992; IDEAM et al., 2017). It is composed of three sub-orobiomes: subparamo, paramo, and superparamo.	●	●			
Peinobiome	These correspond to the savannas of the Orinoquia–Amazon region, located within the Orinoco River basin, the Middle Magdalena region, the Momposina Depression, and the Tolima Grande area (IDEAM, 2007). These biomes are nutrient-poor and have low water retention capacity, derived from white quartzitic sands. They feature savanna communities interspersed with medium to low-stature	●	●	●	●	

	forests, with sclerophyllous foliage resulting from *peinomorphosis*, or tree stands with slender trunks (Hernandez, 1990).	
Tropical Alternohygric Zonobiome	Corresponds to forests located below 800 m.a.s.l., with long dry periods during which the vegetation loses its foliage, recovering it again during the few rainy months. Identification was based on the Caldas–Lang climatic classification, within the Warm climatic belt and the humidity provinces: arid, desert, and semi-arid.	● ● ● ●
Tropical Humid Zonobiome	Corresponds to the humid forests of isomegathermic zones located below 800 m.a.s.l., where vegetation does not experience a significant water deficit throughout the year, or only a very brief one, maintaining its evergreen character. This biome represents about 45% of the country (51'931.076 ha), making it the most extensive biome in the continental territory (IDEAM et al., 2017). It is delimited by broad climatic, edaphic, and zonal vegetation characteristics that reach the ecological climax. It is mainly characterized by two climate types: Very Humid Warm (60%) and Humid Warm (40%). It predominantly occurs over two geomorphological units: fluviogravitational and structural-erosional hills (86%) and alluvial plains (13%), covered mainly by natural forests (92%), pastures (6%), and grasslands (2%).	● ● ● ● ●

2.2.1 Andean Region Biogeography

The Andean region borders the Caribbean region to the north, the Orinoquia and Amazon regions to the west, the Pacific region to the east, and Ecuador to the south. This region, home to some of the country's largest urban centers, including its capital, is composed of three mountain ranges, as shown in **Figure 4**: the Western Range, 820 km long with average elevations between 1500 and 5000 m; the Eastern Range, 1500 km long with average elevations between 1500 and 4500 m; and the Central Range, 850 km long with average elevations between 3000 and 5100 m (Narvaez & Leon, 2001). Their respective maximum elevations reach 4280 m, 5330 m, and 5750 m (Alvarez, 1983). On the summits of the latter two ranges lie five of the six glacial masses of the country, one located in a mountain range (Sierra Nevada del Cocuy) and the others on volcanoes and mountains such as Ruiz, Santa Isabel, Tolima, and Huila (Ceballos et al., 2012). Consequently, the region encompasses climates ranging from cold and paramo in Boyaca to warm in Norte de Santander and Tolima. Likewise, the Colombian Andean region exhibit a bimodal rainfall pattern (Baena Salazar et al., 2020), and above the high Andean forests and below the snow line lies the Andean paramo mountain ecosystem, with Sumapaz standing out as the largest in the world (Ambiente Bogotá, 2017).

This region has been highly influenced by human activities in recent decades (Rodriguez et al., 2004), making it the second most deforested after the Amazon, mainly due to extensive cattle

ranching, grassland expansion, illicit crops, transport infrastructure, forest fires, and illegal mineral extraction (Rudas et al., 2007). The latter activity is led by the department of Boyaca, accounting for 54% of the country's coal extraction, although metallic minerals and precious stones are also exploited in other areas and departments (Baena Salazar et al., 2020). It is worth noting that the Colombian Andean region concentrates important agricultural areas, where productive clusters such as the sugarcane belt, extending from Risaralda to Cauca (Méndez et al., 2018), and the rice-producing elite historically developed in the Ibagué plateau (Santos & Sanabria, 2021) can be identified.

Similarly, the country's most important water bodies are located in this region, including reservoirs, dams, and lakes such as Neusa, Guavio, and Chingaza, respectively. These landscapes contrast with arid and semi-arid zones mainly located in the Caribbean and Andean regions, the latter including the subxerophytic semi-arid zone of the Tatacoa Desert (Minambiente, 2000). Finally, the region is also prone to flood events, most frequently recorded in Cundinamarca and Antioquia, while forest fire events are more recurrent in Tolima and Cundinamarca, with the latter showing the highest number of occurrences (Baena Salazar et al., 2020).

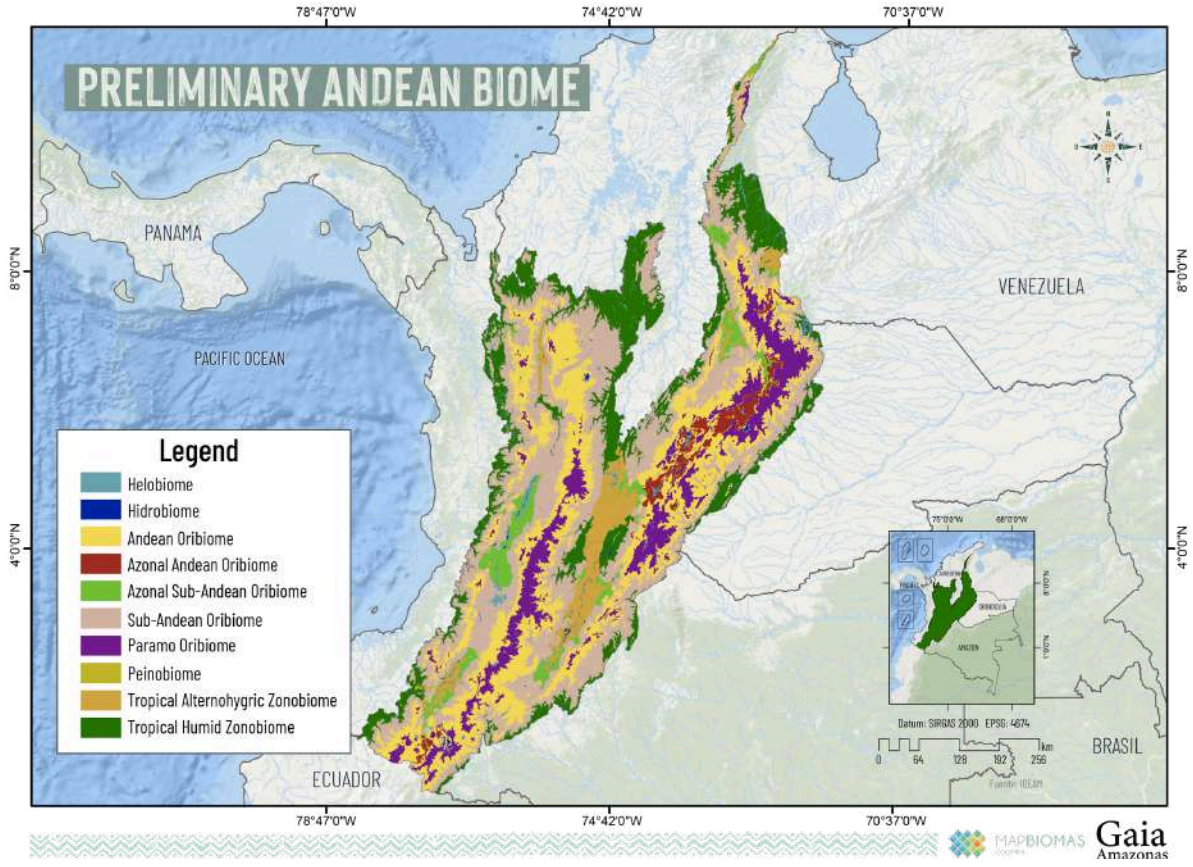


Figure 4 Biogeography of the Colombian Andean Region. Preliminary biomes.

Source: Extracted and adapted from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

2.2.2 Amazon Region Biogeography

This region is composed of five zonal and azonal biomes, with the Tropical Humid Forest Zonobiome containing the largest proportion of area among natural ecosystems of Warm Humid climate, representing 64,9% of the surface, as shown in **Figure 5**. It is followed by the Litobiomes, which account for 14,5% of the area in rocky formations. Also noteworthy is the 12% of the territory influenced by aquatic environments such as alluvial plains, known as Helobiomes. Finally, the Peinobiomes occupy 3,4% of the surface in upland plains (*altillanuras*) (Murcia Garcia et al., 2007). It is worth mentioning that within these biotic units lie most of the representative ecosystems of the Amazon region, such as terra firme forests, flooded forests, natural savannas, rock outcrops, catingas, and shrublands (Hernandez & Sanchez, 1992).

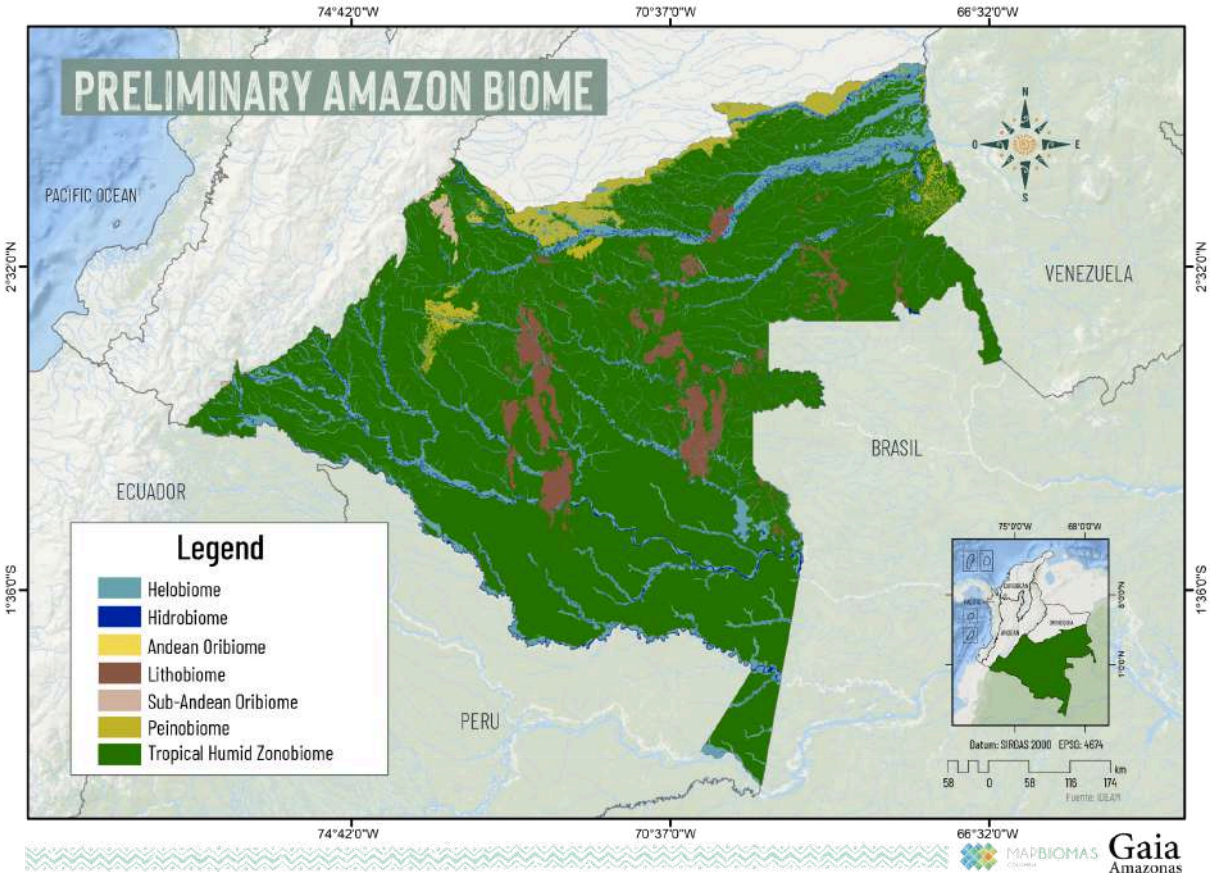


Figure 5 Biogeography of the Colombian Amazon Region. Preliminary biomes.

Source: Extracted and adapted from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

2.2.3 Caribbean Region Biogeography

The Caribbean region (Figure 6) borders Venezuela to the east, the Andean and Pacific biogeographic regions to the south, and the Caribbean Sea to the north, where Colombia's insular department comprising the islands of San Andrés, Providencia, and Santa Catalina is located. This region also contains major urban centers such as Barranquilla, Cartagena, and Santa Marta (Chala-Rosado et al., 2020). Most of its territory consists of lowlands and flat areas, with the exception of the Sierra Nevada de Santa Marta (Ceballos et al., 2012), one of the country's principal mountain and glacial systems. From a hydrological perspective, the region

presents a wide and diverse coverage of water bodies, including the Ciénaga Grande de Santa Marta to the north and La Mojana subregion to the south (Meisel & Pérez, 2006). These aquatic systems, together with the Sierra Nevada and major rivers such as the Magdalena, Cauca, and Sinu, create a complex hydrological dynamic characterized by recurrent flooding events, also influenced by climatic variability.

The region hosts three RAMSAR wetlands: the Magdalena River delta-estuarine system (Ciénaga Grande de Santa Marta), the Zapatosa wetland complex, and the Ayapel wetland complex (RAMSAR, 2018). It also contains an extensive mangroves area of national ecological importance (Mejía et al., 2014). Among the region's main anthropogenic features, coal production stands out as the primary export activity, making mining one of its most significant economic activities (Chala-Rosado et al., 2020), alongside agricultural production of crops such as banana, cotton, maize, and rice. Finally, the region exhibits extreme climatic conditions, ranging from the arid zones of La Guajira Peninsula to the high-altitude environments of the Sierra Nevada de Santa Marta, with a bimodal rainfall regime (Chala-Rosado et al., 2020).

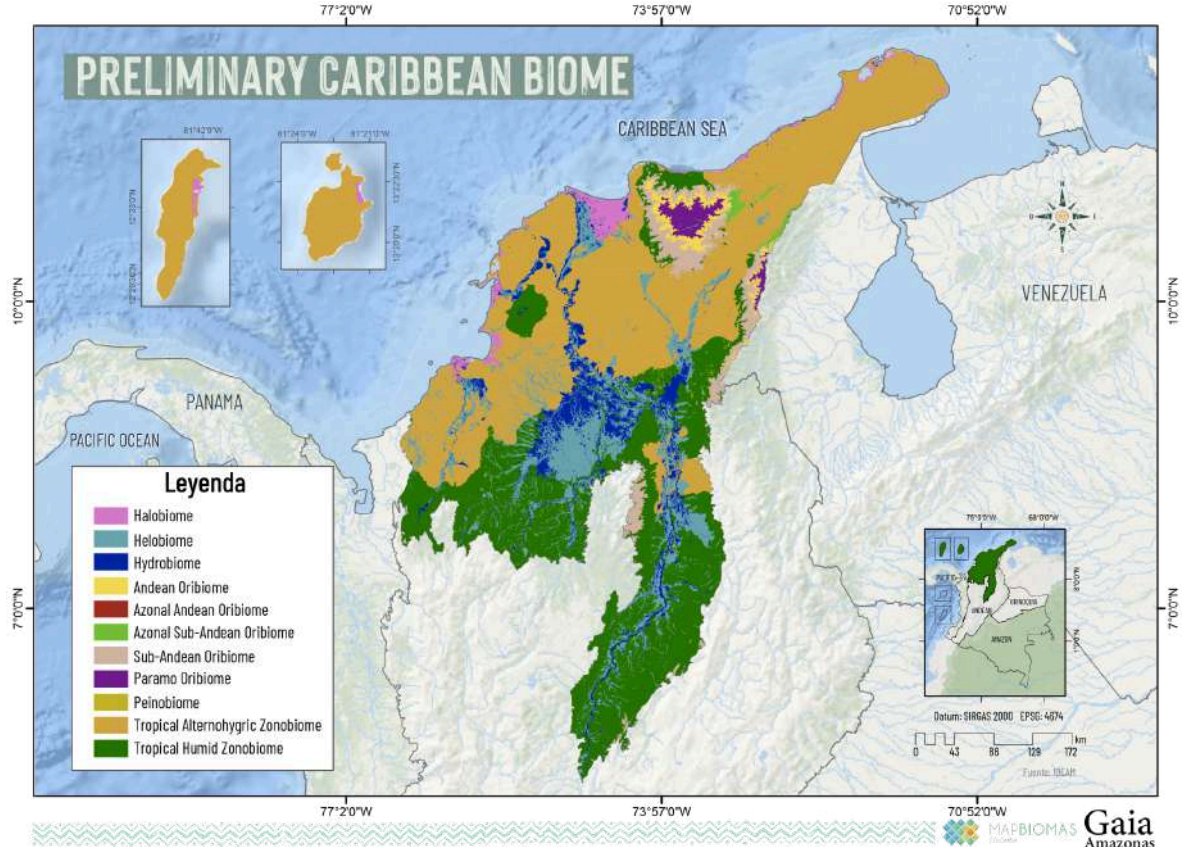


Figure 6. Biogeography of the Colombian Caribbean Region. Preliminary biomes.
Source: Extracted and adapted from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

2.2.4 Orinoquia Region Biogeography

The Orinoquia region, shown in **Figure 7**, comprises parts of the departments of Arauca, Casanare, Meta, and Vichada, covering an area of approximately 152.623 hectares, where more than 200 water bodies can be found. Among these, the main rivers stand out: Meta,

Vichada, Orinoco, and Arauca. Likewise, the Bita River Basin Wetland Complex, part of the Ramsar wetlands, is identified within this region. The Colombian Orinoquia classifies wetlands into four categories and six complexes (Arauca, Casanare, Vichada, Tomo, Guaviare, and Inírida) (Lasso et al., 2014).

The region is characterized by geomorphological units such as floodplains with aeolian influence, fluvio-lacustrine floodplains, abandoned meanders, divagation plains, and sandbars (Vargas, 2015). It exhibits high rainfall patterns ranging from 2.000 to 3.000 mm across most of its territory, reaching 6.000 mm in the foothills and around 1.500 mm in northern Arauca. The area has a monomodal precipitation regime between May and October, with temperatures between 24 and 28°C (Henriquez, 2005). These conditions favor the development of characteristic vegetation such as humid forests, riparian forests, extensive savannas composed of grasses that, together with *moriche* palms, help retain water in these zones; low, shrubby vegetation adapted to enhance water retention; flooded forests, and large wetland complexes that cover a vast portion of the Orinoquia (Romero Ruiz et al., 2004; Velandia, 2020).

Within the region, extensive cattle ranching is one of the most significant forms of land use and occupation, with Casanare standing out as the department with the largest cattle population, followed by Meta and Arauca. Likewise, palm oil cultivation is a major economic activity in the Orinoquia due to its high potential and both national and international demand, leading to significant land-use transformation from natural savannas to large palm plantations (Velandia, 2020). Another highly relevant activity in the region is oil extraction, since on average 64% of the region's economy depends on the hydrocarbon sector, contributing over 70% of national production. Finally, mining activities in the Orinoquia are mainly focused on the extraction of materials from sedimentation zones of the major rivers, such as the Vichada River and the Inirida River (Velandia, 2020).

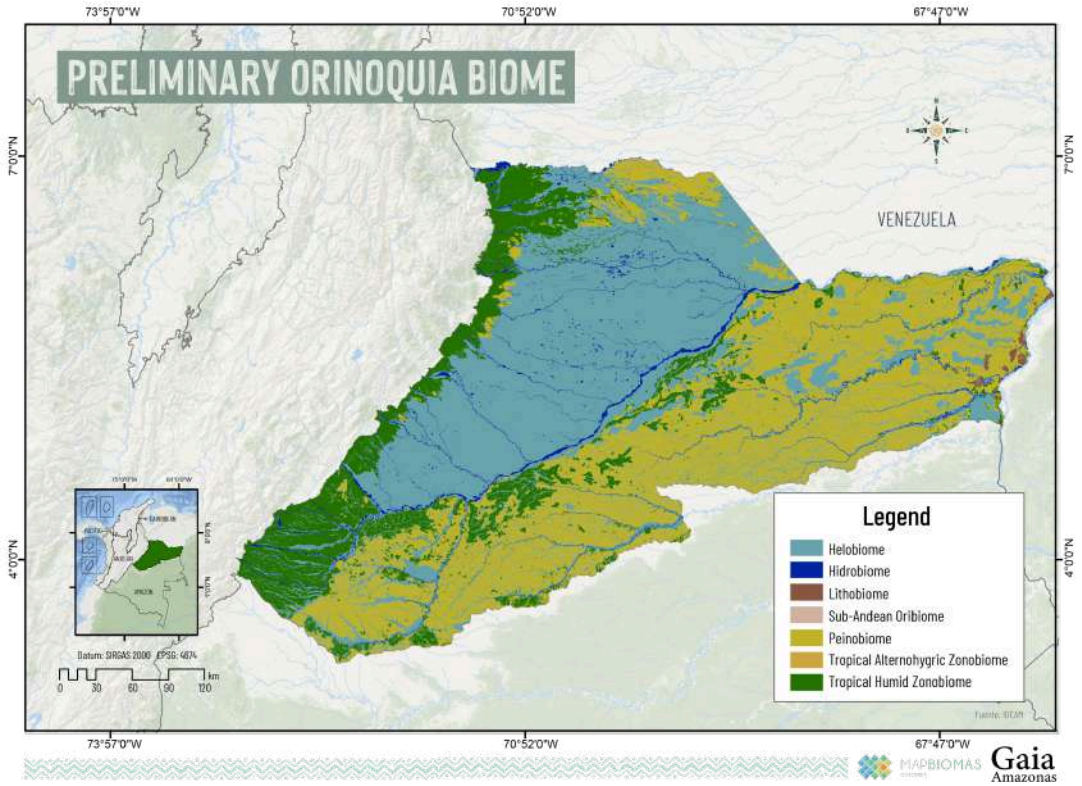


Figure 7 Biogeography of the Colombian Orinoquia Region. Preliminary biomes.

Source: Extracted and adapted from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

2.2.5 Pacific Region Biogeography

The Pacific region, shown in **Figure 8**, is characterized as a natural region encompassing the territories of four departments —Choco, Valle del Cauca, Cauca, and Nariño— which share similar environmental conditions (Restrepo, 2023). It is located along the western strip of the country, bordering Panama to the north, the Caribbean region to the northeast, the Western Range (which separates it from the Andean region) to the east, Ecuador to the south, and the Pacific Ocean to the west, from which it takes its name. The insular area of the Pacific is composed of two main islands: Malpelo Island and Gorgona Island.

The region is distinguished by soils with limitations for agricultural production, mainly due to low nutrient content (Casierra-Posada & Aguilar-Avendaño, 2007). Nevertheless, there is the presence of palm oil plantations and pastures around Tumaco, in the southeastern part, , while banana, forest plantation, and palm oil crops are cultivated in the northern zone bordering the Darién region. For this reason, it can be stated that most of the region is composed of dense forests and jungles, large rivers, and the most extensive mangrove systems in South America, which cover 2.927 km² (Zambrano & Rubiano, 1996). These mangroves have represented, for Afro-Colombian and Indigenous communities of the Pacific coast, an economic, social, and cultural opportunity for many years (Sanchez-Paez et al., 1998).

Additionally, the region contains a Ramsar site known as the Baudo River Delta. This system is composed of shrubby swamps, slow-flowing permanent rivers, flooded forests, mangroves, sandy beaches, shallow marine waters, and estuarine waters. It is characterized by high

biodiversity of flora and fauna and is of vital importance to local communities (Baudo River Delta - Ramsar Sites Information Service, n.d.).

Finally, it is important to emphasize that although the region is rich in biodiversity, with a wide variety of flora and fauna and several protected areas, it has faced significant challenges related to mining. This activity, along with the presence of various actors in the region, has had serious environmental impacts, including the pollution of water sources, largely due to gold mining (Observatorio Pacifico y Territorio – OPT, 2022).

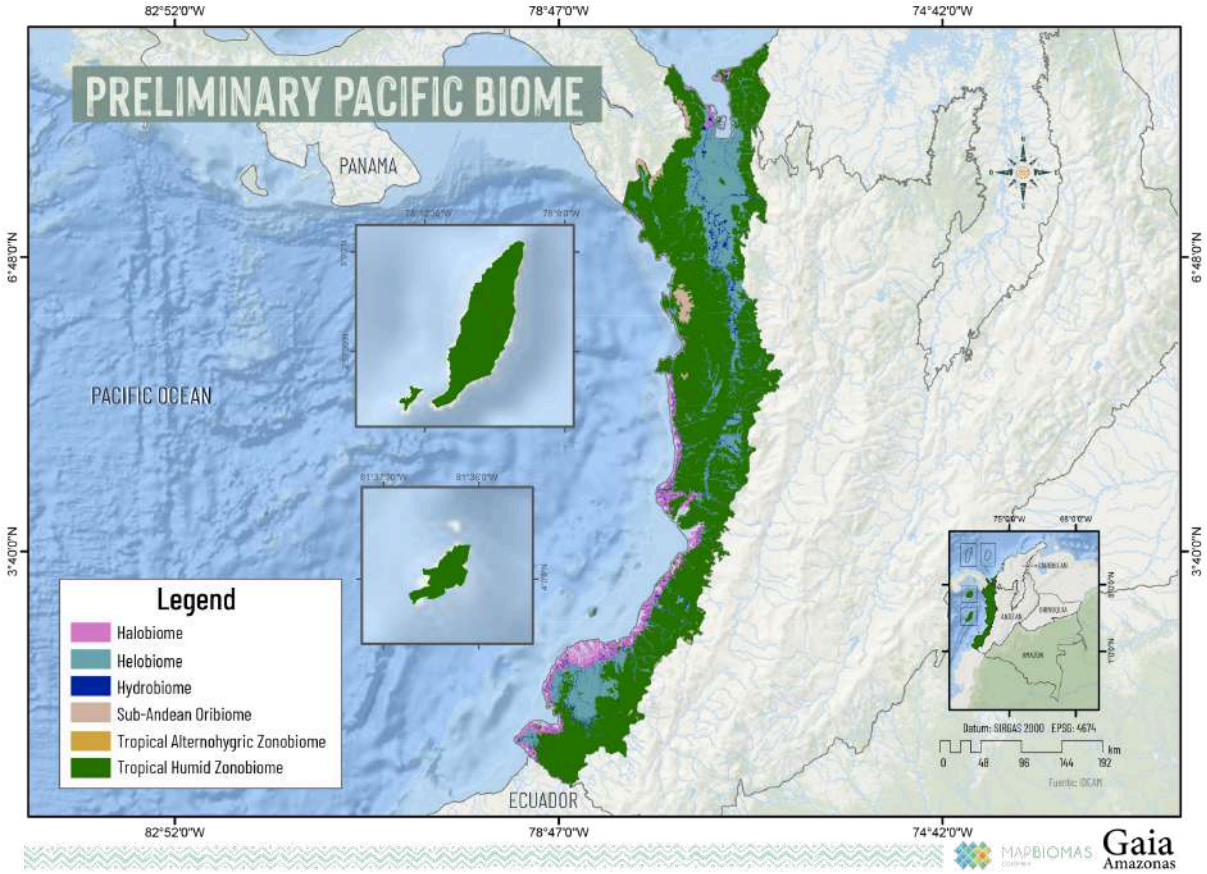


Figure 8 Biogeography of the Colombian Pacific Region. Preliminary biomes.

Source: Extracted and adapted from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

3. Basic Information and Background

3.1. Institutional Context

3.1.1 Institution

Fundación Gaia Amazonas is a Colombian non-governmental organization that works in close collaboration with Indigenous communities to protect the biological and cultural diversity of the Amazon. Its comprehensive and multidisciplinary approach is based on intercultural dialogue, diversity of knowledge systems, and shared responsibility among Indigenous communities, the State, civil society, and the private sector, with a gender-sensitive perspective. Through alliances and concrete actions, the foundation seeks to conserve the

biodiversity and culture of the Amazon, strengthen Indigenous governance, and promote public policies for environmental protection.

Since its establishment in the 1970s, Gaia Amazonas has worked to achieve the recognition of the rights and territories of Indigenous communities in the Colombian Amazon. Among many achievements, it has promoted educational autonomy, supported the creation of community schools, facilitated successful negotiations with armed groups to ensure respect for Indigenous communities, and contributed to the partial decentralization of health services. Over the years, the foundation has consolidated local Indigenous governments, strengthened Indigenous councils, improved the quality of community education and health, and advocated for public policies aimed at protecting the Amazon rainforest.

3.1.2 MapBiomas

MapBiomas is a collaborative initiative aimed at mapping land cover and land use in the Amazon using advanced technologies. Through cloud-based processing and automated classifiers on Google Earth Engine, historical annual maps of the region are produced. The project emerged in 2017 as a result of collaboration between the Red Amazonica de Informacion Socioambiental Georreferenciada (RAISG, for its acronym in Spanish) and MapBiomas, with the objective of providing detailed and up-to-date information on land-use dynamics in the Amazon.

The project stands out for its collaborative network-based approach, working jointly with institutions from the countries involved. In addition, it seeks to create an open, replicable, and collaborative platform to foster the participation and contributions of actors from the scientific community. This initiative contributes to a better understanding of land-use dynamics in the Amazon and its changes over time, facilitating informed decision-making for the conservation and sustainable development of the region. It is worth noting that the initiative has recently expanded beyond the Amazon boundaries in the participating countries.

3.2. Remote Sensing Data

The MapBiomas Colombia initiative used a dataset obtained from the Landsat sensors Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager and Thermal Infrared Sensor (OLI–TIRS)— onboard the Landsat 4 satellite (L4, used to fill data gaps at the beginning of the time series, mainly in 1988), Landsat 5 (L5, for the years 1985–2012), Landsat 7 (L7, for the years 2000–2022), Landsat 8 (L8, from 2013 onward), and Landsat 9 (L9, for the years 2021–2024). For the third collection, satellite imagery was gathered for the period 1985–2024.

The images used to obtain Surface Reflectance belong to Collection 2 of the Landsat data catalog. These images are classified as Tier 1, which means they have undergone radiometric calibration, orthorectification based on ground control points and digital elevation models, ensuring accurate pixel-level registration and appropriate atmospheric correction.

It is important to note that the Landsat images with a 30-meter spatial resolution were accessed through the Google Earth Engine platform, supported by NASA and the United States Geological Survey (USGS). This allowed MapBiomas Colombia to obtain a reliable and consistent dataset to carry out its land mapping initiative across Colombian territory.

3.3. Other Mapping Initiatives

The mapping of land cover and deforestation is also carried out by other international, national, and regional initiatives, whose products serve as reference and validation inputs for the maps produced by MapBiomas Colombia. At the international scale, the Global Forest Watch (GFW) initiative, led by the World Resources Institute (WRI) in collaboration with the Global Land Analysis & Discovery (GLAD) laboratory at the University of Maryland, Google, USGS, and NASA, measures areas of tree cover loss across the Earth (excluding Antarctica and Arctic islands) at a 30 × 30-meter resolution. This project focuses on developing data products based on Landsat satellite imagery, made available through the Global Forest Watch 2.0 web platform (https://www.globalforestwatch.org/). From the GFW platform, users can download annual forest cover change data (gain and loss) from 2000 to 2024, which were used in this collection to verify deforestation and land cover change mapping.

Another global initiative was produced by ESRI for 2020 (ESRI 2020 Global Land Use Land Cover), in which land use and land cover are identified through the use of Sentinel-2 satellite images, using more than 5 billion pixels distributed across 20.000 sites in the main biomes of the world. Similarly, the ESA initiative uses Sentinel-2 satellite images as a source of information, which, when combined with Sentinel-1 data, produces a global land cover classification that includes 11 thematic classes with an accuracy of 75%. The Dynamic World initiative, developed by the World Resources Institute (WRI) together with Google, identifies global land cover types, grouped into nine thematic classes, using Sentinel-2 satellite images.

At the national level, among the initiatives for mapping deforestation and land cover in Colombia, the one developed by the *Instituto de Hidrología, Meteorología y Estudios Ambientales* (IDEAM) stands out. This initiative is reflected in two projects: the land cover map, which uses the CORINE Land Cover (CLC) methodology; and the annual forest loss map of Colombia, generated through the *Sistema de Monitoreo de Bosques y Carbono* (SMByC). The first project was used for the verification and confirmation of specific land cover types for Colombia.

At the regional level, the *Instituto Amazónico de Investigaciones Científicas* (SINCHI) is responsible for mapping land cover in the Amazon region, following the CORINE Land Cover methodology adapted for Colombia at a 1:100.000 scale. This mapping has freely available data for 2002 and 2007. Additionally, since 2012, updates have been made every two years, corresponding to the periods 2012–2014, 2014–2016, 2016–2018, and, from 2020 onward, annually until 2024. Recently, SINCHI has produced open data for the Forest / Non-Forest layer at a 1:10.000 scale and for the land cover layer at a 1:25.000 scale, updated annually since 2018. This more detailed monitoring is carried out only in priority areas of the Colombian Amazon, due to high deforestation rates and the interest of government entities in monitoring forest loss.

Unlike the previous initiatives, the MapBiomas Project is implemented by non-governmental organizations in each country of the network, which are responsible for mapping the territory of their respective countries. Thus, the cartographic process is carried out by experts from each country who possess field knowledge and understanding of the geographical particularities of each region. In this way, annual maps of land use and land cover changes are generated using Landsat image series from 1985 to 2024, with a 30-meter spatial resolution at a 1:100.000 scale, which represents an advantage for monitoring various land cover classes due to its temporal range and thematic scope. Likewise, for this collection, the use of images generated by the Landsat 9 satellite continued, providing an improvement in data quality for the last two years of the series.

In this regard, given the scope of Collection 3, additional reference sources were also used for the validation of land cover classification, among which high spatial and temporal resolution satellite images stand out. Among these were those provided by Microsoft Bing, ESRI, ESA, Planet-NICFI, CIFOR, and Google, which made it possible to verify the type of land cover. Of these, the images developed by Planet-NICFI are noteworthy because of their monthly temporal resolution, which allowed the identification of land cover changes since 2015, proving especially important in identifying deforestation trends in recent years.

Likewise, for this collection, other secondary information sources obtained from open platforms were implemented to improve the accuracy of land cover mapping. For the mining thematic class, external reference sources included information from projects such as CoMiMo (Colombian Mining Monitoring) and EVOA (Evidence of Alluvial Gold Exploitation). Likewise, CIFOR (Center for International Forestry Research) data were used for the validation of flooded forests and wetlands while, for the mapping of Infrastructure data, ESRI Built Area data were used to identify small Infrastructures.

3.4. Google Earth Engine and MapBiomas

Google Earth Engine (GEE) is a cloud computing platform developed by Google that enables the analysis and visualization of large-scale geospatial data. Its strength lies in the ability to process massive volumes of satellite and geographic information without the need for complex local infrastructure, since all operations take place in the cloud. Through its JavaScript and Python APIs, it facilitates the development of custom applications and analyses, while its visualization tools provide a robust environment for exploring spatial information.

The MapBiomas initiative has adopted Google Earth Engine as its main technological platform for processing and analyzing satellite data. Thanks to access to a wide collection of historical and recent images, it is possible to perform detailed temporal assessments of land cover and land use. Cloud-based processing makes it possible to manage large data volumes efficiently and to generate high-resolution maps that reflect the dynamics of the territory. In addition, MapBiomas teams design specific algorithms that, through the GEE API, are automatically executed to classify and map different types of land cover, ensuring regular and accurate updates. The results can be visualized interactively and shared with the community, reinforcing the collaborative and open nature of the project.

4. MapBiomas Colombia Methodology

4.1. Landsat Mosaics

4.1.1. Generation of Landsat Mosaics

The MapBiomas Colombia methodology uses a compilation of Landsat images produced annually from 1985 to 2024 as the basis for mapping land cover. The main objective of creating the mosaics was to obtain a yearly compilation of Landsat images that includes both dry and rainy seasons. This approach allows for better contrast between forest and non-forest classes, minimizes cloud cover to reduce its impact on land cover classification, and ensures the most up-to-date imagery for each year. As a result, it provides an updated record of the annual dynamics of each area.

The reference unit used for the mosaic construction process across all regions was the Worldwide Reference System (WRS), the system used by Landsat to organize its imagery using Path and Row numbers. Satellite images from Landsat sensors 4, 5, 7, 8, and 9 employ the WRS-2 system. Each path-row covers an area of approximately 183 × 170 km, or 31.110 square kilometers. Table 2 summarizes the number of path-rows per region.

Table 2. Number of path-rows per region.

Region	Number of path-row	Mosaics total (x40 years)
Caribbean	17	4240
Andean	34	
Pacific	10	
Orinoquia	11	
Amazon	34	

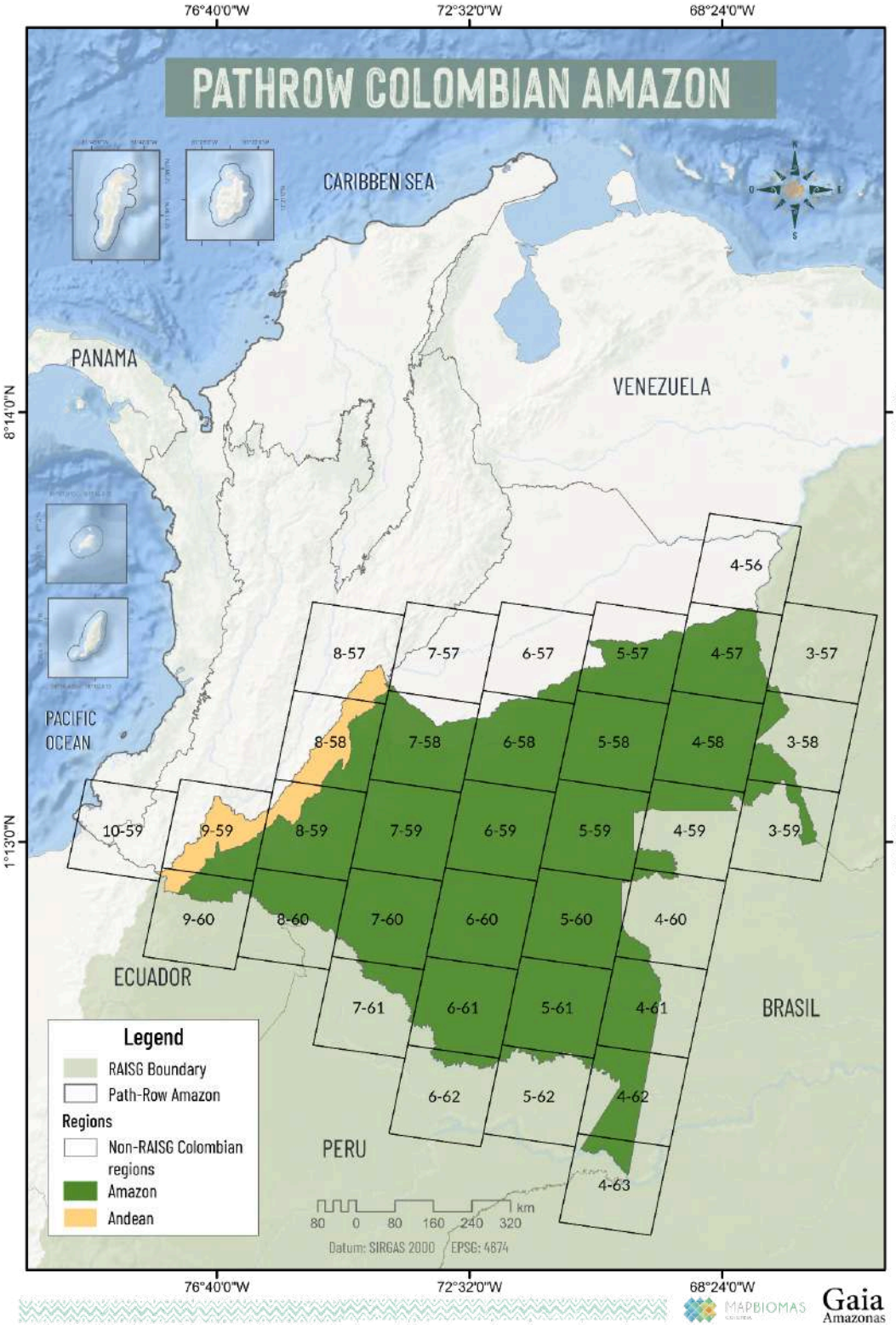


Figure 9 Pat/Rows Colombian Amazon

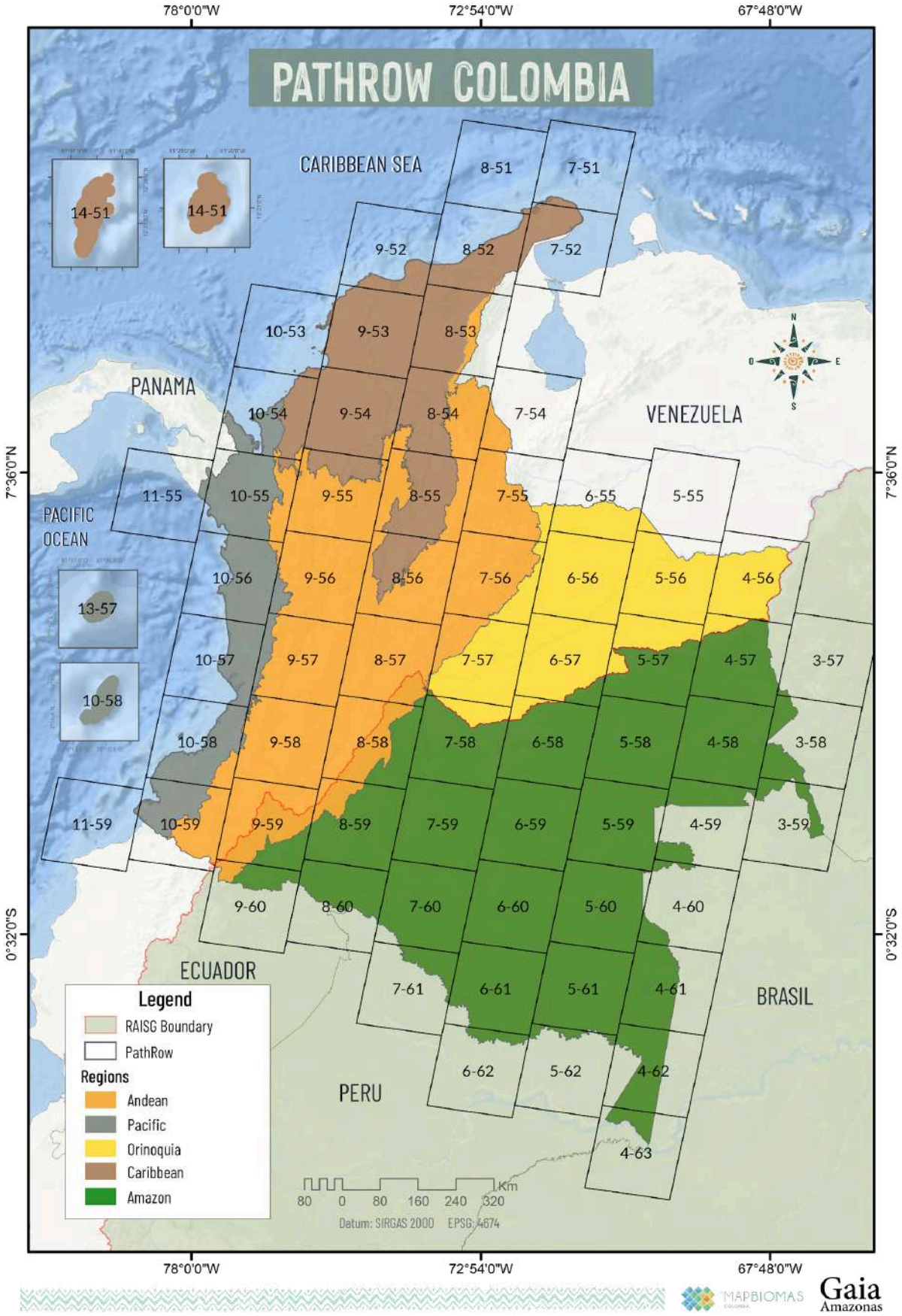


Figure 10 Path-Rows Colombia

Median mosaic:

For each Path-Row and for each year, a mosaic of Landsat images from series 4, 5, 7, 8, and 9 was created. Each mosaic is composed of at least two images, where the value of each pixel per band in the composition is assigned using the median value of the selected set of images (visible red, near infrared, and mid infrared spectrum), as shown in **Figure 11**.

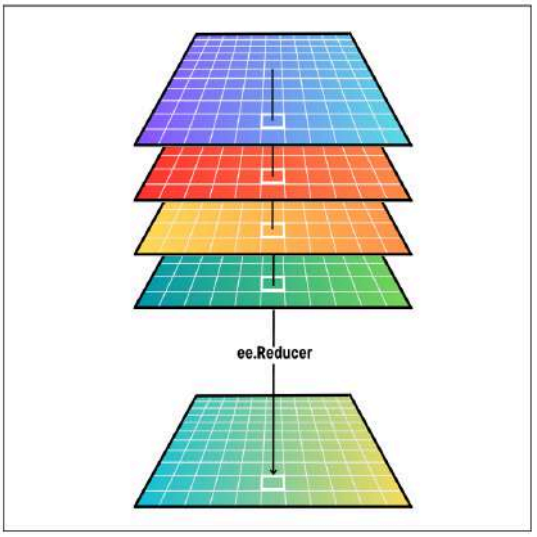


Figure 11 Median pixel

In this process, the pixel used for classification corresponds to the median value of the time series. For example, if for a map the final mosaic is composed of images acquired between the months of October and December with a maximum cloud cover percentage of 30%, the remaining clouds or shadows were first masked, and then the median statistical reducer was used to construct the final interpretation mosaic. Each map was processed individually using the median value among the images selected for each year of the 1985-2024 time series.

Figure 12 shows the mosaics for the continental territory of Colombia. Due to a lack of information in the Landsat collections or high cloud cover, there are gaps throughout the time series. These information gaps are most evident at the beginning of the series, between 1985–1988 and 1992–1996, particularly in high mountain areas such as paramos and glaciers, as well as in the Choco biogeographic region. This situation particularly affects the results in areas with highly dynamic changes in land cover, where the method's ability to fill these gaps is insufficient.

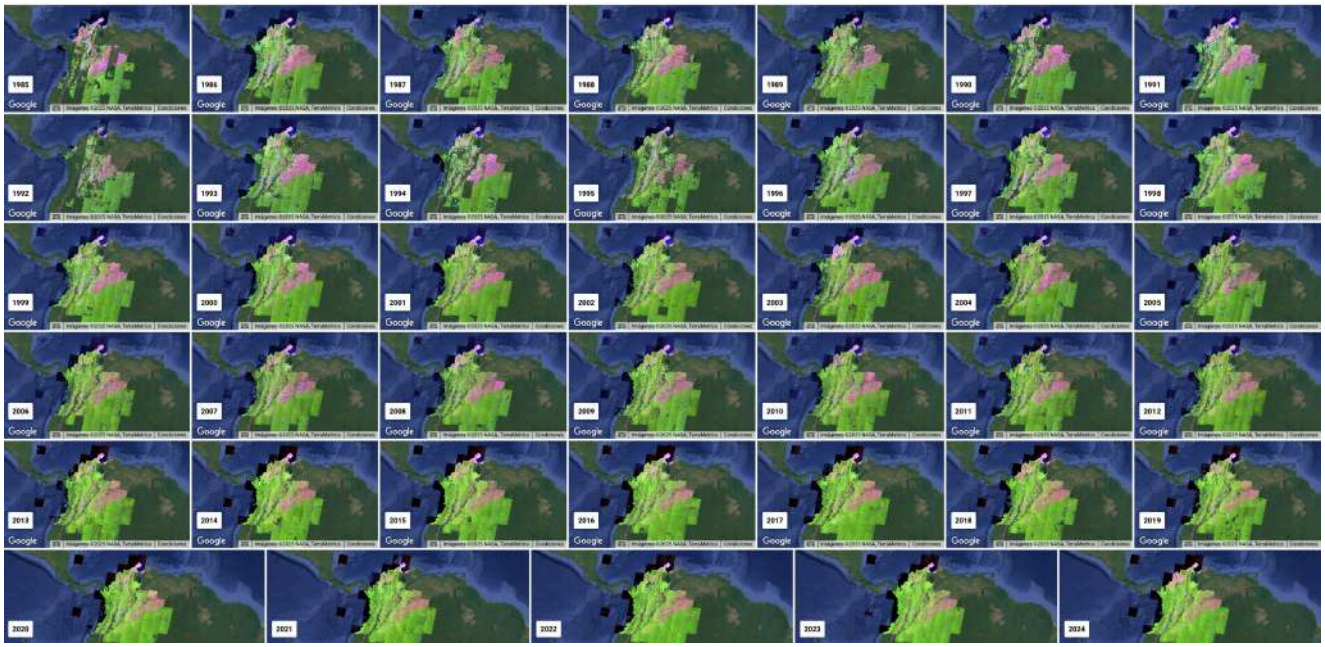


Figure 12 Landsat Collection 3 Mosaics - MapBiomas Colombia C3
https://code.earthengine.google.com/6220d13ce4b39406656db3f4d769beac?noload=true

4.1.2. Mosaic regions

Given the different physiographic and climatic characteristics of the Colombian territory, the mosaics were divided into two regions, Andean and the Lowlands, according to the difference in altitude between them, with the Andean region comprising the entire high mountain area of Colombia (**Figure 13**). This was done in order to improve the quality of the mosaics, since altitude is directly related to cloud cover, which affects the information obtained by the optical sensor used, in this case, the Landsat satellites.

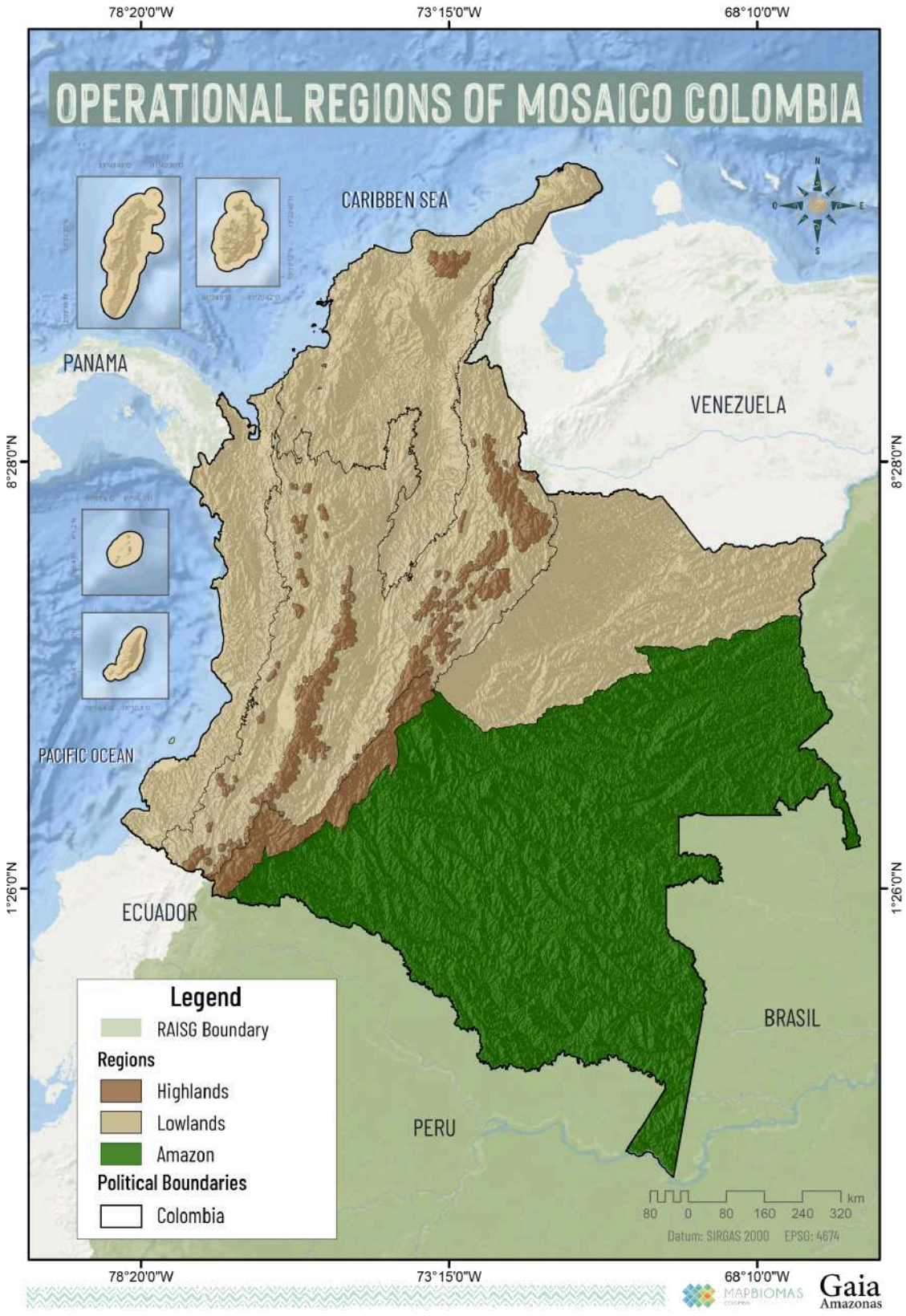


Figure 13 Operational regions of Mosaic Colombia

4.1.3. Mosaic Quality Assessment

A visual evaluation of the mosaics was conducted for each year, considering the parameters of coverage, cloud presence, banding, and shadow presence, through which the quality of each mosaic was assessed annually in three categories. The values indicate the percentage thresholds of the surface area affected by each evaluated parameter within each grid, as shown in **Table 3.**

Table 3. Mosaic Quality Parameters

Quality	Symbol	% Coverage	% Cloud Noise	% Banding Noise	% Shadow Noise
Good	G	>90	< 5	< 5	< 5
Fair	F	65 - 90	5 – 10	5 – 10	5 – 10
Poor	P	< 65	> 10	> 10	> 10

It is important to note that for the "poor" category, mosaic quality can still be considered relatively acceptable. Although these mosaics may not cover a large area or may exhibit certain levels of banding, shadows, pixel overexposure noise, or data gaps due to high cloud cover, they still provide useful information for the classification process. These adverse effects can lead to classification errors; however, they can be mitigated through a series of filters applied during the classification stage.

For the 40-year time series covering the entire Colombian territory, a total of 4.240 mosaics were generated. Of these, 41% were evaluated as good quality, 42% as fair, and 15% as poor. Additionally, 96 mosaics lacked sufficient information to meet the minimum composition threshold required for use in the classification stage.

Regarding overall mosaic quality (**Table 4**), the Pacific region shows the highest proportion of mosaics without information (18%) and of poor quality (20%), highlighting the limitations in the availability of input data. Similarly, the Andean region presents 21% poor-quality mosaics and 42% in the fair category. These deficiencies in both regions are mainly explained by persistent cloudiness in the Pacific and orographic cloud formation in the Andes, which restrict the availability of clear images needed to generate high-quality mosaics. Conversely, the regions with the best results are the Orinoquia and the Amazon, with 58% and 48% good-quality mosaics, respectively, followed by the Caribbean region with 44%. These regions show greater consistency in the generation of input data, allowing for more accurate and reliable analyses of land cover and land use.

Table 4. Percentage by mosaic quality category relative to the total number of images available for each Region

REGIONS	NO DATA	POOR	FAIR	GOOD
Andean	4%	21%	42%	33%
Amazon	3%	8%	41%	48%
Caribbean	4%	7%	45%	44%
Orinoquia	1%	14%	27%	58%
Pacific	18%	20%	43%	19%

Finally, **Figure 14** shows the multitemporal mosaic, where the spatial distribution of mosaic quality across the entire country is consolidated.

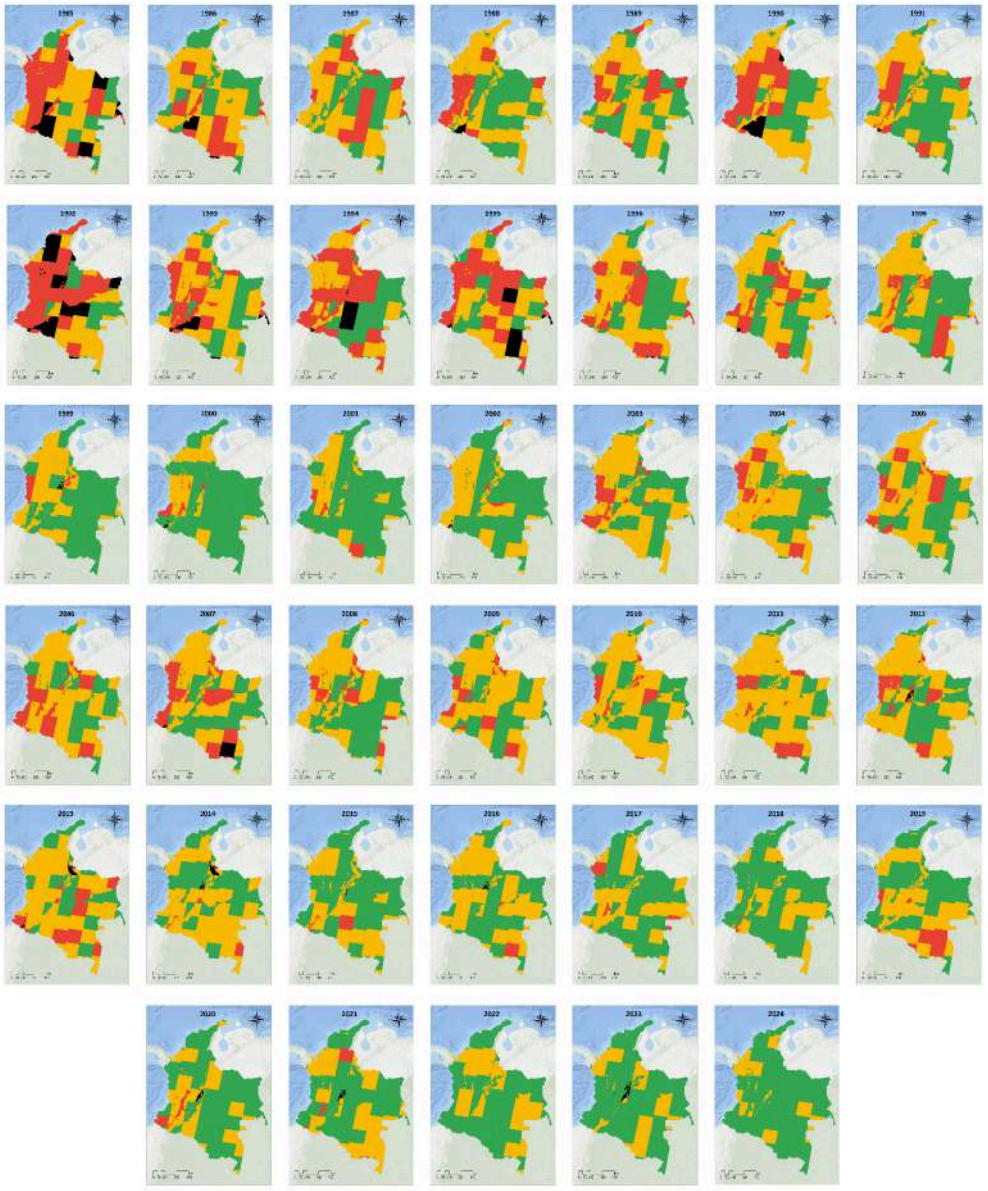


Figure 14 Mosaic quality 1985 - 2024

Mosaic evaluation by regions

It is noteworthy that in the Andean and Pacific regions, there is a higher percentage of fair-, poor-quality, or no-data mosaics, mainly due to limited Landsat data availability, especially between 1985 and 2002. From that year onward, mosaic quality improved thanks to the stability of the Landsat archive. Some Landsat 4 images were also included to fill data gaps prior to 1993, in addition to the availability of Landsat 5 data up to 2011. Landsat 5 and Landsat 7 share similar characteristics, allowing the combination of images from both sensors to generate median mosaics. Landsat 8, which began operating in 2013, brought greater stability in image acquisition, thereby improving mosaic composition. Consequently, since 2014, mosaic quality has significantly improved, with a reduction in the poor and fair categories in the Amazon region. Additionally, for the 2021 and 2022 mosaics, available Landsat 9 imagery was incorporated. The following section presents the evaluation for each biome.

Andean region: In the Andean region, mosaics from 1985 to 1996 are of poor quality. From that year onward, the mosaics begin to improve; however, poor- or fair-quality mosaics persist in high-altitude areas, where the *paramos* present extreme environmental conditions due to low mean temperatures and high relative humidity levels. (Diaz-Granados Ortiz et al., 2005)

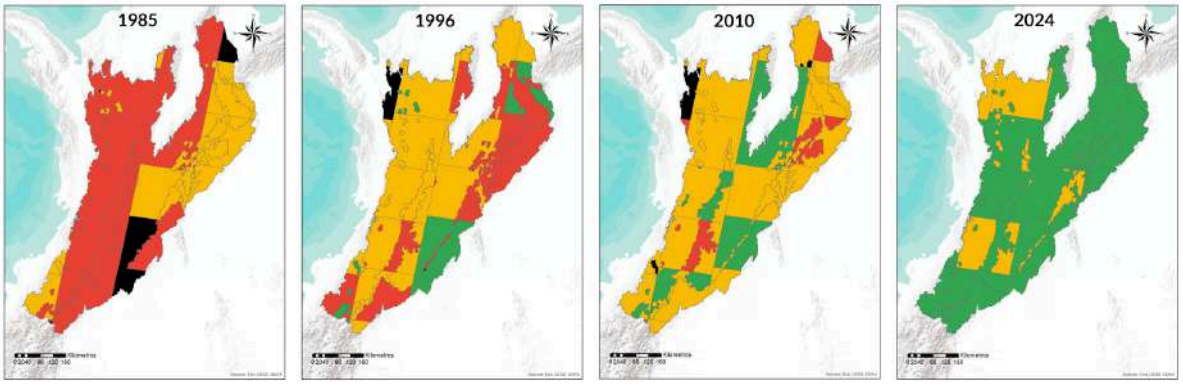


Figure 15. Mosaic Quality the Andes region

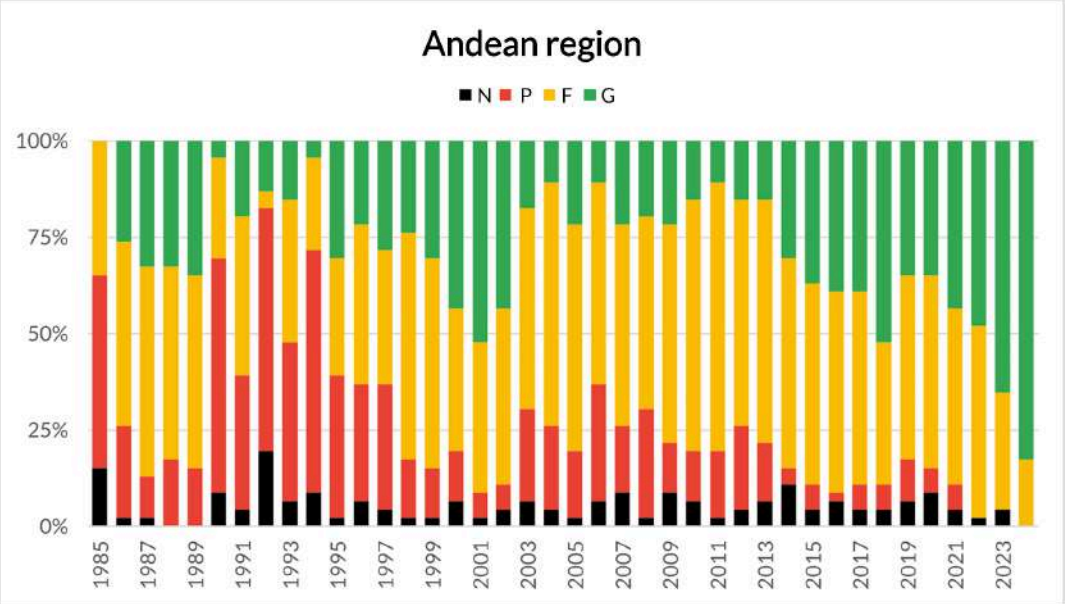


Figure 16 Mosaic Quality the Andes region

Pacific region: The mosaics in the Colombian Pacific region are generally of poor or fair quality, as this area experiences high rainfall. This is caused by a surface current that transports moisture from the cold, humid winds of the Pacific Ocean, which generate rainfall when they interact with warmer or drier air masses from the east (Agencia de noticias UNAL, 2017).

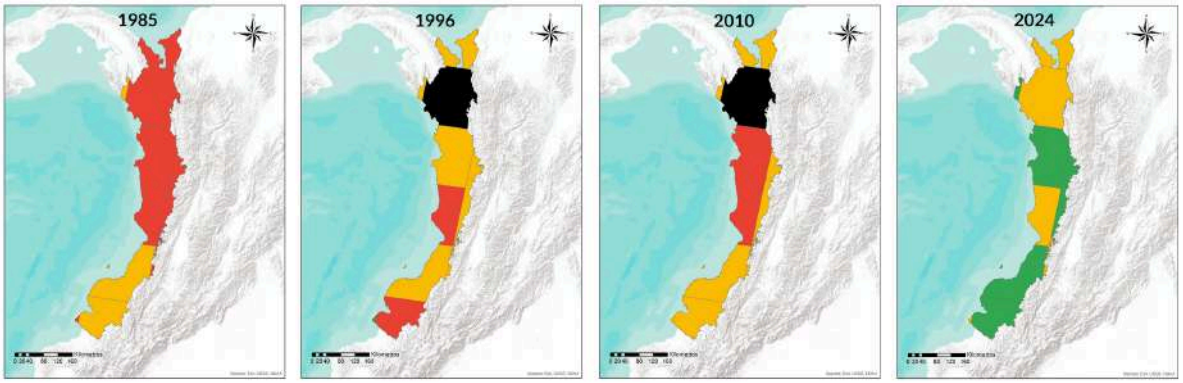


Figure 17. Mosaic Quality the Pacific region

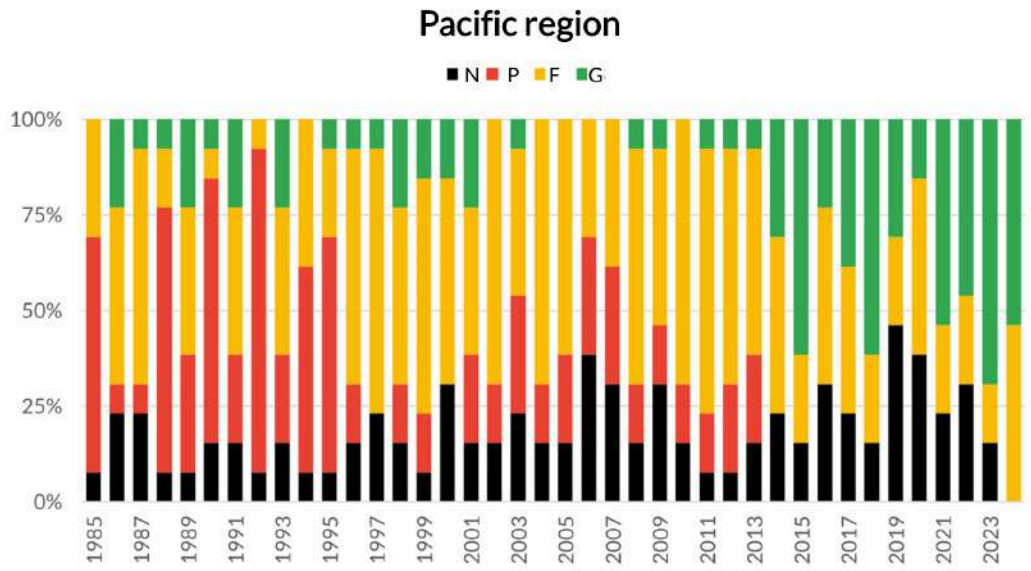


Figure 18. Mosaic Quality the Pacific region

Orinoquia region: It is one of the regions with the greatest amount of mosaic data in the early years, and the quality of the mosaics in recent years is mostly good, considering that it is one of the regions with the lowest rainfall in Colombian territory.

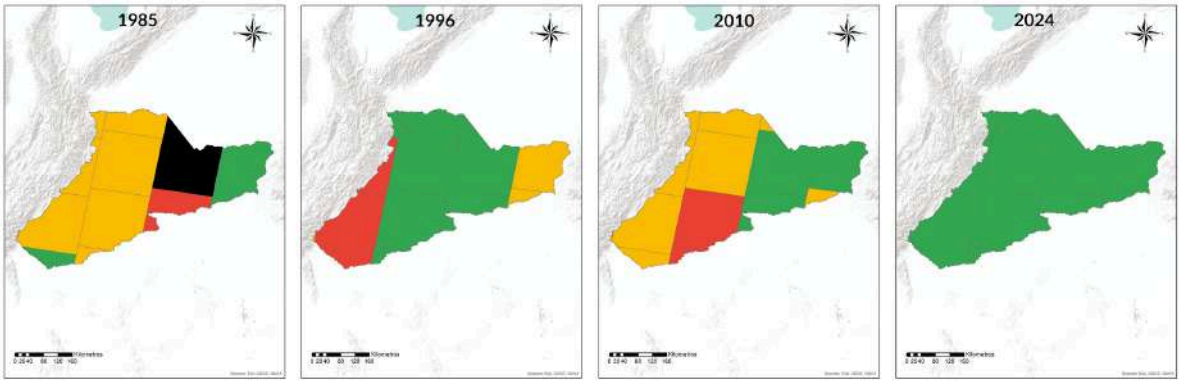


Figure 19. Mosaic Quality the Orinoquia region

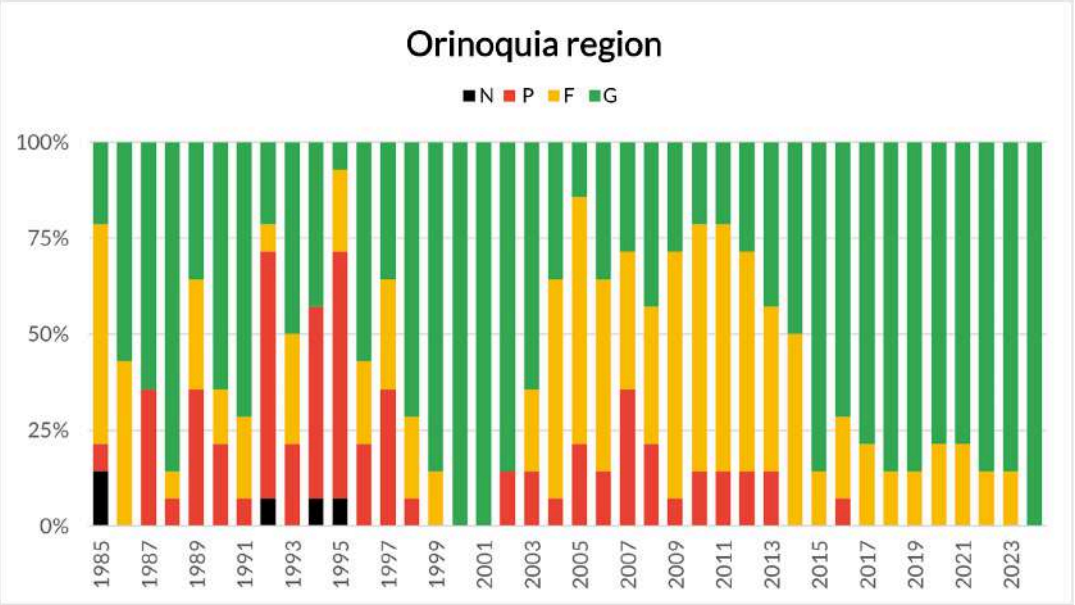


Figure 20 Mosaic Quality the Orinoquia region

Caribbean region: As in the Orinoquia, the Caribbean region has very good mosaics throughout the series, except for the areas bordering the Andean region, which have higher elevations and therefore greater rainfall.

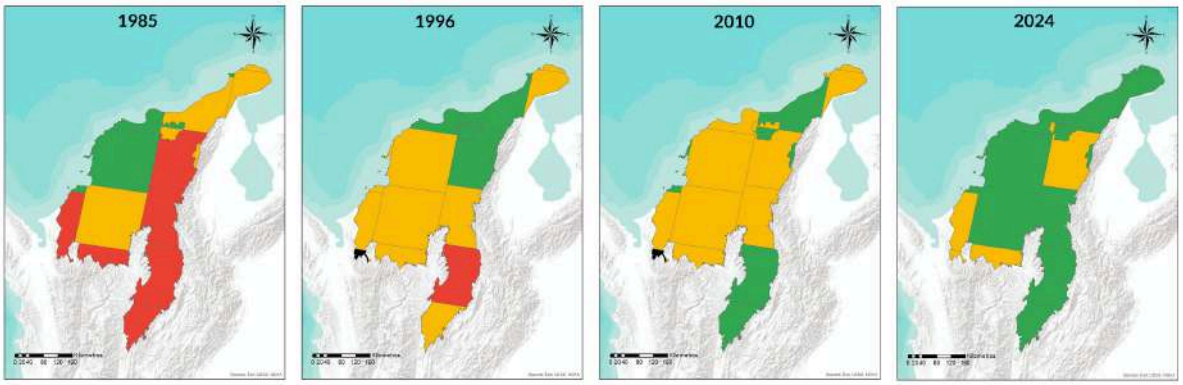


Figure 21. Mosaic Quality the Caribbean region

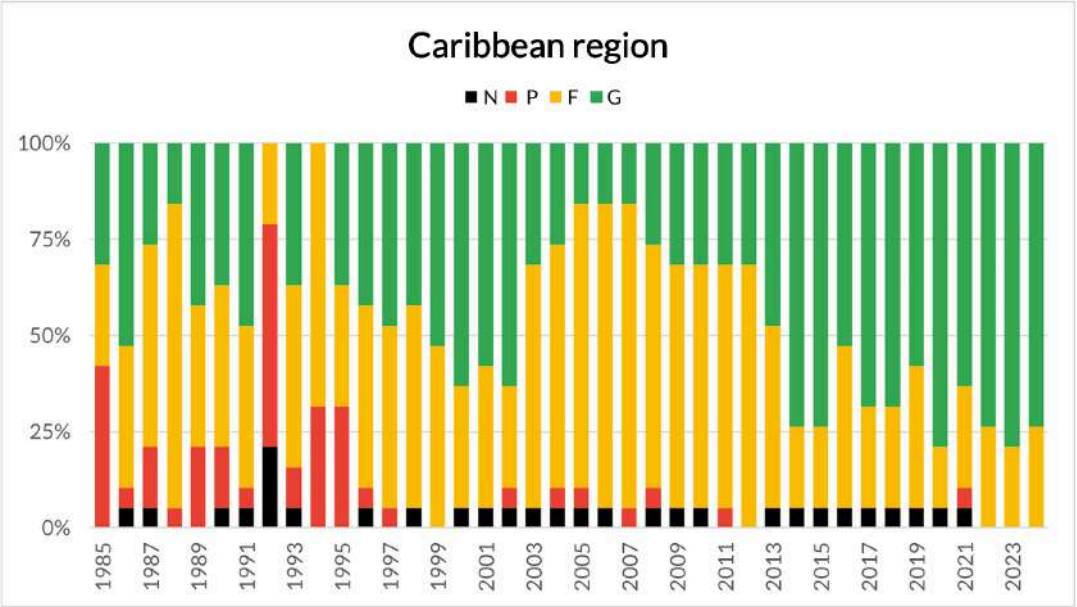


Figure 22 Mosaic Quality the Caribbean region

Amazon region: The Amazon region also has good-quality mosaics, especially in the southern area. In recent years, the overall quality has been mostly good, and it is one of the regions with the fewest mosaics lacking information.

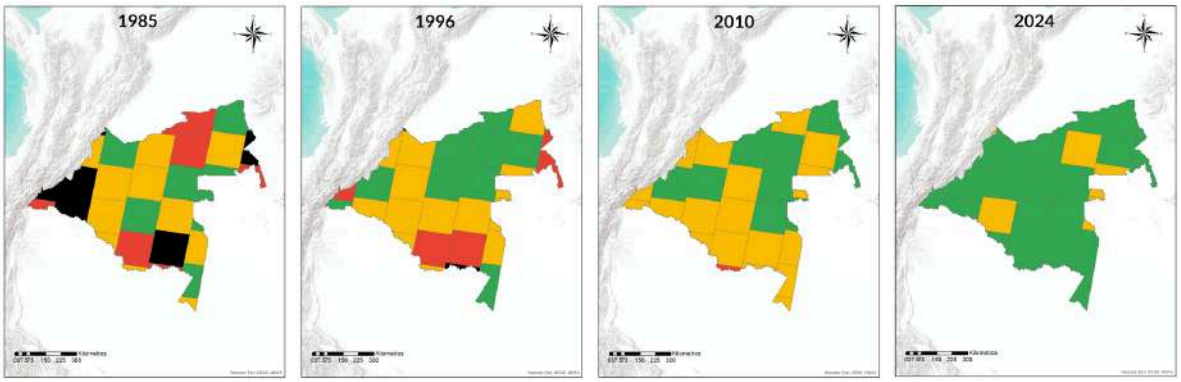


Figure 23. Mosaic Quality the Amazon region

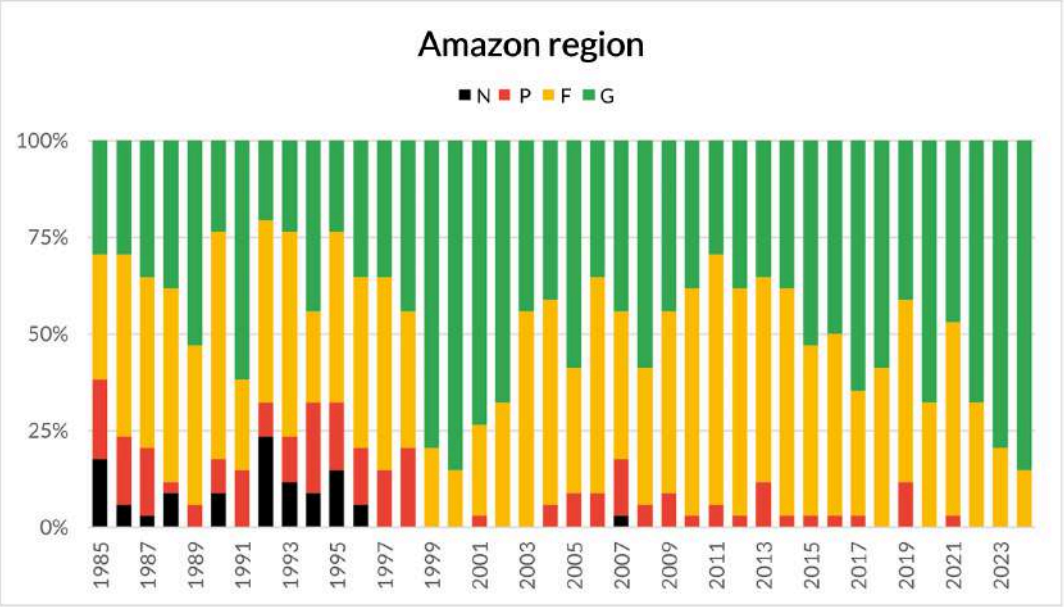


Figure 24 Mosaic Quality the Amazon region

4.1.4. Topographic Correction

Several areas of the country are characterized by mountainous terrain, which often results in shadows appearing in Landsat images due to the orientation of the slopes in relation to the sun and the lighting conditions of each scene, defined by the zenith angle of the sensor at the time of capture. These limitations manifest themselves in such a way that, for the same type of coverage, some pixels show a reduction in light reflection levels, which tends to generate an error when classifying such coverage.

One of the improvements implemented in the Mapbiomas Colombia 3.0 collection consists of applying a topographic correction to the mosaic that attenuates shadows and homogenizes the mapping area. This correction was applied to a total of 2.255 mosaics in 57 path rows in the different mosaic parameterization regions (Table 5). These mosaics were not implemented in the Orinoquia region and the path rows corresponding to the upper Guajira, where the correction was not necessary due to the low slope.

Table 5 Mosaics by path-row and Landsat mosaic regions processed with topographic correction.

Path Row	Mosaic region	Path Row	Mosaic region	Path Row	Mosaic region
008057	301	008055	303	008056	304
008058	301	008056	303	009053	304
007057	301	009055	303	009054	304
008059	301	009056	303	010053	304
009059	301	009057	303	010054	304
009060	301	009058	303	009056	304
010059	301	009059	303	009057	304
007058	302	009060	303	009058	304
008058	302	010055	303	009059	304

Path Row	Mosaic region	Path Row	Mosaic region	Path Row	Mosaic region
006059	302	010058	303	007057	304
006060	302	010059	303	007058	304
009052	303	008055	304	007054	304
007055	303	009052	304	010055	304
008057	303	009055	304	010058	304
007056	303	007055	304	010059	304
008058	303	008057	304	010056	304
007057	303	007056	304	010057	304
008059	303	008058	304	011055	304
008054	303	008059	304	011059	304

An example of the mosaic change for collection three is presented below for Tayrona National Natural Park, where a comparison between the mosaics can be seen:

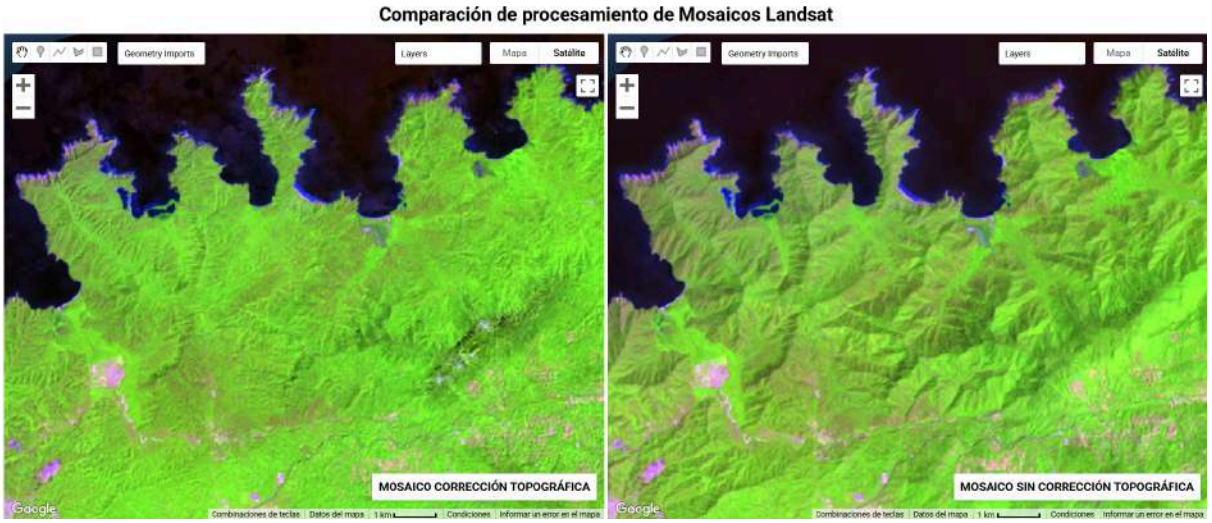


Figure 25 Example of topographic correction - Tayrona National Natural Park.
Left image: Mosaic with topographic correction. Right image: Mosaic without topographic correction.

4.2 Variables

Variables (feature space) were calculated from the annual median mosaic, serving as inputs for the classification process. The Landsat bands, together with the classification variables, are consolidated into raster files comprising a total of 156 bands, which include: Landsat spectral bands, spectral indices, fractional and texture information derived from these bands, and spectral fraction indices. In addition, 7 static variables were used: HAND, shademask2, slppost, altitude, slope, latitude, and longitude, which facilitated the classification of spectrally similar classes but distinguishable by these topographic aspects. Statistical reducers were applied to the available images for each year to generate the values of each pixel. These reducers are:

- **Median:** Median of all available values in the annual mosaic for that location (pixel).
- **Dry season median:** Calculation of the statistical median applied to the pixels in the 25th quartile (with the lowest values) of NDVI, used as an indicator of the dry season.
- **Wet season median:** Calculation of the statistical median applied to the pixels in the 75th quartile (with the highest values) of NDVI, used as an indicator of the wet season.

- **Amplitude:** Range of variation among 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 among all available pixels in the annual mosaic for a given location.
- **Maximum:** Highest value among all available pixels in the annual mosaic for a given location.
- **Minimum of the dry period:** Lowest value among all available pixels in the images of the quartile with the lowest NDVI values, representing the dry season.
- **Minimum of the wet period:** Lowest value among all available pixels in the images of the quartile with the highest NDVI values, representing the wet season.
- **Maximum of the dry period:** Highest value among all available pixels in the images of the quartile with the lowest NDVI values, representing the dry season.
- **Maximum of the wet period:** Highest value among all available pixels in the images of the quartile with the highest NDVI values, representing the wet season.
- **QMO of the dry period:** Highest value that the band presents in the EVI2 index during the dry season.
- **QMO of the wet period:** Highest value that the band presents in the EVI2 index during the wet season.

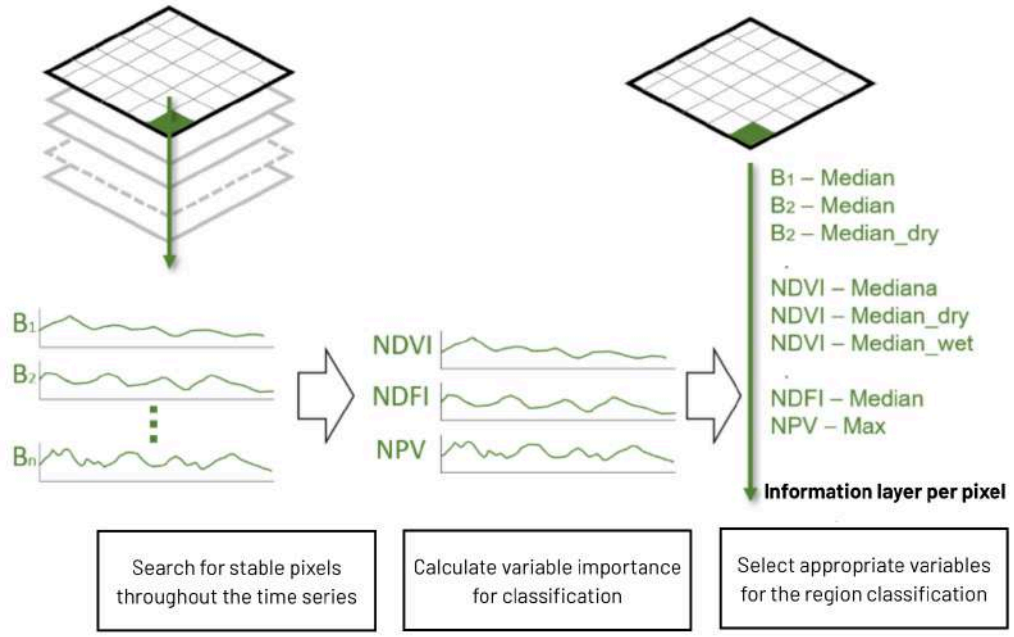
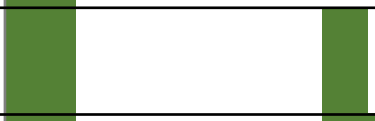
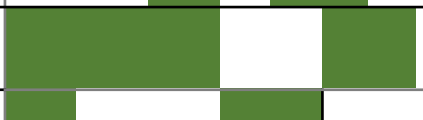


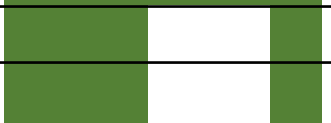
Figure 26 Calculation process of the bands that compose the annual mosaics of Landsat images

The following table shows the complete list of bands from the final mosaics or feature space. Each band represents a training variable of the classifier.

Table 6. Description of bands and variables used for the MapBiomas Colombia Collection 3.

Type	Name	Formula	Description	Reducer											Quality Band	
				Median	Median_dry	Median_wet	amp	ast_Dev	min	max	dry_min	dry_max	wet_min	wet_max	dry_qmo	wet_qmo
Band	blue	B1 (L5 y L7); B2 (L8)	Visible spectrum blue	■												
	green	B2 (L5 y L7); B3 (L8)	Visible spectrum green	■	■				■				■		■	■
	red	B3 (L5 y L7); B4 (L8)	Visible spectrum red	■	■	■			■		■	■		■	■	
	nir	B4 (L5 y L7); B5 (L8	Near infrared	■	■	■		■	■						■	■
	swir1	B5 (L5 y L7); B6 (L8)	Shortwave infrared 1	■	■	■			■			■	■	■	■	■
	swir2	B7 (L5); B8 (L7); B7(L8)	Shortwave infrared 2	■	■	■			■		■	■		■	■	■
Index	ndvi	(nir - red)/(nir+ red)	Normalized Difference Vegetation Index	■	■	■	■	■								
	evi2	(2.5 * (nir - red)/(nir +2.4 * red + 1)	Modified Enhanced Vegetation Index (EVI) that uses only NIR and Red, omitting the blue band.	■	■	■	■	■								
	ndwi_gao	(nir - swir)/(nir + swir)	Normalized Difference Water Index (Gao)	■	■	■	■				■		■	■		■
	ndwi_mcfeeters	(green - nir)/(green+nir)	Normalized Difference Water Index (McFeeters)	■			■									
	gcvi	(nir/green) - 1	Relationships between near-infrared and green bands	■	■	■										
	hallcover	(-red * 0.017) - (nir * 0.007) - (swir2 * 0.079) + 5.22	Land Cover Spectral Index	■												
	pri	(blue - green)/(blue+ green)	Photochemical Reflectance Index	■	■											
	savi	(1 + L) * (nir - red)/(nir + red + 0,5)	Soil-Adjusted Vegetation Index	■	■	■		■								

	textG	('median_green').entropy(ee.Kernel.square({radius: 5}))	Entropy in the Blue band	
	nuaci	UNTL*(1−√(NDWIi−aNDWI)2+(NDWi−aNDWI)2+(DWIi−aNDWI)2)	Normalized Difference Built-up Index	
	ndsi	(green-swir1)/(green+swir 1)	Normalized Difference Snow Index	
	cai	(swir2 / swir1)	Color Alteration Index	
	gli	((2 * green) - red - blue) / ((2 * green) + red + blue)	Green Leaf Index	
	mndwi	(green - nir) / (green + nir)	Normalized Difference Water Index	
	ndbi	(swir1 - nir) / (swir1 + nir)	Cumulative Normalized Difference Index	
	ndgb	(green - blue) / (green + blue)	Normalized Green-Blue Difference	
	ndmi	(nir - swir1) / (nir + swir1)	Normalized Difference Moisture Index	
	mdmir	(swir1 - sir2) / (swir1 + sir2)	Normalized Difference Mid-Infrared Index	
	ndrb	(red - blue) / (red + blue)	Normalized Red-Blue Difference	
	ndsi2	(swir1 - nir) / (swir1 + nir)	Normalized Soil Difference 1	
MME Fraction	gv		Fractional abundance of green vegetation within the pixel	
	npv		Fractional abundance of non-photosynthetic vegetation within the pixel	
	soil		Fractional abundance of soil within the pixel	
	shade	100 - (gv +npv + soil+cloud)	Fractional abundance of shadow within the pixel	

	snow		Fractional abundance of snow within the pixel	
	cloud		Fractional abundance of clouds within the pixel	
MEM Index	gvs	gv / (gv + npv + soil + cloud)	Shadow-normalized green vegetation	
	ndfi	(gvs - (npv + soil)) /(gvs + (npv + soil))	normalized difference fraction index	
	sefi	(gv+npv -soil)	Savanna	
		/(gv+npv + soil)	Ecosystem Fraction Index	
	wefi	((gv+npv)-(soil+shade))/(gv+npv)+(soil+shade)	Wetland Ecosystem Fraction Index	
	fns	((gv+shade) - soil) / ((gv+shade) + soil)	Index based on gv, shade, and soil fractions	
	nfib	GV-(NPV+Soil+Snow)/ GV+(NPV+Soil+Snow)	Adaptation of the NDFI for the Andes	

4.4 Classification

4.4.1 Methodological description

The methodological process carried out in the classification stage for collection 3.0 includes the use of the Random Forest (RF) classifier, which is based on artificial intelligence (AI) algorithms and, with it, machine learning (ML). Based on the construction of various decision trees, the data of a model is classified by performing a series of binary partitions, thus allowing future predictions to be made based on this classification. It should be noted that the decision trees are established randomly in order to reduce the correlation between them (Garcia, 2018).

The correct functioning of the algorithm in question requires a training dataset. For this purpose, stable samples were used. Areas that showed changes over the 40-year time series were excluded, that is, those pixels whose associated coverage class is not repeated across all years of the image time series. During the process, the interpreter can discard areas where the automatic sampling incorporates examples that do not meet the criteria for each class.

Additionally, the PIAO (*Photo-interprétation assistée par ordinateur*; computer-assisted photointerpretation) technique was used for coverage identification, optimizing the selection

and organization of reference samples and increasing classification accuracy in regions with greater spatial heterogeneity. Due to the extension of the territory, the five (5) biogeographic regions: Andean, Caribbean, Orinoquia, Pacific and Amazon, were subdivided into 155 classification subregions according to the present hydrographic basins and some biophysical criteria previously described.

Subsequently, a preliminary classification was generated for the 40 years of the Colombia Collection 3.0, based on the generated samples. The entire process was executed in the Google Earth Engine (GEE) cloud-based geoprocessing environment, following a sequence of iterative steps shown in **Figure 27**, in order to obtain a quality classification product. Each step is briefly described below:

- Definition of classification subregions.
- Identification of stable samples.
- Calculation of variables (feature space) from the mosaic obtained for each year of the time series, which has a maximum of 81 variables, including Landsat spectral bands, indices, and spectral fractions. Additionally, statistical reduction factors were applied to generate a single value for each pixel. These reduction factors were: median, median dry season, median rainy season, amplitude, standard deviation, minimum, minimum, and maximum of the dry season, and minimum and maximum of the rainy season[1].
- Area calculation using exclusion polygons defined according to the behavior of the MapBiomas Colombia map obtained in step 3, as shown in **Figure 27**, yielding a preliminary classification.
- Application of the Gapfill filter to fill in any information gaps that may arise from the annual mosaic, replacing those pixels with the temporally closest value.
- Second identification of stable samples with the option of generating exclusion geometries to skip the selection of stable samples at a given location and area calculation until a second preliminary classification is achieved in step 6.
- In step 6 of the classification, the option to select complementary samples for each coverage class is given, which are included as manual geometries directly from Google EE with the intention of making corrections to the preliminary classification of this step.

Finally, regarding the application of temporal, spatial, frequency, and gap-fill filters, the order and number of iterations performed varies depending on the subregion being analyzed, in order to generate a final classification consistent with the reality of the territory. The processing chain adopted to generate Collection 3.0 for Colombia is shown graphically in **Figure 27**.

Overall, in Collection 3.0, a specific number of decision trees were established to be considered for the classification obtained from Random Forest, generally 60 iterations in each region. Likewise, in order to obtain greater detail in the legend and to improve the quality of some coverages, specific methodologies with binary layers (0-absence, 1-presence) were developed for some of the coverages that represent greater difficulty in mapping and/or that require

[1] It is recommended to review the Algorithm Theoretical Basis Document – ATBD General to detail each of the statistical reducers.

greater detail: Infrastructure, glacier, wetlands, mining, and mangroves. These are subsequently integrated with the classification results of the general map, according to a priority order defined for each category.

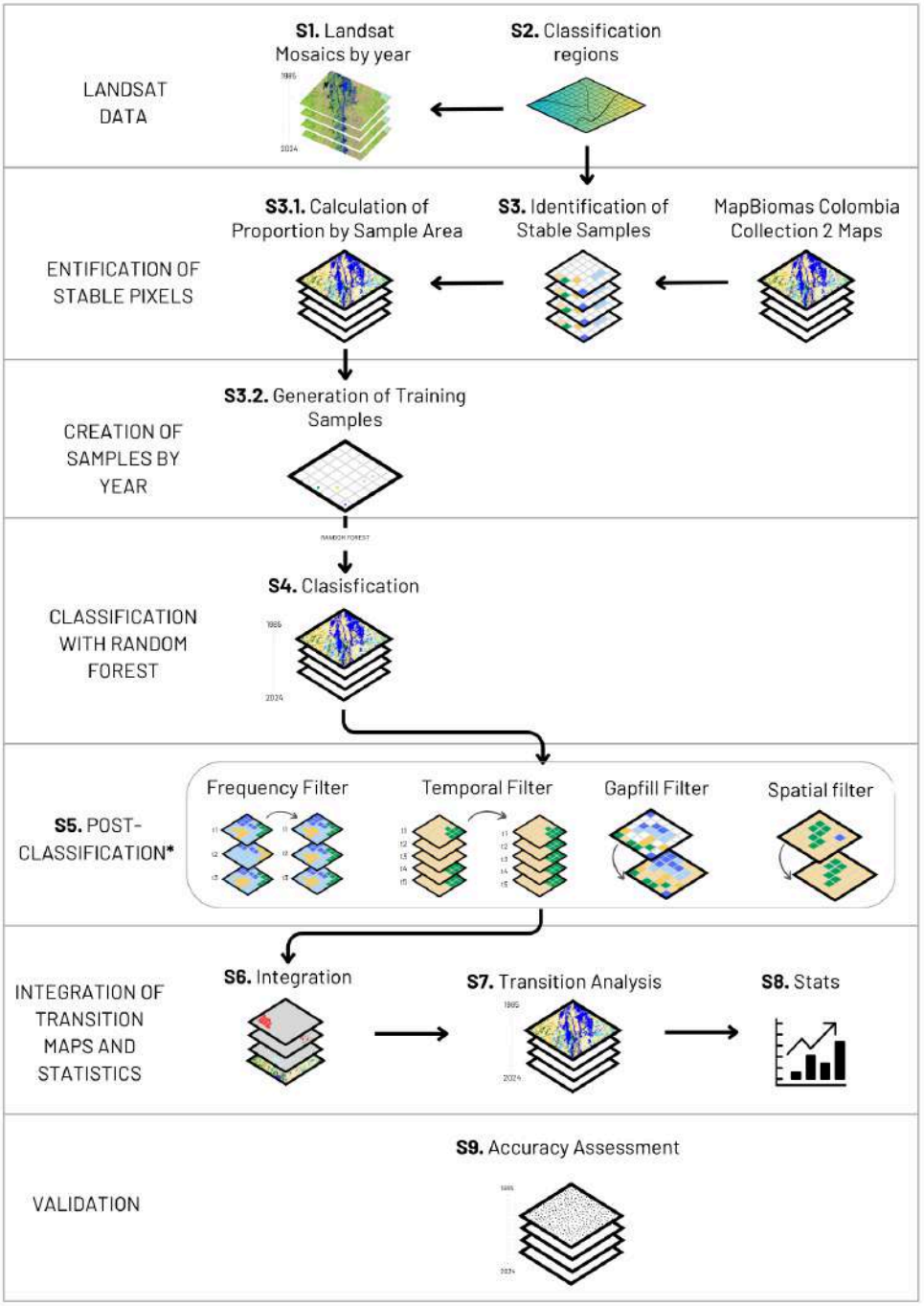


Figure 27. Classification Flow – MapBiomas Colombia Collection 3.0

* The order of the filters varies depending on the region and is defined by each interpreter.

4.4.2 Classification regions

The classification regions are operational areas designed to improve the processing efficiency in the identification of land cover types with similar spectral characteristics. To achieve this, several reference maps developed by official State institutions, as well as by international organizations and companies responsible for producing global mappings, were used as guides. The objective was to group covers with similar reflectance values and separate areas with distinct covers, thereby facilitating easier discrimination among them during the classification process.

Among the reference maps used for defining the regions were the Land Cover Map – CORINE Land Cover Methodology Adapted for Colombia at 1:100.000 Scale (IDEAM, 2021); the Continental and Marine Ecosystems Map of the *Instituto de Hidrología, Meteorología y Estudios Ambientales* (IDEAM et al., 2017); the Hydrographic Zoning of Colombia (IDEAM, 2013); and the Forest and Non-Forest Map (2017) (IDEAM, 2017), which supported the identification of areas with higher change dynamics.

Additionally, global reference layers were used, including the ESRI 2020 Global Land Use/Land Cover Map (ESRI, 2020) and the ESA 2015 Global Land Use Map (ESA, 2015), as well as information from MapBiomas Amazonia Collection 5 (Gaia Amazonas, 2021) and MapBiomas Colombia Collection 1 (MapBiomas Colombia, 2022). Based on these maps, an appropriate separation of territorial dynamics and ecosystem diversity across the Colombian territory was achieved.

It is important to highlight that this regionalization does not correspond to a biogeographical zonation of Colombia; however, it considered the delimitation of hydrographic basins and ecologically significant ecosystems, such as high mountain areas, paramos, wetlands, and the savannas of the Orinoquia, as well as socially strategic areas, including indigenous community settlements in the Amazon region. As a result, a total of 155 classification regions were defined: 28 for the Caribbean region, 62 for the Andean region, 15 for the Orinoquia region, 13 for the Pacific region, and 37 for the Amazon region. Finally, a buffer was created to encompass the dynamic zones of the Caribbean and Pacific coastal areas.

Table 7 Criteria for the Delimitation of Classification Regions by Biogeographical Region

Region	Criteria for the delimitation of classification regions
Caribbean	Due to its proximity to the Caribbean Sea, this region defined its coastal boundary with a 2 km buffer to include islets (Isla Fuerte, Archipelago of San Bernardo), sandbanks, and mangrove areas. On the continental side, the criteria for defining regions included clusters of pasture and agricultural mosaics, clusters of floodable areas, and the identification of special cases, such as: ● Woody and herbaceous vegetation on sand in La Guajira. ● Floodable and swampy areas in La Mojana region. ● Zones under topographic influence associated with the Sierra Nevada de Santa Marta.

	• A specific region for the glacial and periglacial zone of the Sierra Nevada de Santa Marta. • Oil palm cultivation regions embedded within a matrix of pastures and crops. • An exclusive region for the mapping of the islands of San Andrés, Providencia, and Santa Catalina. • Wetlands and buffer areas at the mouth of the Magdalena River.
Andean	Due to its complex mountain system formed by three mountain ranges separated by inter-Andean valleys, this region encompasses multiple altitudinal belts with diverse climatic, topographic, and social influences. The criteria used to delimit the regions in the Andean region include: • Separation of agricultural mosaics, natural grasslands (paramos), and glacial areas in the high Andean mountain zone. • Differentiation between agricultural zones and natural grasslands in dry valleys, such as those of the Patia River and Magdalena River. • Regions focused on the classification of oil palm crops embedded within a matrix of pastures and crops, especially in Tibu. • Separation of humid forests of the Choco-Antioqueño region. • Differentiation between high mountain regions and areas with lower relief, to distinguish highly complex topographic zones from those that are flatter or at lower elevations.
Pacific	Due to its proximity to the Pacific Ocean, this region defined its coastal boundary with a 2 km buffer to include sandbanks and small islets. The criteria used to delimit the regions in this area include: • Using rivers as natural boundaries for regional delimitation. • Grouping highly intervened areas, such as the Tumaco surroundings and the Uraba region. • Regions focused on the classification of oil palm crops embedded within a matrix of pastures and crops..
Orinoquia	Because of the spectral similarity between agricultural mosaics, natural pastures, and native grasslands, one of the main criteria for delimiting regions in this area was to differentiate between the Orinoquia savannas and the zones containing mosaics of pastures and crops. In addition to this main criterion, the following aspects were considered: • Using rivers as natural boundaries, such as the Meta River and Guaviare River. • To avoid confusion between pastures and natural savannas, specific regions were created where the matrix is predominantly composed of natural pastures.

Amazon	Given that the Amazon region is considered strategic for biodiversity conservation and climate change mitigation, it was subdivided with the following priorities: ● Areas with high dynamics along the so-called “Deforestation Arc,” which partially covers the departments of Putumayo, Caqueta, Meta, and Guaviare. ● Detailed regions associated with indigenous communities and their zones of influence, aimed at detecting forest-use dynamics through traditional agricultural plots (chagras).

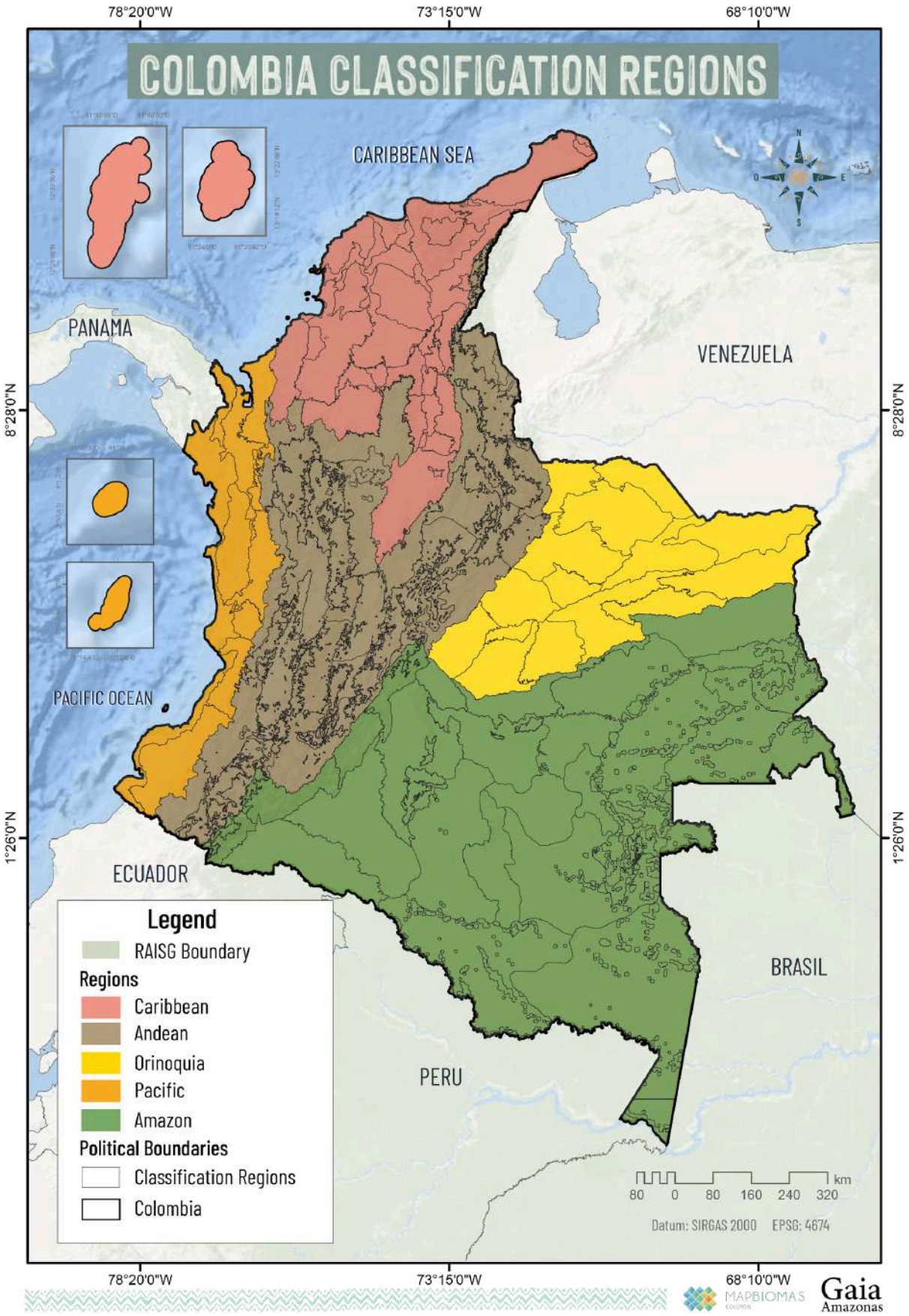


Figure 28 Colombian Classification Regions

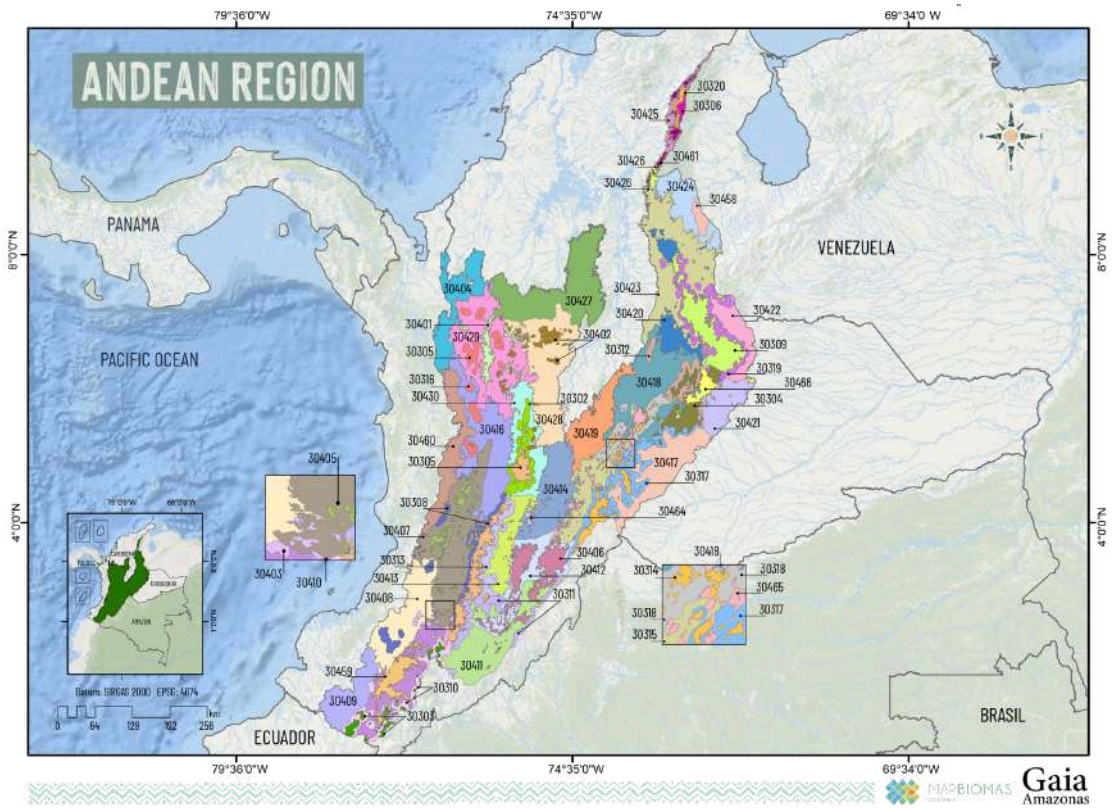


Figure 29 Classification Regions of the Andean Region

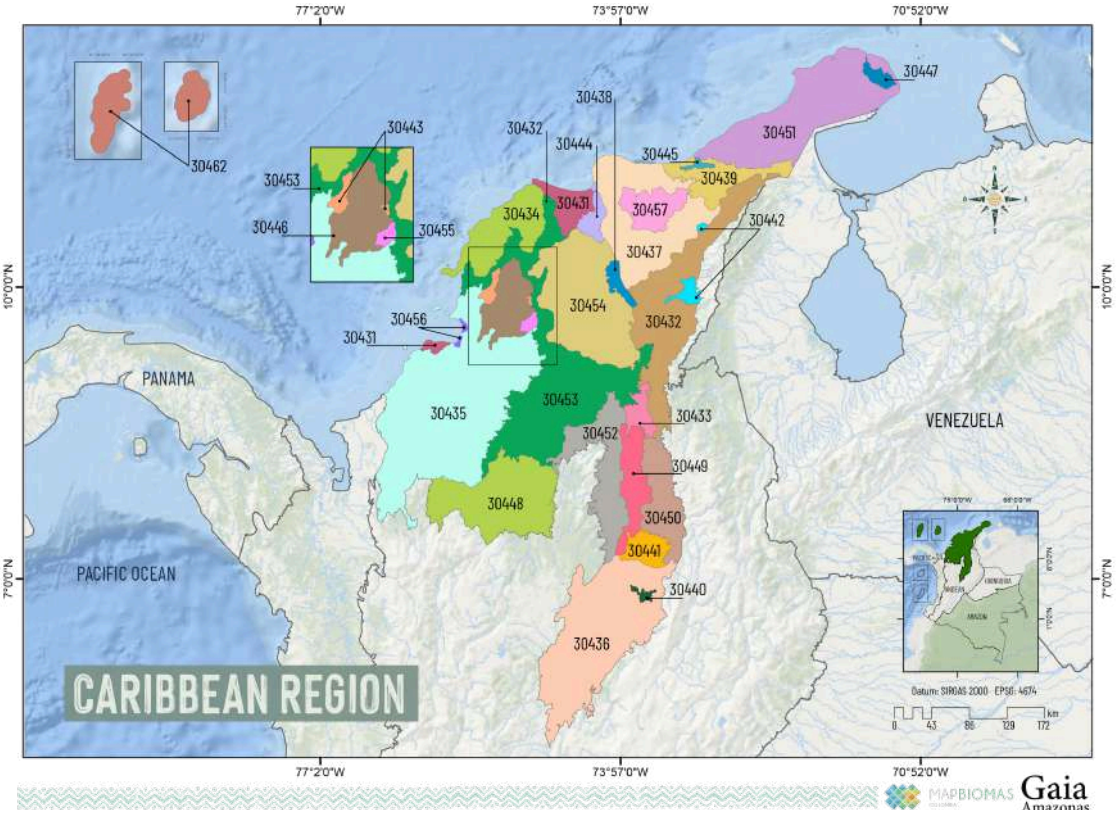


Figure 30 Classification Regions of the Caribbean Region

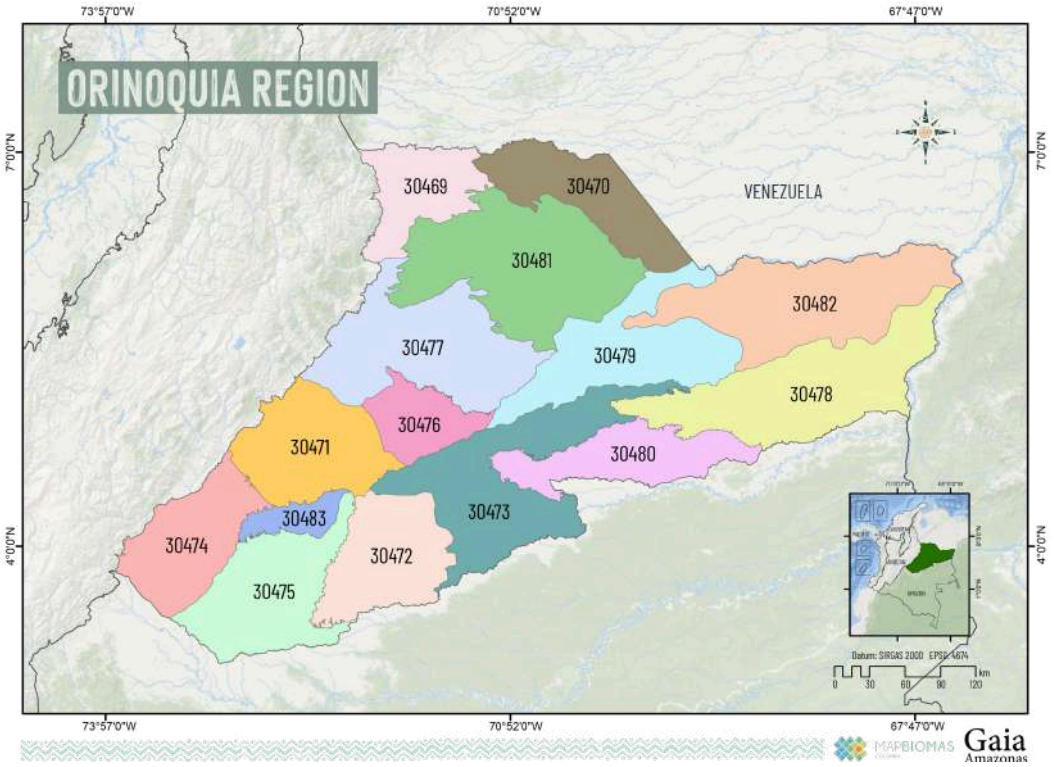


Figure 31 Classification Regions of the Orinoquia Region

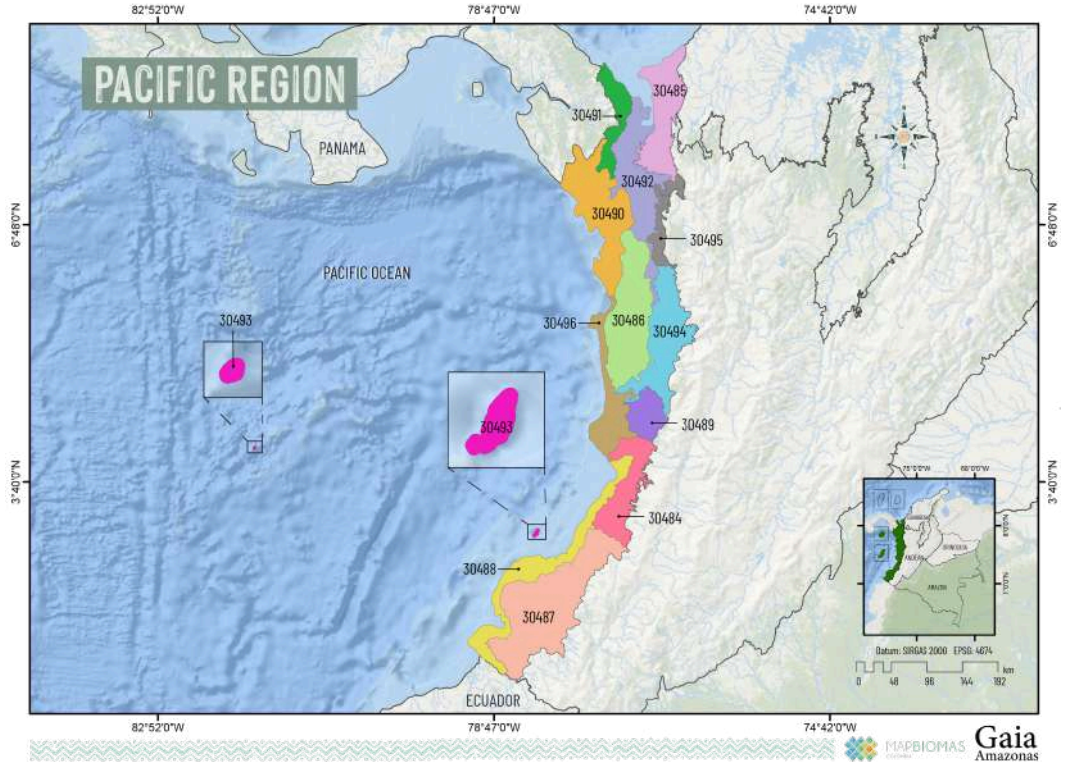


Figure 32 Classification Regions of the Pacific Region

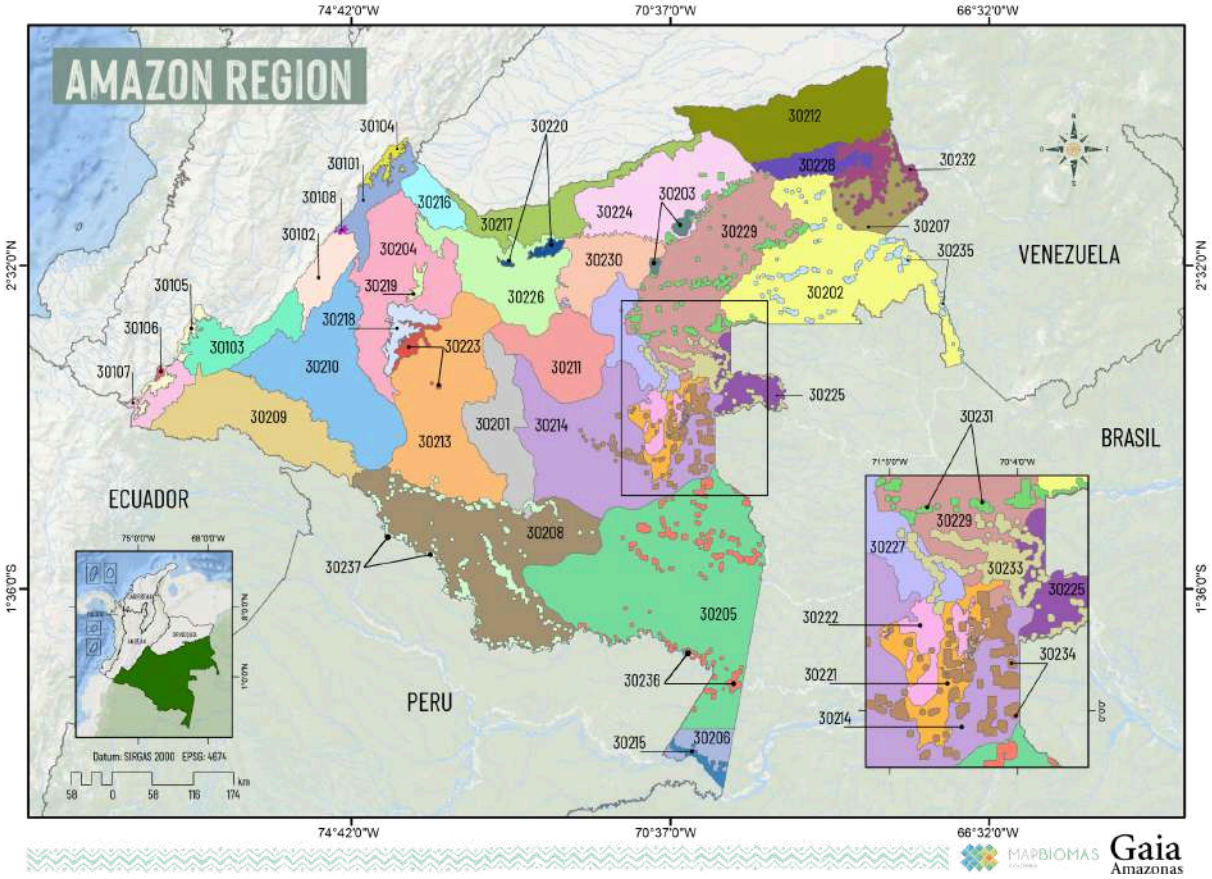


Figure 33 Classification Regions of the Amazon Region

The following **Table 8** presents the main characteristics of each work area defined for MapBiomas Colombia Collection 3. The biophysical descriptions of the regions were prepared based on information extracted through map algebra from the Continental and Marine Ecosystems of Colombia layer (IDEAM et al., 2017).

Table 8. Classes interpreted by classification regions in Colombia.

Item	Region	Classification Region	Description	Class	Ver
1	Andean	30101	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by Very Cold Humid, Very Cold Semi-Humid, Very Cold Super-Humid, Cold Humid, Cold Semi-Humid, Cold Super-Humid, Temperate Humid, Temperate Semi-Humid, Temperate Super-Humid, Warm Humid, Warm Semi-Humid, and Warm Super-Humid climates. The relief is predominantly made up of low hills, mountains, piedmonts, alluvial plains, and valleys.	3,13,21,23, 25,33,68	11
2	Andean	30102	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by Very Cold Humid, Very Cold Semi-Humid, Cold Humid, Cold Semi-Humid, Cold Super-Humid, Temperate Humid, Temperate Semi-Humid, Temperate Super-Humid, Warm Humid, Warm Semi-Arid, and Warm Semi-Humid climates. The relief is predominantly made up of low hills, mountains, piedmonts, and valleys.	3,13,21,23, 25,33,68	7
3	Andean	30103	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; is characterized by a Very Cold Humid, Very Cold Superhumid, Cold Humid, Cold Semi-humid, Cold Superhumid, Temperate Humid, Temperate Semi-humid, Temperate Superhumid, Warm Humid, Warm Semi-humid, and Warm Superhumid climate. The terrain is dominated by hills, mountains, foothills, and valleys.	3,13,21,23, 24,25,30,3 1,33,68	8

Item	Region	Classification Region	Description	Class	Ver
4	Andean	30104	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Orobiome of the Tropical Humid Zonobiome; it is characterized by an Extremely Cold Super-Humid, Very Cold Humid, Very Cold Super-Humid, Cold Humid, and Cold Super-Humid climate. The relief is predominantly mountainous.	3,13,15,21, 33, 68, 81	8
5	Andean	30105	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Orobiome of the Tropical Humid Zonobiome; it is characterized by an Extremely Cold Super-Humid, Very Cold Humid, Very Cold Semi-Humid, Very Cold Super-Humid, Cold Humid, Cold Semi-Humid, and Cold Super-Humid climate. The relief is predominantly characterized by mountains, foothills, and alluvial plains.	3,11,13,15, 18,21,24, 25,27,30, 33,68,81, 82	9
6	Andean	30106	The region is composed of the Pedobiome of the Tropical Humid Zonobiome and the Orobiome of the Tropical Humid Zonobiome; it is characterized by a Very Cold Humid, Very Cold Super-Humid, and Cold Humid climate. The relief is predominantly characterized by mountains, foothills, and alluvial plains.	3,11,13,15, 18,21,24, 25,33	8
7	Andean	30107	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by Very Cold Humid, Very Cold Semi-Humid, Very Cold Super-Humid, Temperate Humid, Temperate Semi-Humid, Temperate Super-Humid, Warm Humid, and Warm Super-Humid climates. The relief is predominantly made up of plateaus, low hills, mountains, piedmonts, alluvial plains, and valleys.	3,11,13,21, 23,24,25, 30,33,68	7
8	Andean	30108	Orobiome of the Tropical Humid Zonobiome; it is characterized by a Very Cold Humid, Very Cold Semi-Humid, Cold Humid, and Cold Semi-Humid climate. The terrain is predominantly mountainous.	3,13,21,68	6

Item	Region	Classification Region	Description	Class	Ver
9	Andean	30302	Region located in the Central Range, dominated by the Orobiome of the Tropical Humid Zonobiome, which covers almost the entire area. It is characterized by a very cold to temperate climate, with predominantly humid and super-humid conditions, favoring the development of Andean and Sub-Andean montane forests. The relief is mainly composed of mountains and foothills, with steep slopes and high altitudinal heterogeneity.	3,9,11,13, 21, 23, 24,25,33, 81,82	10
10	Andean	30303	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, composed of mountain ecosystems within temperate and cold thermal belts, with high humidity. The Azonal Orobiome of the Tropical Humid Zonobiome is also present, associated with local conditions such as extreme slopes or particular geological features, as well as the Pedobiome of the Tropical Humid Zonobiome, linked to soils with specific properties that influence the configuration of the ecosystem.	3,9,11,13,21,23,24, 25,27,29, 33,68,81, 82	8
11	Andean	30304	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, composed of mountain ecosystems within temperate and cold thermal belts, with high humidity. The Azonal Orobiome of the Tropical Humid Zonobiome is also present, associated with local conditions such as extreme slopes or particular geological features, as well as the Pedobiome of the Tropical Humid Zonobiome, linked to soils with specific properties that influence the configuration of the ecosystem.	3,9,11,13, 21,24,23,25,27,30, 33,68, 81, 82	7
12	Andean	30305	Region 30305 is dominated by the Orobiome of the Tropical Humid Zonobiome, composed of mountain ecosystems in temperate and cold thermal belts with high humidity. The Azonal Orobiome of the Tropical Humid Zonobiome is also identified, associated with particular local conditions, along with Pedobiomes of the Tropical Humid Zonobiome,	3,11,13,21, 24,25,27, 29,30, 33,34,81, 82	66

Item	Region	Classification Region	Description	Class	Ver
			defined by specific edaphic properties that determine the structure of the ecosystem..		
13	Andean	30306	Region located to the north of the Eastern Range, dominated by the Orobiome of the Tropical Humid Zonobiome, which covers almost the entire area. It is characterized by a very cold to temperate climate, with predominantly humid and super-humid conditions, favoring the development of Andean and Sub-Andean montane forests. The relief is mainly composed of mountains and foothills, with steep slopes and high altitudinal heterogeneity.	3,13,21,25	5
14	Andean	30308	The region is mainly characterized by the Orobiome of the Tropical Humid Zonobiome, where very cold, humid, and super-humid climates prevail in mountain landscapes. The Azonal Orobiome of the same Zonobiome adds climatic complexity with temperate and cold semi-arid conditions, typical of hill terrains and more open mountainous areas. In addition, the Pedobiome of the Tropical Humid Zonobiome is present, associated with areas under particular edaphic influence, which favor warm humid and sub-humid climates in flatter or gently sloping landscapes. Overall, the region combines marked altitudinal variation with a diversity of microclimates, dominated by humid conditions.	3,13,21,24, 25,33	6
15	Andean	30309	The region is mainly composed of the Orobiome of the Tropical Humid Zonobiome, consisting of mountain ecosystems under humid, temperate, and cold climatic conditions. The Azonal Orobiome of the Tropical Humid Zonobiome is also present, associated with local factors such as slope and geology, as well as the Pedobiome of the Tropical Humid Zonobiome, influenced by soil properties that determine vegetation cover.	3,11,13,21, 24,25,27, 29,30,33, 34,81,82	10

Item	Region	Classification Region	Description	Class	Ver
16	Andean	30310	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, which shapes a mountain landscape with cold, humid, and super-humid climatic conditions. This predominance gives the territory a marked altitudinal identity, where high mountain ecosystems play a central role. In more restricted areas, units of the Pedobiome of the same Zonobiome are found, associated with particular edaphic conditions that favor the presence of vegetation adapted to specific soils, usually in altitudinal transition zones. Likewise, the Azonal Orobiome of the Tropical Humid Zonobiome appears locally, contributing to the landscape diversity with semi-arid climates and hill landforms. Together, these biomes form a complex and heterogeneous environment, in which cold and humid conditions prevail over a mountainous relief.	3,11,13,21, 24,25,33, 81,82	12
17	Andean	30311	The region is strongly influenced by the Orobiome of the Tropical Humid Zonobiome, resulting in a mountainous landscape dominated by cold, humid, and super-humid climates. This configuration generates stable environmental conditions that favor the presence of high mountain ecosystems, characteristic of areas with high rainfall and low temperatures. More specifically, units of the Pedobiome of the same Zonobiome are present, associated with particular edaphic conditions manifested in localized areas with specific soils. Overall, the region reflects a typically humid environment, with strong topographic controls and soils that, although less extensive, contribute to the ecological diversity of the territory.	3,11,13,21,24,25,33,81, 82	5
18	Andean	30312	Region located in the Eastern Range, dominated by the Orobiome of the Tropical Humid Zonobiome, with mountain ecosystems under temperate and humid climates. It is accompanied by the Azonal Orobiome of the Tropical Humid Zonobiome, influenced by local conditions, and the	3,13,21,24, 25,27,30, 33	7

Item	Region	Classification Region	Description	Class	Ver
			Pedobiome of the Tropical Humid Zonobiome, associated with soils with specific properties that determine vegetation patterns.		
19	Andean	30313	Region located in the Central Range, dominated by the Orobiome of the Tropical Humid Zonobiome, which covers almost the entire area. It is characterized by a very cold to temperate climate, with predominantly humid and super-humid conditions, favoring the development of Andean and Sub-Andean montane forests. The relief is mainly composed of mountains and foothills, with steep slopes and high altitudinal heterogeneity.	3,11,13,21, 24,25,81, 82	5
20	Andean	30314	Region located in the Eastern Range, dominated by the Orobiome of the Tropical Humid Zonobiome, with mountain ecosystems under temperate and humid conditions. The Azonal Orobiome of the Tropical Humid Zonobiome is also present, linked to local factors such as relief. To a lesser extent, the Pedobiome of the Tropical Humid Zonobiome appears, associated with specific soils that influence vegetation cover. This region includes part of the Sumapaz paramo.	3,13,21,24, 25,30,33, 81	7
21	Andean	30316	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, with mountain ecosystems in temperate and humid climates. In smaller proportions, the Pedobiome of the Tropical Humid Zonobiome appears, influenced by particular edaphic conditions, along with the Azonal Orobiome of the Tropical Humid Zonobiome.	3,9,13,21, 23,24,25	7
22	Andean	30317	The study region is mainly characterized by the Orobiome of the Tropical Humid Zonobiome, with a predominance of mountain landscapes under temperate and cold climates, both super-humid and humid. Areas with cold semi-humid and temperate semi-humid climates are also found, always within mountain environments. Additionally, there are zones of the	3,9,13,21,2 3,24,25, 30,33,68	7

Item	Region	Classification Region	Description	Class	Ver
			Tropical Humid Zonobiome with warm humid and super-humid climates in mountain landscapes, as well as some hill terrains with warm humid climates.		
23	Andean	30318	The region is marked by a clear dominance of the Orobiome of the Tropical Humid Zonobiome, which provides cold and humid climatic conditions over a mountainous relief. This biome gives the territory an ecological identity defined by altitude and high water availability. Complementarily, the Azonal Orobiome of the same Zonobiome is present, introducing greater environmental heterogeneity, with climates tending toward semi-arid conditions in hill terrains or less rugged mountain areas. Additionally, the territory includes localized areas of the Pedobiome of the Tropical Humid Zonobiome, associated with soils with particular properties that influence the composition of vegetation.	3,9,13,21,24,25,30,33	12
24	Andean	30319	The region is located in the Eastern Range and is dominated by the Orobiome of the Tropical Humid Zonobiome, representing mountain ecosystems under temperate and humid climatic conditions. The Azonal Orobiome of the Tropical Humid Zonobiome is also identified, associated with local factors such as relief, as well as the Pedobiome of the Tropical Humid Zonobiome, related to specific soils that affect vegetation composition.	3,13,21,24,25,27,33,81	6
25	Andean	30320	Region located to the north of the Eastern Range, dominated by the Orobiome of the Tropical Humid Zonobiome, which covers almost the entire area. It is characterized by a very cold to temperate climate, with predominantly humid and super-humid conditions, favoring the development of Andean and Sub-Andean montane forests. The relief is	3,13,21,25	7

Item	Region	Classification Region	Description	Class	Ver
			mainly composed of mountains and foothills, with steep slopes and high altitudinal heterogeneity.		
26	Andean	30401	Region located in the Western Range and the Inter-Andean Valleys, dominated by the Orobiome of the Tropical Humid Zonobiome, which occupies more than half of the area, with mountain ecosystems under very cold to temperate climates, and humid to super-humid conditions. It is accompanied by the Tropical Alternohygric Zonobiome, characterized by seasonal variations in water availability, and by the Azonal Orobiome of the Tropical Humid Zonobiome, influenced by local conditions such as slope or drainage. The relief is mainly composed of mountains and foothills, with marked altitudinal heterogeneity.	3,9,13,21, 23,24,25, 30,33,75	8
27	Andean	30402	The region is located in the Western and Central Ranges, and is predominantly composed of the Orobiome of the Tropical Humid Zonobiome, where temperate humid climates dominate a mountainous landscape, representing most of the area. A cold super-humid climate is also observed, present in mountain landscapes and high plateaus. Additionally, a cold humid climate occurs in both mountain and high plateau landscapes. Although to a lesser extent, warm humid climates are recorded in hill and mountain areas. Overall, the region exhibits a diversity of cold and temperate climates, with a clear predominance of humid conditions in mountain environments.	3,9,13,21,2 4,25,30,31, 33,75	19
28	Andean	30403	The region is predominantly formed by the Orobiome of the Tropical Humid Zonobiome, characterized by a temperate humid climate and a high plateau landscape, which represents most of the area. It is associated with a cold super-humid climate, which is also abundant in mountain landscapes. Complementarily, there is a notable presence of a cold humid	3,13,21,24, 25,30,33	5

Item	Region	Classification Region	Description	Class	Ver
			climate in both hill and mountain terrains. In general, the region is characterized by its climatic diversity, with a strong predominance of temperate and cold climates across different landscape configurations.		
29	Andean	30404	Region located in the Western Range, predominantly composed of the Tropical Humid Zonobiome and its Orobiome, with a predominance of mountain landscapes. Climates range from warm humid, warm super-humid, and temperate humid, also highlighting areas with warm semi-humid and temperate super-humid climates. To a lesser extent, foothill zones with warm humid climate are present.	3,21,23,24, 25,30,33	18
30	Andean	30405	This region is composed mainly of the Azonal Orobiome of the Tropical Humid Zonobiome, which contributes broad climatic variability, including areas with temperate and cold semi-arid climates associated with hill and mountain landscapes. Secondly, the Orobiome of the same Zonobiome contributes extensive humid mountain areas, characterized by cold and super-humid climates. Localized units of the Pedobiome of the Tropical Humid Zonobiome are also found, linked to specific edaphic conditions that influence vegetation distribution.	3,9,13,21,2 3,24,25,30, 33,75	11
31	Andean	30406	The region is located in the Central Range and part of the Eastern Range and is characterized mostly by Orobiomes of the Tropical Humid Zonobiome, where temperate semi-humid climates and mountains predominate. There is also a notable presence of very cold humid and cold semi-humid climates, all within mountain landscapes. In addition, areas with warm semi-humid and semi-arid climates are observed, maintaining the same mountain landscape structure.	3,13,21,23, 24,25,30,6 8	9
32	Andean	30407	The region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, featuring a temperate semi-humid climate and a mountain	3,9,13,21,2 3,24,25,	42

Item	Region	Classification Region	Description	Class	Ver
			landscape, which represents a significant portion of the area. Cold humid and cold semi-humid climates also occur in mountain landscapes. In addition, temperate semi-arid climates are identified in both foothill and mountain landscapes. Alongside this, temperate humid climates occur in mountains and high plateaus. Although in smaller proportion, a temperate semi-arid climate is recorded in alluvial plain and hill landscapes. Overall, the region reflects a diversity of climatic conditions across different landscape configurations, with a predominance of mountain environments.	27,30,31, 33	
33	Andean	30408	Region predominantly formed by the Orobiome of the Tropical Humid Zonobiome, which represents most of the area and develops within a mountain landscape under temperate super-humid conditions. Zones with cold super-humid, temperate humid, and temperate semi-humid climates are identified, all in mountain settings. To a lesser extent, warm super-humid and cold humid climates appear; a small area with temperate humid climate is recorded in a hill landscape. In addition, the region hosts areas of the Tropical Humid Zonobiome, typical of warm zones with high humidity; the Tropical Alternohygric Zonobiome, associated with seasonal moisture variations; as well as Pedobiomes and Azonal Orobiomes of the Tropical Humid Zonobiome. Taken together, this region reflects notable climatic and ecological diversity.	3,9,13,21,24,25,27,33	99
34	Andean	30409	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, which is associated with cold, humid, and super-humid climates in mountain areas. There is also a considerable proportion of the Tropical Humid Zonobiome, characterized by warm, humid climates at lower elevations. Locally, units of the Tropical Alternohygric Zonobiome appear, representative of environments with marked seasonality in	3,11,21,24, 25,27,33	6

Item	Region	Classification Region	Description	Class	Ver
			moisture availability, as well as the Pedobiome of the Tropical Humid Zonobiome, linked to soils with particular properties that affect vegetation cover.		
35	Andean	30410	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, which defines a mountain landscape with cold, humid, and super-humid climates. To a lesser extent, the Azonal Orobiome of the same Zonobiome contributes altitudinal and climatic variability, especially in hill areas and moderate slopes. Units of the Pedobiome of the Tropical Humid Zonobiome are also identified, associated with specific edaphic conditions, and of the Tropical Alternohygric Zonobiome, characterized by marked seasonality in moisture availability. Locally, the Tropical Humid Zonobiome appears in low-elevation areas with warm, humid climates.	3,9,11,13,21,24,25,27,30,33	7
36	Andean	30411	The region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, with mountain landscapes predominating under cold humid, temperate semi-humid, and cold semi-humid climates. To a lesser extent, areas with very cold super-humid and very cold humid climates occur, as well as foothill landscapes under warm semi-arid climate. Hill and high plateau zones are also observed, associated with cold humid and temperate semi-humid climates. Finally, there are small areas with temperate semi-arid climate in mountain landscapes.	3,13,21,23,24,30,25,31,33,68, 75	51
37	Andean	30412	The region is mostly composed of the Tropical Alternohygric Zonobiome, with warm semi-arid climates and landscapes that include foothills, mountains, and valleys. Areas of the Orobiome of the Tropical Humid Zonobiome also predominate, characterized by temperate and cold climates, both humid and semi-humid, and mountain landscapes. In addition, smaller portions with warm semi-humid climates associated with	3,13,21,23,24,25,30,31,33,68	13

Item	Region	Classification Region	Description	Class	Ver
			the Tropical Humid Zonobiome are observed in mountain and foothill landscapes. Finally, a small part corresponds to the Pedobiome of the Tropical Humid Zonobiome.		
38	Andean	30413	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, characterized by cold, humid, and super-humid climates in mountainous relief. The Tropical Humid Zonobiome is also present, associated with warm, humid conditions at lower elevations. Localized units of the Pedobiome of the Tropical Humid Zonobiome are identified in sectors with distinct soils and gentle slopes.	3,13,21,24, 25,30,33	6
39	Andean	30414	The region lies mainly in the Central Range and is largely composed of the Tropical Alternohygric Zonobiome, with a predominance of warm semi-arid climates in foothill, mountain, and valley landscapes. Areas with mountain landscapes under warm semi-humid climate of the Tropical Humid Zonobiome are also observed and, to a lesser extent, temperate semi-humid zones in mountains, together with semi-arid areas in hill terrains.	3,13,21,23, 24,25,30, 33,31,68, 75	18
40	Andean	30415	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, associated with cold and humid climates in mountain areas. Secondly, the Azonal Orobiome of the same Zonobiome is present, introducing greater climatic and topographic variability, especially in hill areas. The Tropical Humid Zonobiome, corresponding to warm, humid lowlands, and the Tropical Alternohygric Zonobiome, characterized by marked seasonality in moisture availability, are also present. More specifically, the Pedobiome of the Tropical Humid Zonobiome occurs in areas with specific edaphic conditions that influence the dominant vegetation.	3,11,13,21, 24,25,30,3 3	7

Item	Region	Classification Region	Description	Class	Ver
41	Andean	30416	The study region is composed mostly of the Orobiome of the Tropical Humid Zonobiome, with mountain landscapes predominating under temperate humid, cold humid, and cold super-humid climates. Significant areas with temperate semi-humid and temperate super-humid climates are also found in mountain landscapes. To a lesser extent, there are foothill zones associated with temperate humid and temperate semi-humid climates, as well as some mountain areas with very cold super-humid climate.	3,9,13,21, 23,24,25, 30,33	67
42	Andean	30417	The study region is characterized mainly by the Orobiome of the Tropical Humid Zonobiome, with a predominance of mountain landscapes under temperate and cold climates, both super-humid and humid. Areas with cold semi-humid and temperate semi-humid climates are also found, always within mountain landscapes. In addition, zones of the Tropical Humid Zonobiome with warm humid and warm super-humid climates are observed in mountain landscapes, as well as some hill areas with warm humid climate.	3,9,13,21, 23,24,25, 30,33,68	8
43	Andean	30418	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, which dominates the landscape with cold, humid, and super-humid climates in mountain areas. To a lesser extent, the Azonal Orobiome of the same Zonobiome contributes diversity in topography and climatic conditions, especially in hill areas and medium slopes. Units of the Tropical Humid Zonobiome are also present, linked to warm, humid climates in lower-altitude sectors, and of the Tropical Alternohygric Zonobiome, representative of zones with seasonal variation in moisture. Locally, the Pedobiome of the Tropical Humid Zonobiome appears in areas where soils condition the structure and composition of vegetation.	3,9,11,13,21,24,25,30, 33,75	6

Item	Region	Classification Region	Description	Class	Ver
44	Andean	30419	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, associated with cold, humid, and super-humid climates in mountain areas. A significant proportion of the Tropical Humid Zonobiome is also present, characterized by warm, humid climates at lower elevations. More locally, small extents of the Tropical Alternohygric Zonobiome are identified, representative of environments with seasonal moisture, as well as the Pedobiome of the Tropical Humid Zonobiome, linked to soils with particular properties. In a smaller proportion, the Azonal Orobiome of the Tropical Humid Zonobiome also appears, related to hill terrains and altitudinal transition zones.	3,13,21,23,24,25,27,33	6
45	Andean	30420	The region is dominated by the Azonal Orobiome of the Tropical Humid Zonobiome and the Orobiome of the Tropical Humid Zonobiome, both developed in mountain landscapes with temperate and cold climates, humid to super-humid, locally influenced by relief. These are followed by the Tropical Alternohygric Zonobiome, which reflects marked seasonality in moisture availability, and the Tropical Humid Zonobiome, present in foothill or hill areas under warm, humid conditions. This configuration evidences a strong predominance of mountain environments with climatic diversity.	3,9,13,21,23,24,25,30,33,68	9
46	Andean	30421	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, characterized by cold and humid climates in mountain areas. A significant proportion of the Tropical Humid Zonobiome is also present, associated with warm, humid climates at lower elevations. Locally, the Pedobiome of the Tropical Humid Zonobiome is present in sectors with particular edaphic conditions that influence vegetation cover and its distribution.	3,9,11,13,21,23,24,25,30,33	6

Item	Region	Classification Region	Description	Class	Ver
47	Andean	30422	The region is dominated by the Orobiome of the Tropical Humid Zonobiome in a mountain landscape, with temperate and cold climates, both humid and super-humid, which constitute most of the area. Zones with cold semi-humid and warm super-humid climates also stand out, still within the mountain context. Finally, smaller areas with warm and temperate semi-humid climates contribute to the climatic diversity within the region.	3,9,13,21, 23,24,25, 30,33	8
48	Andean	30423	The region is located in the Eastern Range and is composed mostly of the Orobiome of the Tropical Humid Zonobiome, followed by the Tropical Humid Zonobiome and the Azonal Orobiome of the same Zonobiome. This configuration corresponds to high- and mid-mountain landscapes under high-humidity conditions. The ecosystems present include Andean vegetation formations such as sub-Andean and Andean humid forests, as well as covers typical of lower-altitude zones with warm-humid climates. The Azonal Orobiome reflects steep slopes and poorly developed soils that generate specific microenvironments in the vegetation.	3,13,21,23, 24,25,30,3 1	81
49	Andean	30424	The study region is characterized mostly by belonging to the Tropical Humid Zonobiome, with a predominance of warm humid climate and a mountain landscape. It also presents zones with warm semi-humid climate, both in mountain areas and in valleys. To a lesser extent, hills with warm humid climate and mountains with warm super-humid climate are found. Additionally, there are small areas with temperate humid climate in mountain settings, associated with the Orobiome of the Tropical Humid Zonobiome.	3,13,21,23, 24,25,33, 31,35	8
50	Andean	30425	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, with significant participation of the Tropical Humid	3,13,21,25	8

Item	Region	Classification Region	Description	Class	Ver
			Zonobiome and the Tropical Alternohygric Zonobiome. This combination reflects a territory with a strong mountain influence in its central zone, transitioning toward warm lowlands and environments with hydrological seasonality. The ecosystems present develop under climates ranging from very cold to warm, under predominantly humid conditions, and include Andean and sub-Andean forests, as well as vegetation formations typical of plains and foothills. The relief comprises mountains, foothills, and alluvial plains.		
51	Andean	30426	The study region is characterized mostly by being dominated by the Orobiome of the Tropical Humid Zonobiome, with a mountain landscape and a temperate semi-humid climate. It also has relevant areas of warm semi-humid climate in mountain environments. To a lesser extent, mountains with cold humid climate and, in smaller measure, areas with temperate humid climate are found. There are small foothill and hill areas, both with temperate semi-humid and warm semi-humid climates, although these landscapes are significantly less representative.	3,13,21,25, 30	8
52	Andean	30427	The study region is characterized mainly by being dominated by the Tropical Humid Zonobiome, with a mountain landscape and a warm humid climate. The presence of the Orobiome of the Tropical Humid Zonobiome is also notable, where mountain landscapes with temperate humid and temperate super-humid climates prevail. To a lesser extent, hills associated with a warm humid climate occur, as well as mountains with warm super-humid climates. Areas with cold super-humid climate in mountain environments are more reduced.	3,13,21,23, 24,25,30,3 3	11

Item	Region	Classification Region	Description	Class	Ver
53	Andean	30428	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, associated with cold and humid climates in mountain areas. There is also an important presence of the Tropical Humid Zonobiome, characteristic of warm and humid areas located at lower elevations. Locally, the Pedobiome of the Tropical Humid Zonobiome is distributed in areas with particular soils and gentle slopes, which condition the vegetation present in those environments.	3,9,11,13,21,23,24,25,27,30,33	7
54	Andean	30429	This region is composed mainly of the Orobiome of the Tropical Humid Zonobiome, associated with cold, humid, and super-humid climates in mountain areas. To a lesser extent, the Tropical Humid Zonobiome, characteristic of warm, humid areas in low-altitude zones, and the Tropical Alternohygric Zonobiome, which reflects environments with seasonal moisture variation, are present. Units of the Azonal Orobiome of the same Zonobiome are also identified in areas with greater topographic heterogeneity, and Pedobiomes of the Tropical Humid Zonobiome occur in sectors with distinct soils.	3,13,21,24,25,30,33	7
55	Andean	30430	The region, located mainly in the Central Range, is completely dominated by the Orobiome of the Tropical Humid Zonobiome, corresponding to mountain ecosystems under high-humidity conditions. These develop in climates ranging from temperate to very cold, with a predominance of vegetation formations such as sub-Andean and Andean humid forests. The relief is characterized by mountains and foothills, with marked slopes and strong altitudinal variation, which configure a complex landscape influenced by topography.	3,9,13,21,23,24,25,30,31,33	6
56	Andean	30458	This region is composed mainly of the Tropical Humid Zonobiome, characterized by warm, humid climates in low-altitude zones. To a lesser	3,21,23,24,25,33,35	6

Item	Region	Classification Region	Description	Class	Ver
			extent, the Pedobiome of the same Zonobiome is present in areas where soil conditions influence vegetation cover and its distribution. Locally, this Pedobiome extends over gently sloping terrains or areas with particular edaphic properties. Small areas with characteristics similar to those of the Tropical Humid Zonobiome are also identified, reinforcing the climatic homogeneity of the territory.		
57	Andean	30459	The region located in the southern Andes consists of a combination of humid mountain ecological units, with a predominance of the Azonal Orobiome and the Orobiome of the Tropical Humid Zonobiome, together with the Tropical Alternohygric Zonobiome. This configuration reflects an abrupt and varied relief, influenced by local factors such as extreme slopes and particular drainage. Ecosystems develop under temperate to very cold climates, in high-humidity conditions with hydrological seasonality, where Andean and sub-Andean forests are distributed, as well as vegetation formations subject to moisture pulses. The landscape includes mainly mountains and foothills.	3,13,21,23 24,25, 33	20
58	Andean	30460	The region located in the Western Range is characterized mostly by the Tropical Humid Zonobiome, highlighting a warm super-humid climate and a mountain landscape, which represents a significant part of the area. Alongside this, a temperate super-humid climate also occurs in mountain landscapes, as well as temperate semi-humid and temperate humid climates in the same setting. Additionally, there is a notable presence of warm semi-humid and warm humid climates, all in mountain landscapes. Although in smaller proportion, a warm super-humid climate occurs in a valley landscape, thus contributing to the climatic diversity of the region. Overall, the region reflects a rich variety of climatic conditions in mountain environments.	3,13,21,23, 25,27,33	18

Item	Region	Classification Region	Description	Class	Ver
59	Andean	30461	The region located in the northern sector of the Eastern Range is dominated by the Orobiome of the Tropical Humid Zonobiome, with the presence of the Azonal Orobiome of the same Zonobiome. It corresponds to a mountain territory with temperate to very cold climates and high-humidity conditions, where typical Andean and sub-Andean forest ecosystems develop. The presence of the azonal component indicates the influence of local factors such as steep slopes, poorly developed soils, or surface drainage, which generate micro-environmental variations in the vegetation. The relief consists mainly of mountains and foothills, with marked topographic complexity.	3,13,21,24, 25	8
60	Andean	30464	The region presents a dominance of the Tropical Humid Zonobiome, followed by the Tropical Alternohygric Zonobiome and the Orobiome of the Tropical Humid Zonobiome. This combination reflects an altitudinal transition between warm lowlands and mountain areas, under humid to very humid climatic conditions. The ecosystems include tropical humid forests in plains and foothills, as well as vegetation formations subject to hydrological seasonality in alternohygric zones. In the higher zones, montane ecosystems characteristic of colder, high-humidity climates are found. The relief integrates alluvial plains, foothills, and mountain systems.	3,9,13,21,2 3,24,25,30, 33	7
61	Andean	30465	The study region is distinguished mostly by the presence of the Orobiome of the Tropical Humid Zonobiome, characterized by very cold super-humid, humid, and semi-humid climates, all within a mountain landscape. A cold semi-arid climate is also observed, occurring in mountain areas and in miscellaneous eroded landscapes. Additionally, there are sections with warm semi-humid and temperate semi-humid climates.	3,9,13,21, 25,27,33	7

Item	Region	Classification Region	Description	Class	Ver
62	Andean	30466	The region is dominated by the Orobiome of the Tropical Humid Zonobiome, characterized primarily by very cold climates, both humid and semi-humid, within mountain landscapes. It also features significant areas with cold semi-arid climate, likewise in mountains. Zones with very cold super-humid climate also stand out and, to a lesser extent, small portions with extremely cold super-humid and cold semi-humid climates, with the mountain landscape remaining the constant across the entire region.	3,9,13,21,23,25,27, 33,68,81	8
1	Amazon	30201	Region composed of the Tropical Humid Zonobiome Pedobiome and the Amazon Lithobiomes; characterized by rocky outcrops, it has a very humid warm climate and a humid warm climate. The predominant terrain consists of plateaus or mountains with flattened peaks.	3,11,13,18, 23,25,33	8
2	Amazon	30202	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid climate. The relief is predominantly characterized by peneplains, alluvial plains, and valleys.	3,6,11,18, 21, 25,30, 33	8
3	Amazon	30203	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by hills, massifs, alluvial plains, and valleys.	3,6,11,12,25, 33	7
4	Amazon	30204	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by a Warm Humid, Warm Semi-Humid, Warm Super-Humid, Temperate Humid, Temperate Semi-Humid, and Temperate Super-Humid climate. The relief is predominantly composed of high plains, hills, mountains, foothills, alluvial plains, and valleys.	3,6,15,21, 24,25,33	8

Item	Region	Classification Region	Description	Class	Ver
5	Amazon	30205	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is defined by low hills, peneplains, and valleys.	3,6,11,13,21,23,24,25,30,33,68	9
6	Amazon	30206	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by hills, massifs, peniplanicies, alluvial plains, and valleys.	3,6,11,18,23,24,25,33	10
7	Amazon	30207	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is associated with the geological formation of the Guiana Shield and is mostly flat with slight undulations.	3,6,11,12,21,23,24,25,29,33,68	8
8	Amazon	30208	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid climate. The relief is predominantly characterized by high plains, hills, massifs, alluvial plains, and valleys.	3,6,11,15,18,21,25,33	8
9	Amazon	30209	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; It is characterized by a warm humid, warm superhumid, warm semi-humid, temperate humid, temperate superhumid, and cold humid climate. The relief is dominated by hills, mountains, foothills, alluvial plains, river plains, and valleys.	3,6,11,13,15,18,21,23,24,25,30.31,33,75	10
10	Amazon	30210	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by a Warm Humid, Warm Semi-Humid, Warm Super-Humid, Temperate Humid, Temperate Semi-Humid, and Temperate Super-Humid climate. The relief is predominantly	3,6,9,11,15,21,24,25,30,31,33,	10

Item	Region	Classification Region	Description	Class	Ver
			characterized by high plains, hills, mountains, foothills, alluvial plains, and valleys.		
11	Amazon	30211	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid climate.	3,6,11, 15,21,24, 25,33	9
12	Amazon	30212	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid and Warm Semi-Humid climate. The relief is predominantly composed of high plains, hills, peneplains, alluvial plains, and valleys.	3,6,9,11,12, 15,18,21, 23,24,25, 29,33,35	10
13	Amazon	30213	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by high plateaus, hills, massifs, and valleys.	3,6,11,12,1 315,21,23, 33	8
14	Amazon	30214	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by high plateaus, hills, massifs, peniplateaus, and valleys.	3,6,11,13,1 5,18,21,23, 24,25,33,6 8,	8
15	Amazon	30215	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by hills, floodplains, and valleys.	3,6,11,13,1 5,18,21,23, 25,30,31,3 3,75	9
16	Amazon	30216	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by a Warm Humid, Warm Super-Humid, Temperate Humid, and Temperate Super-Humid climate. The relief is	3,6,15,18, 21,23,24, 25,31,33, 35,75	10

Item	Region	Classification Region	Description	Class	Ver
			predominantly composed of hills, mountains, foothills, alluvial plains, and valleys.		
17	Amazon	30217	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome. The terrain is dominated by high plateaus, hills, foothills, floodplains, and valleys.	3,6,11,12,13,15,18,21,23,24,25,33,35	8
18	Amazon	30218	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by high plains, hills, and valleys.	3,6,12,15,21,25,33,	7
19	Amazon	30219	Region composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; it is characterized by a Warm Humid, Warm Semi-Humid, and Temperate Humid climate. The relief is predominantly composed of high plains, hills, mountains, alluvial plains, and valleys.	3,6,11,12,13,15,21,24,25,33	9
20	Amazon	30220	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid climate. The relief is predominantly composed of high plains, hills, massifs, alluvial plains, and valleys.	3,6,11,12,15,18,21,24,25,33,35	8
21	Amazon	30221	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly made up of plains.	3,6,11,13,21,25,33,68	8

Item	Region	Classification Region	Description	Class	Ver
22	Amazon	30222	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly made up of low hills, massifs, peneplains, and valleys.	3,6,13,21,25,33,68	8
23	Amazon	30223	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is characterized by low hills.	3,6,11,12,13,21,24,23,33,68	7
24	Amazon	30224	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome. The terrain is dominated by high plateaus, hills, massifs, peniplateaus, alluvial plains, and valleys.	3,6,11,12,1315,21,23,25,33,68	8
25	Amazon	30225	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by plateaus and valleys.	3,6,13,18,21,25,33	9
26	Amazon	30226	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome. The terrain is dominated by high plateaus, hills, massifs, mountains, foothills, alluvial plains, and valleys.	3,6,11,12,1315,18,21,23,24,25,33,35	9
27	Amazon	30227	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid climate. The relief is predominantly composed of hills, massifs, and valleys.	3,6,11,13,21,25,33	8
28	Amazon	30228	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by peneplains, alluvial plains, and valleys.	3,6,11,13,15,18,21,23,25,33,68	10

Item	Region	Classification Region	Description	Class	Ver
29	Amazon	30229	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief ranges from flat to gently undulating.	3,6,11,13,21,23,25,33,68	10
30	Amazon	30230	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly made up of plateaus and plains.	3,6,11,13,21, 23,24,25,33,68	7
31	Amazon	30231	Region composed of the Tropical Humid Zonobiome and Tropical Humid Pedobiome; it is characterized by a warm, humid climate. The terrain is dominated by high plateaus, hills, massifs, peniplateaus, alluvial plains, and valleys.	3,6,11,13,15,18,23,25,33	11
32	Amazon	30232	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly flat, with slopes not exceeding 3%.	3,6,11,12,21,23,24,25, 29,30,33,68,75	13
33	Amazon	30233	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. This area is completely flat, with minimal elevations.	3,6,11,13,21,23,24,25, 29,30,33,68	11
34	Amazon	30234	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly flat, with gentle slopes.	3,6,11,13,21,23,24,25, 33,68	11
35	Amazon	30235	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm Humid	3,6,11,21,24, 30,25,29,	10

Item	Region	Classification Region	Description	Class	Ver
			climate. The relief is predominantly composed of hills, peneplains, and valleys.	33	
36	Amazon	30236	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly made up of low hills, massifs, peneplains, and valleys.	3,6,11,13,21,23,24,25,33,68	12
37	Amazon	30237	Region composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome; it is characterized by a Warm and Humid climate. The relief is predominantly made up of plateaus, low hills, massifs, mountains, peneplains, and valleys.	3,6,11,13,21,23,24,25,33,68	10
1	Caribbean	30431	The region is composed of the Pedobiome of the Tropical Humid Zonobiome; it is characterized by a Warm Semi-arid climate and a marine plain landscape.	3,5,6,11,21,23,24,25,31,32,33	8
2	Caribbean	30432	Region composed of the Tropical Alternohygric Zonobiome, Tropical Humid Zonobiome, and a very small part by the Tropical Humid Pedobiome. Its climate ranges from Warm Semi-arid to Semi-humid, with a landscape of foothills, mountains, and hills.	3,6,9,11,13,21,23,24,25,30,31,33,35,68,75	9
3	Caribbean	30433	The region is composed of the Tropical Humid Zonobiome, characterized by a Warm Semi-humid climate and a landscape of foothills and alluvial plains.	3,6,9,11,21,23,24,25,30,33,35,75	8
4	Caribbean	30434	Region with two biomes: the Tropical Alternohygric Zonobiome and the Pedobiome of the Tropical Humid Zonobiome. The region also presents a Warm Arid and Warm Semi-arid climate and landscapes of hills, foothills, and alluvial plains.	3,5,6,9,11,21,23,24,25,30,31,33,35,75	7

Item	Region	Classification Region	Description	Class	Ver
5	Caribbean	30435	The region is composed of the Tropical Alternohygric Zonobiome and the Pedobiome of the Tropical Humid Zonobiome with landscapes of fluvio-lacustrine plains, hills, foothills, mountains, and alluvial plains; climate Warm Semi-arid and Warm Semi-humid.	3,5,6,9,11,21,24,25,30,33,35	11
6	Caribbean	30436	This region presents two major biomes: Tropical Humid Zonobiome and Pedobiome of the Tropical Humid Zonobiome. It has Warm Humid and Warm Semi-humid climates. The relief is mainly hills, mountains, and alluvial plains.	3,6,11,21,23,24,25,30,33,35	12
7	Caribbean	30437	This region consists of two main biomes: Orobiome of the Tropical Humid Zonobiome and Tropical Alternohygric Zonobiome. Its climate is Temperate Semi-humid, Warm Semi-arid, and Warm Semi-humid. Landscape mainly mountains and foothills.	3,5,6,11,13,21,23,24,25,30,33,35,74	9
8	Caribbean	30438	The region is composed of the Tropical Alternohygric Zonobiome, the Pedobiome of the Tropical Humid Zonobiome, and the Orobiome of the Tropical Humid Zonobiome; its climate is Warm Semi-arid, Temperate Semi-humid, and Warm Semi-humid, with landscapes of alluvial plains, mountains, and foothills.	3,6,9,11,21,24,25,33,35	9
9	Caribbean	30439	The region is composed of the Tropical Alternohygric Zonobiome and the Azonal Orobiome of the Tropical Humid Zonobiome; climate is Warm Arid, Semi-arid; landscape includes hills, mountains, and fluvio-marine plains.	3,5,6,11,13,21,23,24,25,30,33,35	9

Item	Region	Classification Region	Description	Class	Ver
10	Caribbean	30440	The region is composed of the Tropical Humid Zonobiome, characterized by a Warm Semi-humid climate and a landscape of hills and alluvial plains.	3,9,11,21,23,24,25,33,35,75	8
11	Caribbean	30441	The region is composed of the Tropical Humid Zonobiome; characterized by a Warm Semi-humid and Warm Humid climate, with landscapes of alluvial plains, foothills, and some hills.	3,6,11,21,23,24,25,30,33,35	8
12	Caribbean	30442	The region is composed of the Tropical Alternohygric Zonobiome; characterized by a Warm Semi-arid climate and foothill landscapes with some mountains.	3,6,11,13,21,24,25,33,35	7
13	Caribbean	30443	The region is composed of the Tropical Humid Zonobiome and the Tropical Alternohygric Zonobiome; characterized by a Warm Sub-humid, Semi-arid climate, and foothill landscapes with hills.	3,6,9,11,21,24,25,30,33,35	7
14	Caribbean	30444	The region is composed of the Tropical Alternohygric Zonobiome and the Pedobiome of the Tropical Humid Zonobiome; climate mainly Warm Semi-arid, with landscapes of alluvial plains and foothills.	3,5,6,11,21,23,24,25,30,33,35,74,75	8
15	Caribbean	30445	The region is mainly composed of the Tropical Alternohygric Zonobiome, characterized by predominantly Warm Semi-arid climate, with landscapes of foothills and fluvio-marine plains.	3,5,6,9,21,23,24,25,33,35	8
16	Caribbean	30446	The region is composed of the Tropical Alternohygric Zonobiome and the Tropical Humid Zonobiome; characterized by a Warm Semi-arid climate and landscapes of hills and mountains.	3,6,9,11,21,24,25,30,33,35	9

Item	Region	Classification Region	Description	Class	Ver
17	Caribbean	30447	The region is composed of the Tropical Alternohygric Zonobiome, characterized by a Warm Desert climate with predominantly mountain, hill, and fluvio-marine plain landscapes.	3,21,23,24,25,33,49,75	9
18	Caribbean	30448	The region is composed of the Tropical Humid Zonobiome; characterized by Warm Humid and Warm Semi-humid climates, with predominantly hilly landscapes.	3,6,9,11,21,24,25,30,31,33,35,75	9
19	Caribbean	30449	The region is composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Tropical Alternohygric Zonobiome; climate Warm Semi-arid, Warm Semi-humid; landscapes include alluvial plains, mountains, and foothills.	3,6,11,21,23,24,25,30,33	9
20	Caribbean	30450	The region comprises two major biomes: Tropical Humid Zonobiome and the Pedobiome of the Tropical Humid Zonobiome. Climates include Warm Semi-humid and Warm Semi-arid. Landscapes: foothills, alluvial plains, and mountains.	3,6,9,11,21,23,24,25,30,33,35	9
21	Caribbean	30451	The region is mainly composed of the Tropical Alternohygric Zonobiome, characterized by Warm Desert and Warm Arid climates, with landscapes of fluvio-marine plains and hills.	3,5,6,11,21,23,24,25,29,30,32,33,49,50	10
22	Caribbean	30452	The region is composed of the Tropical Humid Zonobiome and the Pedobiome of the Tropical Humid Zonobiome; characterized by Warm Semi-humid, mainly Warm Humid, and Temperate Semi-humid climates. Landscapes include mountains with hills, alluvial plains, and foothills.	3,6,11,21,23,24,25,30,33,35	7

Item	Region	Classification Region	Description	Class	Ver
23	Caribbean	30453	The region is composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Tropical Alternohygric Zonobiome; climate Warm Semi-humid, Warm Semi-arid, Warm Arid; landscapes include alluvial plains, marine plains, foothills, and hills.	3,5,6,11,21,23,24,25,30,31,33,35	12
24	Caribbean	30454	The region is composed of the Pedobiome of the Tropical Humid Zonobiome, the Tropical Humid Zonobiome, and the Tropical Alternohygric Zonobiome; climate Warm Humid, Semi-humid, Warm Semi-arid; landscapes include alluvial plains, hills, fluvio-lacustrine plains.	3,6,9,11,21,24,25,30,33,35,75	9
25	Caribbean	30455	The region is mainly composed of the Tropical Alternohygric Zonobiome, characterized by a Warm Arid climate with landscapes of hills and foothills.	3,6,9,11,21,23,24,25,30,31,33	8
26	Caribbean	30456	The region mainly contains the Pedobiome of the Tropical Humid Zonobiome; climate Semi-arid; landscapes include marine plains and fluvio-lacustrine plains.	3,5,6,11,21,24,25,33	6
27	Caribbean	30457	The region is covered by the Orobiome of the Tropical Humid Zonobiome and the Pedobiome of the Tropical Humid Zonobiome; landscape mainly mountains; climate Very Cold Super-humid and Cold Humid.	3,13,21,29,33,34	11
28	Caribbean	30462	The region is mainly composed of seas and oceans and the Tropical Alternohygric Zonobiome, characterized by a Warm Semi-arid climate with hilly landscapes.	3,5,21,23,25,33,68	5
1	Orinoquia	30469	The studied region, belonging to the Orobiome of the Tropical Humid Zonobiome, is predominantly characterized by a humid and super-humid temperate climate, as well as by a mountainous landscape. In addition,	3,6,11,12,21,23,24,25,33	12

Item	Region	Classification Region	Description	Class	Ver
			there are areas with a warm humid climate and a mountainous or hilly landscape. Characteristics of a cold super-humid climate are also identified, although in smaller proportions, including high plateau and mountain landscapes. In general, the mountainous landscape and the temperate and warm climates are the most representative of the region.		
2	Orinoquia	30470	The study region is predominantly located in the Pedobiome of the Tropical Humid Zonobiome, mainly characterized by a warm semi-humid climate. The most common landscapes include eolian plains, alluvial plains, and valleys. There is also a significant presence of areas with a warm semi-arid climate, associated with alluvial plains.	3,6,11,12,21,23, 24,25,33	8
3	Orinoquia	30471	The region is mainly characterized by belonging to the Orobiome of the Tropical Humid Zonobiome, presenting a mosaic of mountainous and piedmont landscapes. A humid temperate climate predominates, although areas with a semi-humid temperate climate are also found. To a lesser extent, the region includes areas belonging to the Pedobiome of the Tropical Humid Zonobiome, with humid climates and mountain, piedmont, and alluvial plain landscapes.	3,6,9,11,12, 21,23,24,25,30,31,33, 35,75	12
4	Orinoquia	30472	The studied region, mostly belonging to the Pedobiome of the Tropical Humid Zonobiome, is mainly characterized by a warm semi-humid climate and a predominant hilly landscape. Extensive valley areas with the same climatic conditions are also observed. To a lesser extent, high plateaus are identified, complementing the landscape. The hilly terrain is the most prominent geographic feature, followed by valleys and high plateaus, all within a warm semi-humid climatic context.	3,12,21,25, 33,35,75	10
5	Orinoquia	30473	The studied region, dominated by the Pedobiome of the Tropical Humid Zonobiome, is mainly characterized by a warm semi-humid climate and a	3,6,11,12,21,23,25,33	11

Item	Region	Classification Region	Description	Class	Ver
			high plateau landscape, which covers most of the area. There are also hilly and valley zones, although to a lesser extent. The high plateaus are the most prominent geographical feature, followed by areas of hills and valleys, all under a warm semi-humid climate.		
6	Orinoquia	30474	The region is mainly composed of the Orobiome of the Tropical Humid Zonobiome and the Pedobiome of the Tropical Humid Zonobiome. It is characterized by the presence of mountain, valley, foothill, hilly, and alluvial plain landscapes. A humid temperate climate predominates, while areas with a semi-humid temperate and warm humid climate exist to a lesser extent.	3,6,9,11,12,21,23,24,25,30,31,33,35,75	12
7	Orinoquia	30475	The study region is mostly composed of the Pedobiome of the Tropical Humid Zonobiome, standing out for its warm humid and semi-humid climates. The predominant landscapes are hills and valleys, with a notable presence of areas that exhibit these climatic and landscape characteristics.	3,6,9,11,12,21,23,24,25,33,35	10
8	Orinoquia	30476	The studied region, mostly belonging to the Pedobiome of the Tropical Humid Zonobiome, is mainly characterized by a warm semi-humid climate and the predominance of landscapes formed by floodplains. Alluvial plains also stand out, and to a lesser extent, valleys. The territory is dominated by these extensive plains, while the valley areas have a more limited presence.	3,6,11,12,21,23,25,33,35	71
9	Orinoquia	30477	The region is composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome. It is dominated by highland plateaus, alluvial plains, and valleys. The region is characterized by a warm humid climate and a warm semi-humid climate.	3,6,11,12,21,23,24,25,33, 68	95

Item	Region	Classification Region	Description	Class	Ver
10	Orinoquia	30478	The region, mostly belonging to the Pedobiome of the Tropical Humid Zonobiome, is primarily characterized by a warm climate, both humid and semi-humid, with a dominant highland plateau landscape. Additionally, areas of peniplains are identified under both climates, and to a lesser extent, valleys. The highland plateaus are the most prominent geographic feature, followed by the peniplains, while the valleys occupy a smaller portion of the territory.	3,6,11,12,21,24,25,29,33	9
11	Orinoquia	30479	The region is composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome. The dominant landscapes are high plateaus, alluvial plains, and valleys. It is characterized by the presence of a warm humid and warm semi-humid climate.	3,6,9,11,12,21,23,25,33,35	700
12	Orinoquia	30480	The region is mostly composed of the Pedobiome of the Tropical Humid Zonobiome and, to a lesser extent, of the Tropical Humid Zonobiome. It is dominated by a warm humid and warm semi-humid climate, characterized by valleys, alluvial plains, and high plateaus.	3,6,9,11,12,21,24,25,33,35	29
13	Orinoquia	30481	In the region, the Orobiome of the Tropical Humid Zonobiome predominates, characterized by a humid temperate climate. On the other hand, the Pedobiome of the Tropical Humid Zonobiome presents a warm humid climate. These are mainly distributed across piedmont, valley, and alluvial plain landscapes.	3,6,11,12,21,23,24,25,33	12
14	Orinoquia	30482	The region is mainly composed of the Pedobiome of the Tropical Humid Zonobiome and the Tropical Humid Zonobiome. Piedmont, alluvial plain, valley, and upland plain landscapes predominate, along with a warm humid and warm semi-humid climate.	3,6,9,11,12,21,23,24,25,30,33,35	8

Item	Region	Classification Region	Description	Class	Ver
15	Orinoquia	30483	The region is mainly characterized by belonging to the Orobiome of the Tropical Humid Zonobiome, with a predominantly temperate climate. It also includes areas with a semi-humid climate and, to a lesser extent, zones belonging to the Pedobiome of the Tropical Humid Zonobiome with a warm humid climate, and foothill, alluvial plain, valley, and hilly landscapes.	3,6,9,11,12,21,23,24,25,31,33,35	10
1	Pacific	30484	The study region is mostly located within the Tropical Humid Zonobiome, mainly characterized by a warm and super-humid climate. Hilly and mountainous landscapes predominate, with a small proportion of valley areas. Zones with a warm humid climate and undetermined characteristics (N.A.) are less significant in the region's overall distribution.	3,5,6,11,21,23,24,25,30,33	10
2	Pacific	30485	The region exhibits a warm climate that ranges from arid to semi-humid and humid, with landscapes including hills, mountains, foothills, valleys, and alluvial plains. The relief includes fans, hills, small valleys, and terraces. It is part of the Pedobiome and Orobiome of the Tropical Humid Zonobiome, as well as the Alternohygric Tropical Zonobiome.	3,5,6,9,11,13,21,23,24,25,30,31,33,35	93
3	Pacific	30486	It mainly features landscapes of alluvial, fluviomarine, and marine plains, with some hills, mountains, and valleys; the relief includes ridges, spines, hills, and terraces. The climate of the region is warm super-humid and temperate super-humid. It is located within the Tropical Humid Zonobiome.	3,6,11,21,23,24,25,30,33	91
4	Pacific	30487	It is located within the Orobiome and Pedobiome of the Tropical Humid Zonobiome. The region has a primarily warm and temperate climate, which can be humid, semi-humid, or super-humid. The relief consists of fan	3,5,6,11,21,23,24,25,	27

Item	Region	Classification Region	Description	Class	Ver
			formations, glacis, terraces, hills, small valleys, and floodplains and tidal flats.	30,31,33, 35	
5	Pacific	30488	The study region is largely composed of areas without a precise specification of climatic and landscape characteristics, as well as zones of seas and oceans. Areas of the Pedobiome of the Tropical Humid Zonobiome predominate, mainly characterized by a warm humid climate, and to a lesser extent by a warm super-humid climate. The landscapes associated with these areas include alluvial, marine, and fluvio-marine plains, as well as some unidentified zones (U.I.).	3,5,6,11,21, 23,24,25,3 0,31,33,35	10
6	Pacific	30489	The study region is predominantly located within the Pedobiome of the Tropical Humid Zonobiome, featuring a warm climate that ranges from humid to semi-humid and super-humid, and is mostly associated with valley landscapes. There are also some areas with unspecified climatic and landscape characteristics.	3,5,6,11,21, 23,24,25,3 0,33	9
7	Pacific	30490	This region contains parts of the Hydrobiomes and Halobiomes of Nechi, San Juan, Truando, and Darien, as well as the Tropical Humid Zonobiome and Sub-Andean Orobiome. Its landscapes and relief are made up of mountains, plains, and valleys, with fans, ridges, spines, terraces, and crests. The climate is primarily warm and temperate, varying between humid, semi-humid, and super-humid.	3,5,6,11,21, 23,24,25, 30,33	95
8	Pacific	30491	The climate is characterized by being warm, semi-humid, and humid, or temperate semi-humid and humid. The landscapes that make up the region are primarily mountains, plains, hills, and valleys, with a relief consisting of terraces, small valleys, ridges, spines, floodplains, and fringing reefs. The region is part of the Halobiome, Hydrobiome, and Orobiome Darien-Tacarcuna, as well as the Tropical Humid Zonobiome.	3,5,6,11,21, 23,24,25, 30,33	99

Item	Region	Classification Region	Description	Class	Ver
9	Pacific	30492	The study region is mainly composed of areas without a precise specification of climatic and landscape characteristics. In addition, a significant portion of the region belongs to the Pedobiome of the Tropical Humid Zonobiome, featuring a warm humid climate associated with diverse landscapes, mainly piedmont and plains, including alluvial, fluvio-marine, and marine plains.	3,5,6,9,11,21,23,24,25,33,35	9
10	Pacific	30493	The study region is mostly composed of areas without a precise specification of climatic and landscape characteristics. In addition, a significant portion of the region corresponds to seas and oceans, whose climatic and landscape characteristics are not determined.	3,5,25,29,33	5
11	Pacific	30494	The region is part of the Sub-Andean Orobiome, Hydrobiome, Halobiome, and Tropical Humid Zonobiome of San Juan and the Pacific-Choco Watershed. The predominant climate is warm super-humid and semi-humid, although temperate super-humid conditions are also present. The landscape and relief consist of mountains, foothills, plains, and valleys, along with fans, terraces, ridges, crests, spines, hills, and small hills.	3,6,11,21,23,24,25,30,33	77
12	Pacific	30495	The study region is mainly composed of the Orobiome and Pedobiome of the Tropical Humid Zonobiome. Areas with a temperate super-humid climate predominate in mountainous landscapes, while zones with a warm humid and warm super-humid climate are associated with various landscapes such as piedmonts, alluvial plains, and valleys.	3,6,9,11,21,23,24,25,33	7
13	Pacific	30496	The study region is mostly characterized by areas without a precise specification of climate and landscape, as well as by the presence of seas	3,5,6,11,21,23,24,25,33	6

Item	Region	Classification Region	Description	Class	Ver
			and oceans with undetermined characteristics. In addition, a significant portion of the region corresponds to the Pedobiome of the Tropical Humid Zonobiome, featuring a warm super-humid climate mainly associated with fluvio-marine plains, marine plains, and valleys.		

4.4.3 Legend

The thematic legend of MapBiomas Colombia has been developed through an interdisciplinary effort that brings together professionals from various Earth science disciplines, in coordination with other South American countries. This collaboration seeks to ensure thematic coherence and consistency at the regional level within the framework of the MapBiomas Network.

The construction of land cover classes was based on international references, such as the categories established by the Intergovernmental Panel on Climate Change (IPCC) and the legend of the Food and Agriculture Organization of the United Nations (FAO). In addition, elements of the National Land Cover Legend were incorporated under the CORINE Land Cover methodology adapted for Colombia at a 1:100.000 scale (IDEAM, 2010), which has served as the main reference framework for land cover mapping in the country.

Since Collection 1, the legend of MapBiomas Colombia has evolved through the gradual incorporation of new classes aimed at more accurately capturing the diversity of landscapes and land uses across the country. Initially, categories used in other MapBiomas Network initiatives, such as MapBiomas Brazil and Atlantic Forest, were adapted. As the collections advanced, specific classes were integrated to reflect significant territorial transformations. An example of this evolution is the inclusion of the classes Solar Panel Farm, Andean Herbaceous and Shrubby Vegetation, and Flooded Andean Herbaceous and Shrubby Vegetation in Collection 3, responding to the need to represent emerging dynamics in the Colombian territory. Currently, the legend is structured in two hierarchical levels: Level 1 groups the classes into broad thematic categories, while Level 2 breaks them down into 25 specific classes—15 corresponding to natural cover, 9 to land use, 1 to water bodies (both natural and anthropogenic), and 1 additional class representing information gaps throughout the 40-year time series.

Table 9. Legend applied to MapBiomas Colombia.

LEVEL 1				LEVEL 2				COVERAGE/ USE
ID	Level 1 class	Hexadecimal code	Color	ID	Level 2 class	Hexadecimal code	Color	
1	Forest formation	#1F8D49		3	Forest	#1F8D49		Coverage
				5	Mangrove	#04381D		Coverage
				6	Flooded forest	#026975		Coverage
				49	Wooded sand vegetation	#02D659		Coverage
10	Natural non forest formation	#D6BC74		11	Wetland	#519799		Coverage
				12	Grassland	#D6BC74		Coverage
				29	Rocky outcrop	#FFAA5F		Coverage
				32	Hypersaline tidal flat	#FC8114		Coverage
				50	Herbaceous sand vegetation	#AD5100		Coverage
				13	Other non forest formation	#D89F5C		Coverage
				81	Andinean herbaceous and shrubby vegetation	#dfeb62		Coverage

				82	Flooded andinean herbaceous and shrubby vegetation	#6fc179	Coverage
				9	Forest plantation	#7A5900	Use
				35	Palm oil	#9065D0	Use
14	Agricultural and livestock area	#FFEFC3		74	Banana (beta)	#BE83F7	Use
				21	Mosaic of agriculture and pasture	#FFEFC4	Use
				23	Beach, dune and sand spot	#FFA07A	Coverage
				24	Infrastructure	#D4271E	Use
				30	Mining	#9C0027	Use
22	Non vegetated area	#D4271E		68	Other natural non vegetated area	#E97A7A	Coverage
				25	Other non vegetated area	#DB4D4F	Use
				75	Solar panel farm	#C12100	Use
				33	River, lake or ocean	#2532E4	Coverage/Use
26	Water body	#2532E4		31	Aquaculture	#091077	Use
				34	Glacier	#93DFE6	Coverage
27	Not observed	#FFFFFF		27	Not observed	#FFFFFF	NA

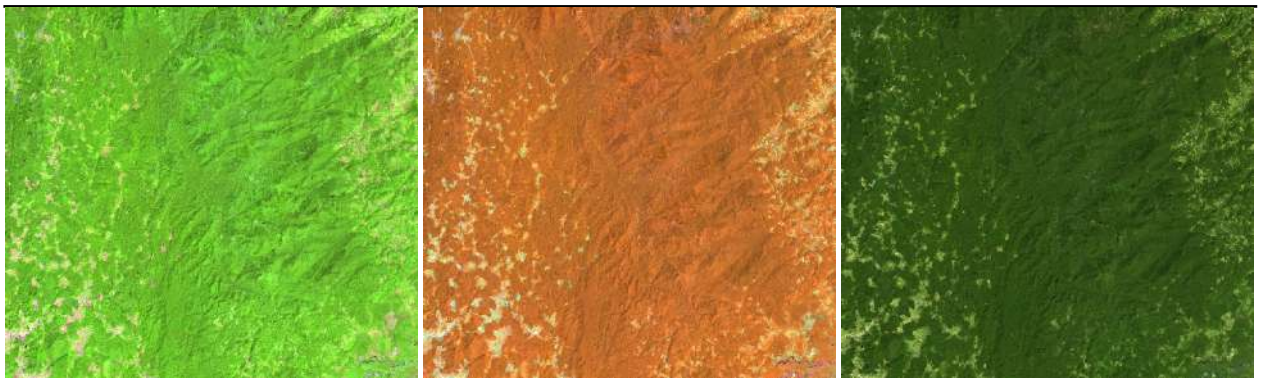
The types of coverage detected according to classification regions are described below.

4.4.3.1 Andean region legend

Forest (ID:3)

Natural areas formed by a plant community dominated by trees or shrubs, with the presence of some palm trees, forming a more or less continuous canopy exceeding 5 m in height. These cover areas have not been disturbed or have been selectively disturbed. They include dense basal and montane forests of terra firme, riparian forests, some dense shrublands, and secondary vegetation in an advanced stage of succession, where some of its structural attributes have already been recovered. This cover includes the tropical dry forest of the Magdalena Valley, the sub-Andean, Andean, and high-Andean forests, which in turn include natural oak forests, among others.

For differentiation, Andean forests respond to structural physiognomic criteria easily observed in remote sensing images, such as density, shading associated with altitude, and drainage conditions. The different shades observed depend on the height of the vegetation and its photosynthetic activity.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Serranía San Lucas - Antioquia, Year: 2017, Scale: 5000 m, Coordinates: -74.2832, 7.2931

Figure 34 Spectral response of Forest in the Andean region.

As can be seen in **Figure 34**, in the satellite image in false color combination RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4, a light green color with dark green shades is presented, in a combination RGB 564 Landsat 8 and RGB 453 Landsat 7, 5 and 4, intense red with dark shades are observed, in true color, deep dark green tones are observed, darker tones can be observed due to the relief and the shadow produced by it. The different shades that are observed depend on the height of the vegetation and its photosynthetic activity. The texture is highly rough given by the large canopies.

Forest Plantation (ID:9)

Tree vegetation plantations with forestry management purposes. It is made up of forestry wheels established through plantation during forestry or reforestation, for timber production. It has a regular geometric pattern and lots of trees generally from the same age. Antioquia is the department with the largest planted area (22,1%) of the national total; The species with the largest unbroken area are the Pine Patula (*Pinus patula*) and Eucalyptus (*Eucalyptus grandis*)

(MADR, 2022), the majority of these plantations are located in areas of slopes with gentle to medium slopes, and are characterized by having a uniform and continuous canopy.

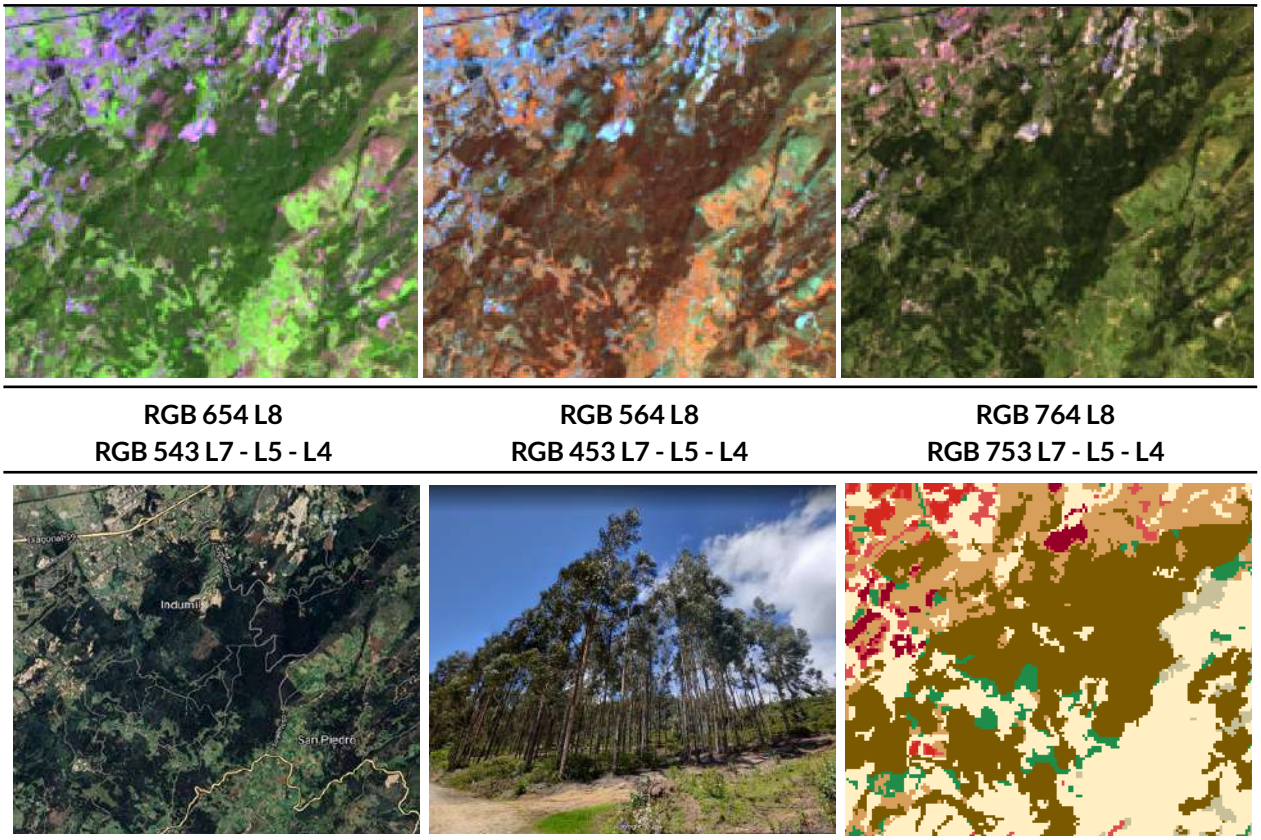


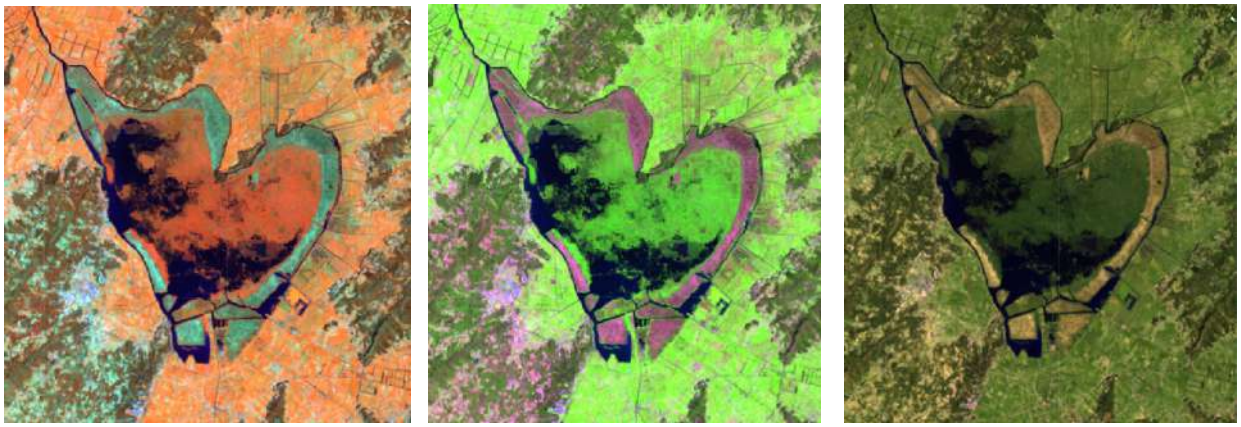
Figure 35 Spectral response of Forest Plantation in the Andean region.

The spectral response of forest plantations varies according to the species analyzed, and their patterns are characterized by clearly defined boundaries; in some cases, they have rectangular geometries. They present intense green colors with some lime green hues in RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4, and intense, slightly dark orange colors with intense red and brown hues in RGB 564 Landsat 8 and RGB 453 Landsat 7, 5 and 4. In true color, they are displayed in very dark green tones with black colorations.

Wetland (ID:11)

In the Andean region, this cover is found in low-lying, swampy, spongy-textured terrain, whose soil is composed primarily of mosses and decomposed plant matter (commonly called peat bogs). It also includes herbaceous vegetation established in marshy areas near bodies of water, and natural plant species that partially or completely cover the water table, such as Andean lakes and lagoons undergoing eutrophication (IDEAM, 2010). However, this class does not include the natural

floodable formations located in the Andean Mountains above 2.900 meters above sea level, which belong to the class "Flooded Andinean Herbaceous and Shrubby Vegetation" (ID82), detailed below.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Fuquene lagoon, Cundinamarca, Year: 2024, Scale: 1 km, Coordinates: -73.74398 W 5.46042N

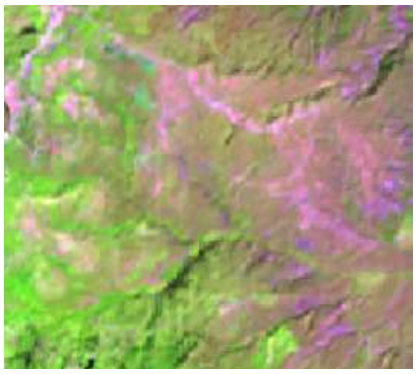
Figure 36 Spectral response of Wetlands in the Andean region.

The spectral response of this coverage is highly variable. As observed in **Figure 36**, at the edge of the water body, for the false color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5 and Landsat 4, the class presents intense pink tones, but brownish to maroon colors are also often found. In images with the combination RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5 and Landsat 4, it stands out for its orange tones with intense pink and green hues in some swampy areas. Finally, in RGB 764 Landsat 8 and RGB 753 in Landsat 7, Landsat 5 and Landsat 4, vivid greens are observed. It presents a fine heterogeneous texture without defined patterns.

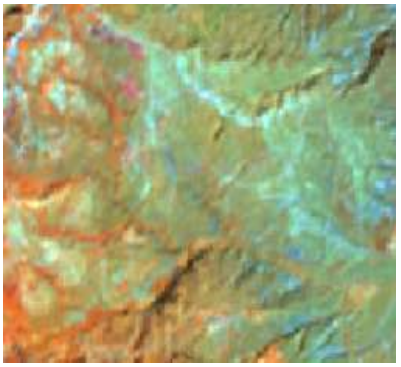
Other non forest formation (ID:13)

This includes high-mountain grasslands, some burnt grasslands in transition, and different types of grasslands that may present some scattered tree and/or shrub elements (Castellanos, 2010). This also includes vegetation cover resulting from natural ecological succession, with a shrubby and herbaceous growth habit, developed on altitudinal mountain floors such as Andean and high Andean formations, paramo, and cloud forests, with little or no human intervention. However, it does not include those grasslands and shrublands located in the Andes Mountains above 2.900 meters, which are part of the "Andinean herbaceous and shrubby vegetation" class (ID 81), detailed below.

Other types of cover are included, such as areas covered mainly by shrubby vegetation with an irregular canopy and the presence of shrubs, palms, vines, and low-growing vegetation. The plant communities included in this class are dominated by typically herbaceous elements that biologically correspond to non-lignified or barely lignified plants, with a soft consistency in all their organs, both underground and epigeal. Shrub communities form an irregular canopy with perennial plants with a woody or lignified stem structure, growing between 0,5 and 5 meters in height. They are strongly branched at the base and have no defined crown (Parques Nacionales Naturales de Colombia, 2021). The largest number of *paramos* in Colombia are concentrated in the Andean region, where the paramos of Sumapaz, Chingaza, Los Picachos, and El Cocuy, among others, stand out.



RGB 654 L8
RGB 543 L7 - L5 - L4



RGB 564 L8
RGB 453 L7 - L5 - L4

RGB 764 L8
RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

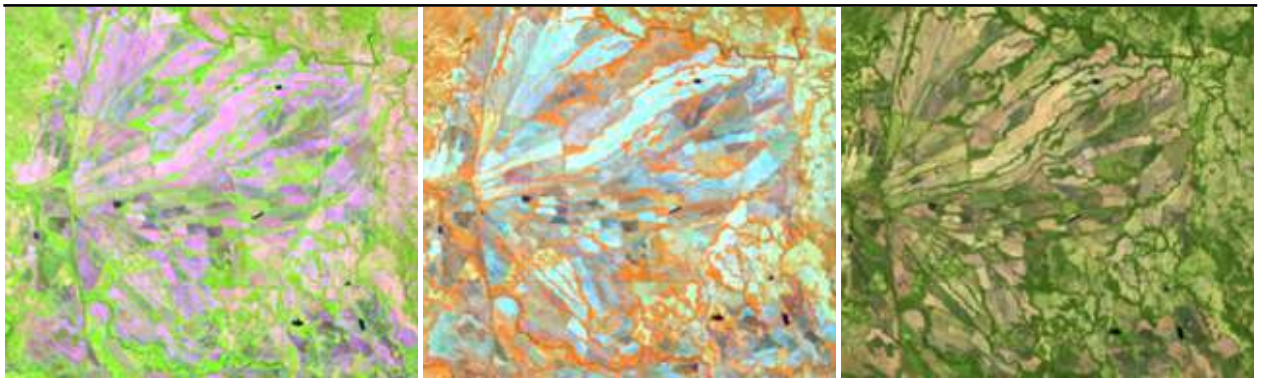
Location: Páramo de Sumapaz - Cundinamarca, Year: 2021, Scale: 2000 m, Coordinates: -74.1828 W, 4.0823 N

Figure 37 Spectral response of Other non forest formation in the Andean region.

As shown in **Figure 37**, in false color combinations of RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4, it appears pink. In a combination of RGB 564 Landsat 8 and RGB 453 Landsat 7, 5 and 4, shades of cyan to light pale green are observed, and in areas of greater flooding, shades of dark blue. In true color, a yellowish-brown tone is observed. This cover presents a fine to medium heterogeneous texture and a pattern associated with areas with little human intervention and hilly relief.

Mosaic of agriculture and pasture (ID:21)

It comprises an association of crops and pastures located on land primarily dedicated to the production of food, fiber, and other industrial raw materials, whether cultivated, grazed, in rotation, or left fallow. These include areas dedicated to permanent crops, temporary crops, pasture areas, and heterogeneous agricultural zones that may also be used for livestock in addition to agricultural purposes.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Venadillo - Tolima, Year: 2021, Scale: 1000 m, Coordenada: -74.88584, 4.67224

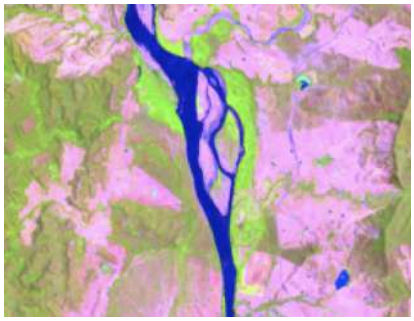
Figure 38 Spectral response of Mosaic of agriculture and pasture in the Andean region.

Transitional crops are located in areas occupied by crops with a vegetative cycle of less than one year, sometimes only a few months, with the characteristic that after harvesting, it is necessary to replant or sow to continue producing. Permanent crops are related to territories dedicated to crops with a vegetative cycle of more than one year, producing several harvests without the need to replant; they include herbaceous crops and shrub crops (Castellanos, 2010).

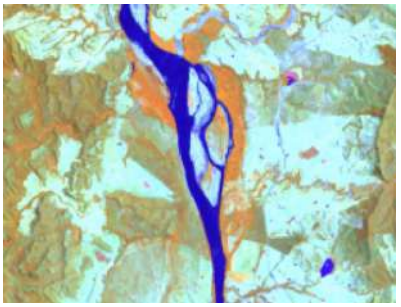
Satellite images generally display a mosaic of pastures and crops in a characteristic geometric spatial arrangement that facilitates interpretation. Crop cover is also seen in a wide range of tones and colors due to their different phenological states and varied management practices. Additionally, patterns of nearby road networks and drainage ditches are evident. At the spectral signature level, as seen in **Figure 38**, this type of cover presents a matrix of light green tones in the false color combination of RGB 654 Landsat 8 and 543 Landsat 7, 5, and 4. Within this, pink colors are also observed, which correspond to soils under preparation, crops in different phenological states, and pastures, respectively. In the combination of RGB 564 Landsat 8 and RGB 453 Landsat 7, 5, and 4, it appears very light red given the youth of the vegetation. Within this, some cyan tones are observed in small patches. It has a fine, homogeneous texture following a geometric pattern given by the division of the properties.

Beach, dune and sand spot (ID:23)

In the Andean region, this cover corresponds to the remains of abandoned shifting banks and meanders. These areas are also considered low-lying, flat terrain composed primarily of sandy and stony soils, which are often devoid of vegetation or covered by sparse vegetation of low, scattered shrubs. These areas are considered areas where the presence of vegetation is less than 2%. These terrains are composed primarily of sand, earth, and rocks. Desert or xerophytic formations with scattered vegetation, accounting for no more than 20% of the cover, are also included.



RGB 654 L8
RGB 543 L7 - L5 - L4

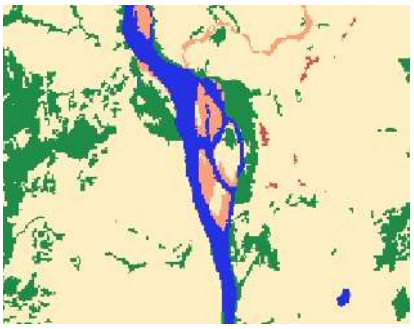


RGB 564 L8
RGB 453 L7 - L5 - L4

RGB 764 L8
RGB 753 L7 - L5 - L4

Google Earth

Landscape



MapBiomas

Location: Magdalena - boundaries between Tolima and Cundinamarca, Year: 2018, Scale: 500 m, Coordinates: -74.72068 W, 5.12159 N

Figure 39 Spectral response Beach, dune and sand spot in the Andean region.

This natural formation, in the RGB 654 band combination, displays lilac to lavender hues with pale pink to whitish nuances; in the RGB 564 band combination, it displays intense blue tones with shades of grayish blue, and in some cases, steel blue tones can be observed; in the RGB 764 band combination, it displays pale pink tones with opaque purple hues, and in some cases, peach or salmon pink tones. Additionally, it is characterized by having a medium texture in the beach areas of water tributaries and tends to be smoother in the floodplain areas.

Infrastructure (ID:24)

It comprises predominantly small urban centres (towns) and peripheral areas that are being incorporated into Infrastructures through a gradual process of urbanisation or land use change towards residential, commercial, industrial, service and recreational purposes.

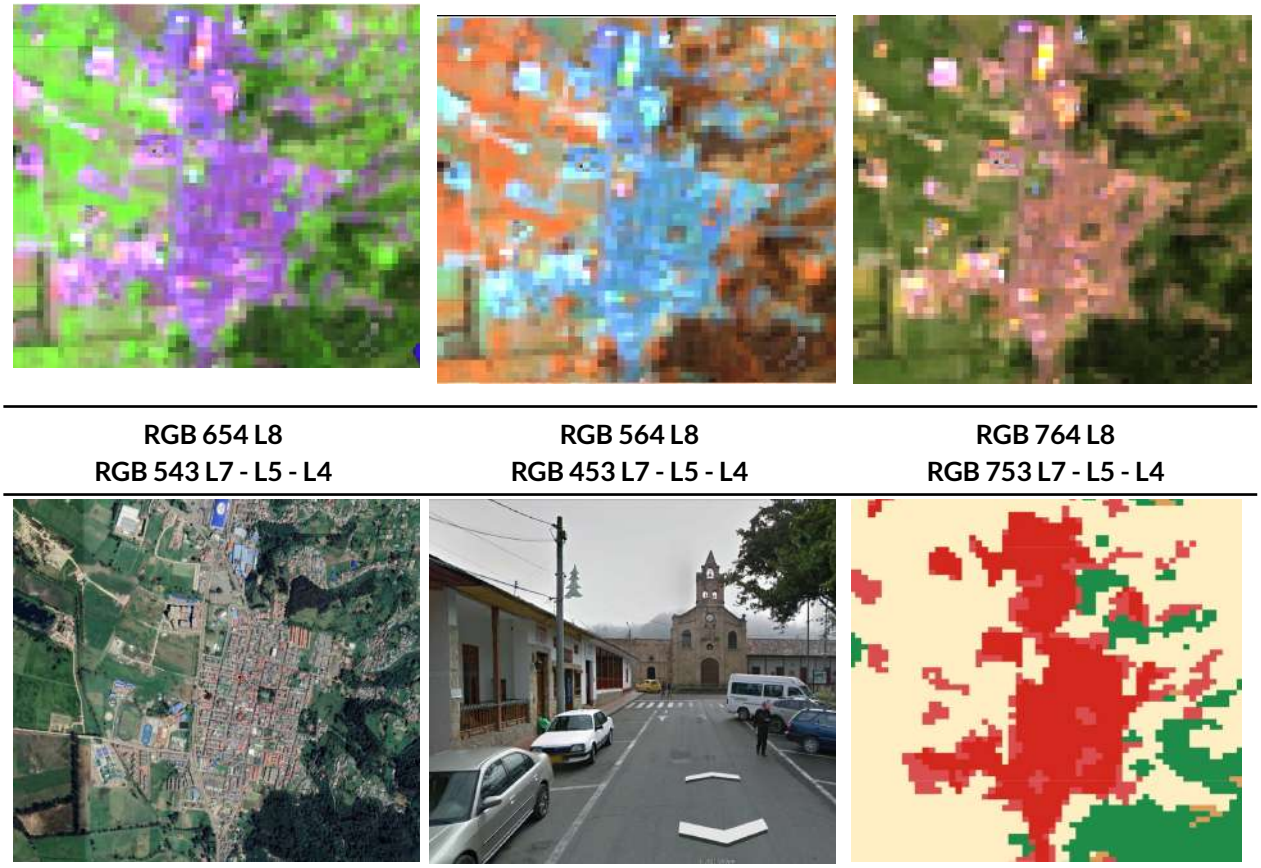


Figure 40 Spectral response Infrastructure in the Andean region.

Infrastructure is represented by large towns and some hamlets or scattered buildings that do not comply with the minimum cartographic mapping unit (5 pixels), as well as large and important urban centers such as Medellin, Cali, Bucaramanga and Bogotá. As seen in **Figure 40**, in false color combination RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4 it is characterized by presenting a bright strong violet color, in false color combination RGB 564 Landsat 8 and 453 Landsat 7, 5 and 4 it is characterized by presenting a bright light blue tone, in true color you can see matrices of mostly gray tones, with green and brown hues, this coverage shows a fine to medium uniform texture, determined by the size and density of the buildings. The homogeneous distribution of these and the road network give it a geometric pattern that resembles a grid.

Other non-vegetated area (ID:25)

This class includes all areas devoid of any vegetation due to anthropogenic processes. This class includes burned areas, crop preparation or fallow areas, and bare soils. Due to the incorporation of different types of unvegetated areas within this class, classification patterns vary greatly. Burned areas are identified by their homogeneous texture, defined geometric patterns, primarily

resembling rectangular shapes, and intense dark purple colors in the false color combinations RGB 654 Landsat 8 and 543 Landsat 7, 5, and 4; in RGB 564 Landsat 8 and 453 Landsat 7, 5, and 4, these are characterized by opaque, dark aquamarine colors. Bare soils tend to have whitish colors or pale tones in all three combinations, with a medium heterogeneous texture.

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

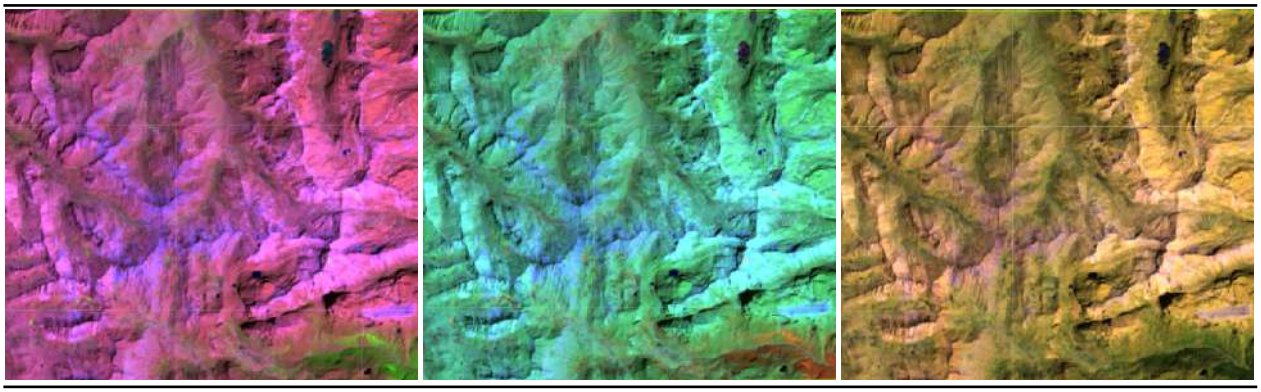
Google Earth	Landscape	MapBiomas

Location: Bogotá D.C., Year: 2023, Scale: 500 m, Coordinates: -74.19697W, 4.64473 N

Figure 41 Spectral response Other non-vegetated area in the Andean region.

Rocky outcrop (ID:29)

It corresponds to areas made up of layers of exposed rocks, where erosion and precipitation processes have caused the exposure of the bedrock, with low or no presence of vegetation, generally located on steep and steep slopes. In the Andean region they are usually associated with mountain glaciers, volcanoes, faults and geological deformations, generally in areas of steep slopes and steep slopes forming escarpments and cliffs.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Güican - Boyaca, Year: 2024, Scale 1000 m, Coordinates: -72.15791 W 6.51145 N

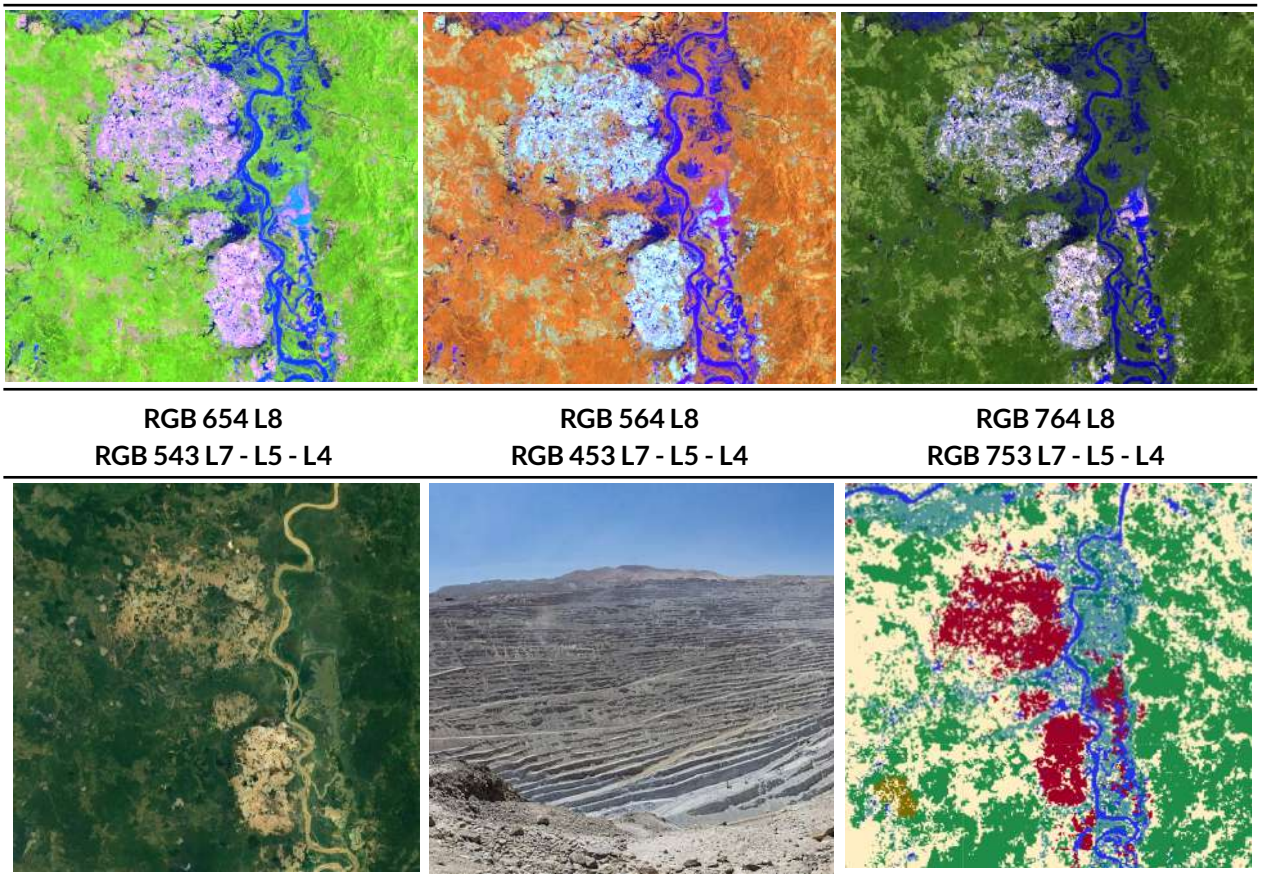
Figure 42 Spectral response Rocky outcrop in the Andean region.

The spectral response of this coverage, in combination false color RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4 varies between light and intense lilac tones to dark purples, presenting white, blue and indigo purple hues. On the other hand, in RGB false color combination 564 Landsat 8 and 453 Landsat 7, 5 and 4 is displayed in blue with shades that vary between light blue to cobalt blue, with grayish and Aegean blue hues. Finally, in the RGB 764 L8 RGB combination it comes in dark violet to faint lavender tones, with magenta, grayish and whitish nuances. They do not have a clearly defined pattern and their texture is medium heterogeneous.

Mining (ID:30)

It includes areas where materials are extracted or accumulated from open pit mining or river mining with clear exposure of the soil. It is not differentiated whether it is industrial, artisanal, riverside or illegal, in addition, sedimentation pools associated with this activity were included, it appears in small irregular shapes similar to elongated or rounded patches and in some cases in

well-defined geometric shapes. Included are areas dedicated to the extraction of materials (sand pits, gravel pits, quarries) and areas intended for the exploitation of coal, gold, among others. They are characterized by having a spectral response similar to class 25, due to the removal of the soil for mining activity as evidenced in **Figure 43**. In RGB false color combination 654 Landsat 8 and 543 Landsat 7, 5 and 4 are observed in bright purple tones, to strong purple, in RGB false color combination 564 Landsat 8 and 453 Landsat 7, 5 and 4, They can be observed in the same way in blue tones with pastel tones, in true color these areas are perceived in opaque yellow tones, due to the removal of the soil for mining activity.



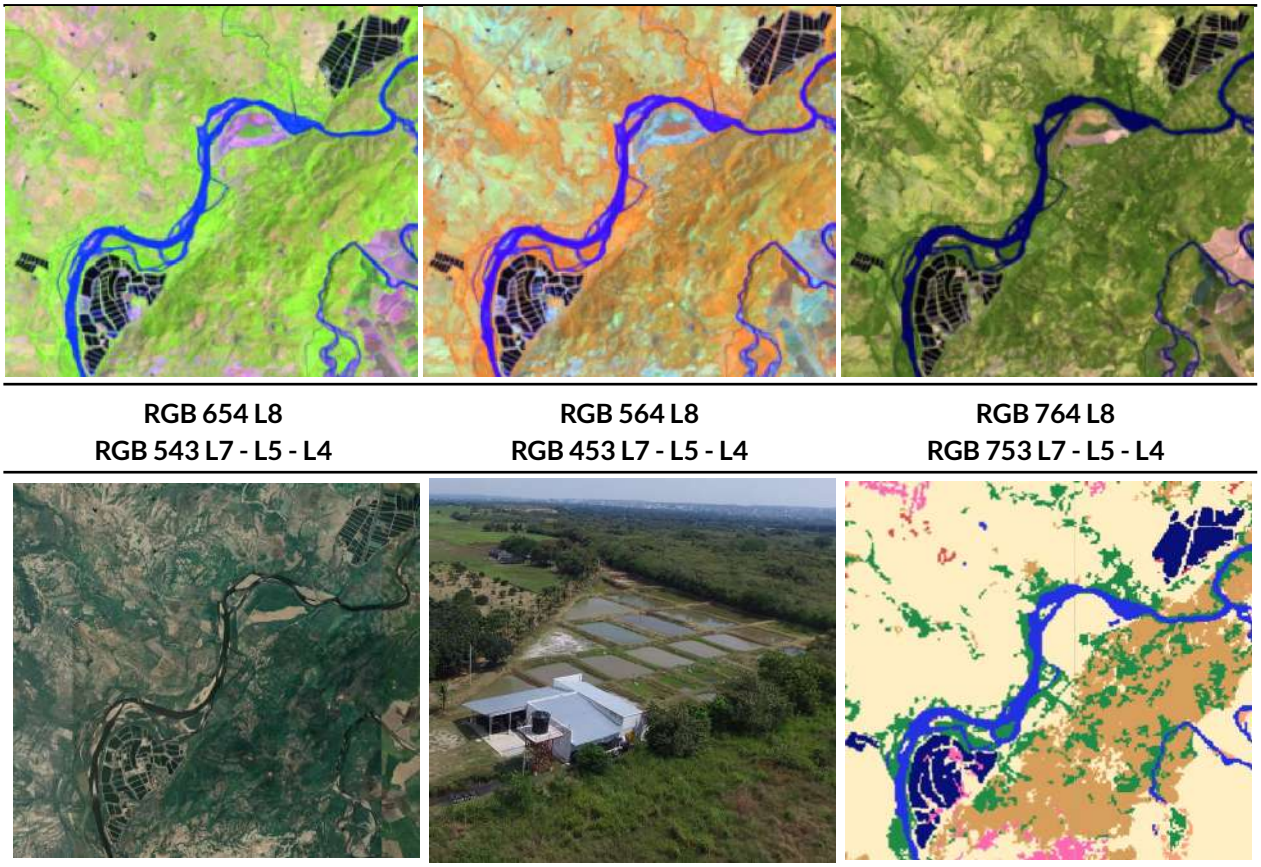
RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Mina Nechí - Antioquia, Year: 2021, Scale: 2000 m, Coordinates: -74.8447 W, 7.9133 N

Figure 43 Spectral response Mining in the Andean region.

Aquaculture (ID:31)

Artificial bodies of water intended for the breeding of freshwater fish. This coverage is made up of a series of adjacent pools, which is why they are characterized by having a regular geometric pattern. The spectral response of this coverage in the 3 combinations used present colorations ranging from dark blues to black, and a homogeneous texture.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Municipio de Villavieja, Huila, Year: 2022, Scale: 1000 m, Coordinates: -75.1656 W, 3.40665 N

Figure 44 Spectral response Aquaculture in the Andean region.

River, lake or ocean (ID:33)

It corresponds to permanent, intermittent and seasonal bodies of water that include lakes, lagoons, and natural or artificial ponds of fresh water (non-saline), reservoirs and moving bodies of water, such as rivers (Castellanos, 2010). The spectral response of the water bodies depends on the load of suspended particles, therefore the rivers have a dark blue color due to the content of sediments and organic matter in an RGB combination 654 Landsat 8 and 543 Landsat 7, 5 and 4 as seen in **Figure 45**; In a combination RGB 564 Landsat 8 and RGB 453 Landsat 7, 5 and 4, a dark red, almost black color is observed, in true color, this can vary from an opaque yellow in some clay rivers to dark blue tones, and bluish blacks. This coverage shows a very fine homogeneous texture with a drainage pattern that follows the different water courses in some cases of a dendritic type.

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

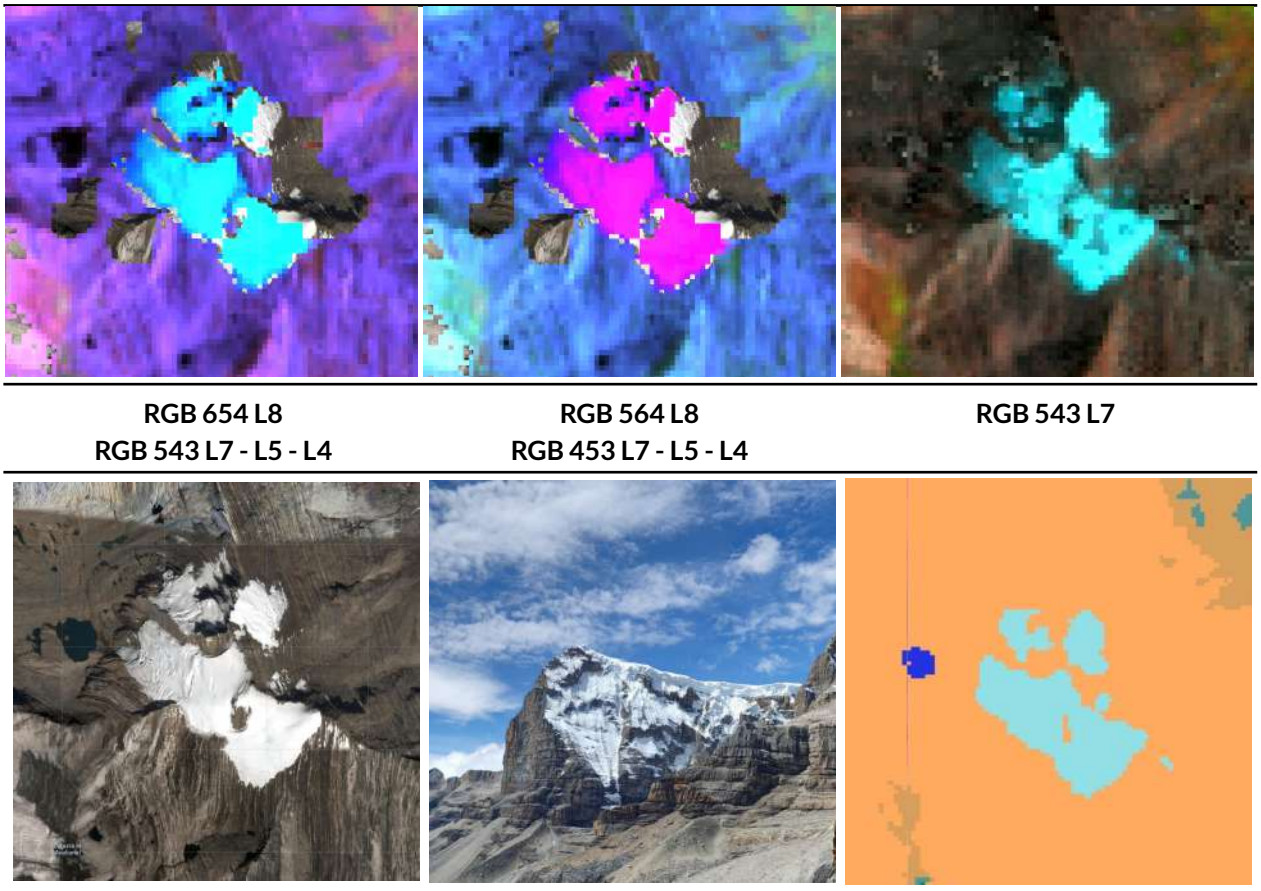
Google Earth	Landscape	MapBiomas

Location: Chaguani - Cundinamarca, Year: 2022, Scale: 1000 m, Coordinates: -71.71508 W, 4.98193 N

Figure 45 Spectral response River, lake or ocean in the Andean region.

Glacier (ID:34)

Coverage area of permanent ice mass and/or constant snow in areas of accumulation and/or ablation (Serrano & Gonzalez, 2004), located in the summits of the Andes mountain range, in a focal and/or distributed manner, above 4.900 m a.s.l, occupying climates that are called extremely cold and superhumid and superhumid nival. They are characterized by being surrounded by rocky outcrops and some possible glacial lagoons. In combination RGB 654 Landsat 8 and 543 Landsat 7, 5 and 4 it is seen in an intense cyan color, with some shades of dark blue on the periphery of the glacier, on the other hand, in combination RGB 654 Landsat 8 and 543 Landsat 96 7, 5 and 4 it is seen in an intense fuchsia color with some violet hues. This coverage does not have a clearly defined pattern and its texture is homogeneous and fine grained.



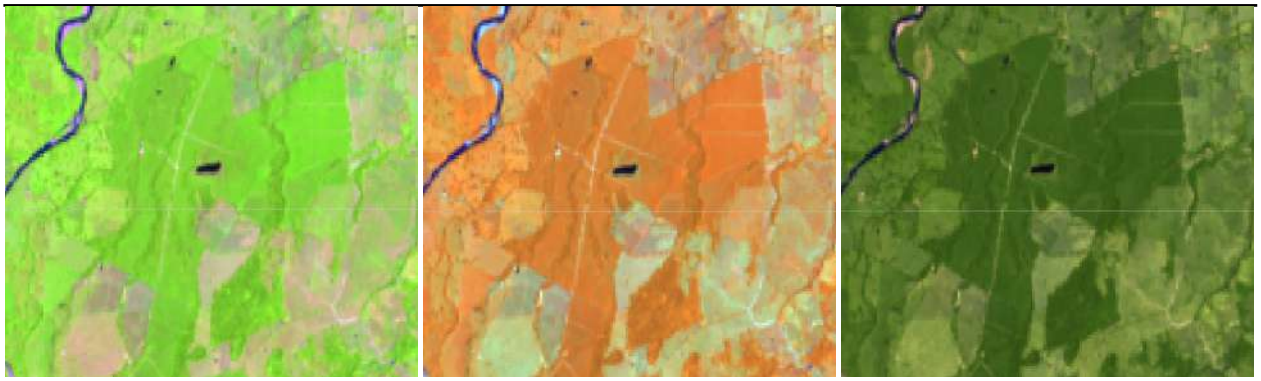
RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 543 L7
Google Earth	**Landscape**	**MapBiomas**

Location: El Cocuy - Boyacá, Year: 2021, Scale: 100 m Coordenada: -72.282054W, 6.515076N

Figure 46 Spectral response Glacier in the Andean region.

Palm Oil (ID:35)

This coverage includes extensive crop areas with symmetrical and regular palm oil (Elaeis guineensis) plantations, which can be transitory or permanent. They are grown on considerably large plots compared to traditional crops, and their production is carried out on an industrial scale. This monoculture develops favorably in volcanic soils and alluvial and marine clays in low areas (below 500 m a.s.l), with good permeability and well drained (Aguilera, 2002).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 543 L7

Google Earth	Landscape	MapBiomas

Location: San José de Cúcuta - Norte de Santander, Year: 2023, Scale: 200 m Coordenada: -72.390962W, 8.153034N

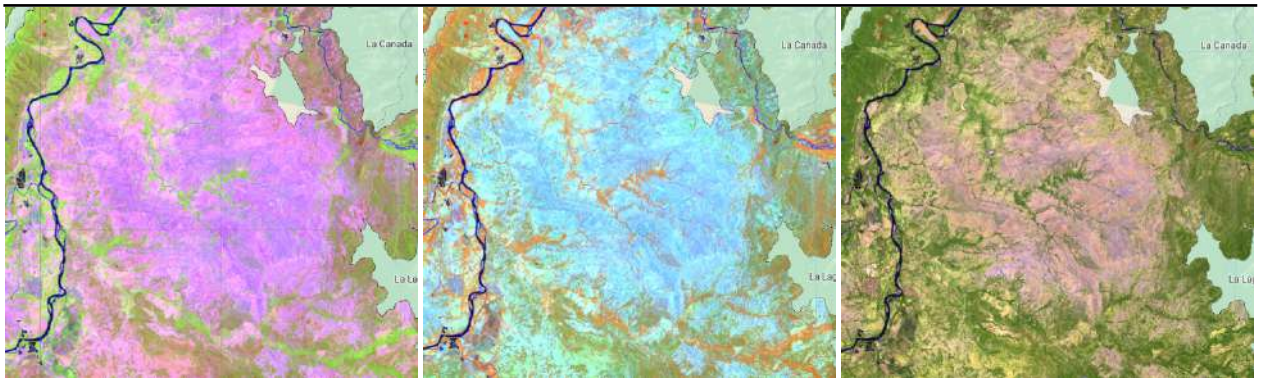
Figure 47 Spectral response Oil palm in the Andean region.

It is recognized by its homogeneous and smooth texture. In the satellite image, the star-shaped shape of its crown and planting rows can usually be detected, as well as a particular reflectance in bright tones for Landsat images; In the combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5 and Landsat 4, bright green (almost neon) colors are observed, in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5 and Landsat 4, the pixels are brightly colored with orange hues, and with RGB 764 Landsat 8 and 753 on Landsat 7, Landsat 5 and Landsat 4 in pine green (**Figure 47**).

Other natural non-vegetated area (ID:68)

This class covers those areas devoid of vegetation or with little vegetation cover, caused by natural erosive processes or natural phenomena. In Andean region, units such as the Tatacoa desert, the Chicamocha canyon, and landslides distributed throughout the region stand out. It is

characterized by its fuchsia, cyan, and pink tones respectively in the combinations mentioned in **Figure 48**, highlighting a grainy texture due to the relief of the coverage.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

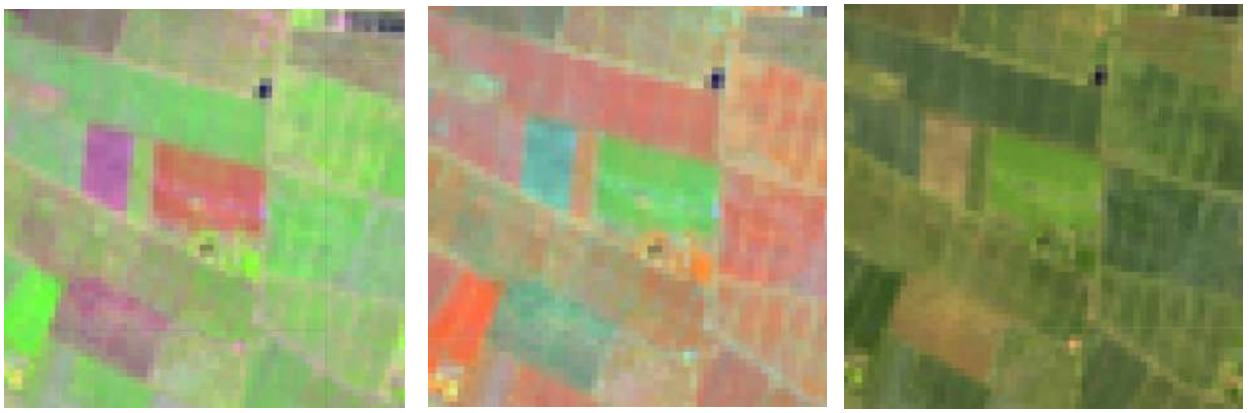
Location: Villavieja, Huila, Year: 2023, Scale: 5 Km, Coordinates: -75.1218 W, 3.2784 N.

Figure 48 Spectral response Other natural non-vegetated area in the Andean region.

Solar panel farm (ID 75)

It includes areas occupied by installations for the generation of solar energy, characterized by the presence of modular structures (solar panels) organized in a regular manner, generally on flat and clear surfaces. These areas have clearly defined anthropic origin and are not confused with other types of Infrastructure or industrial infrastructure.

They are recognized by their regular geometric pattern and characteristic shades in the different RGB combinations. In the **Figure 49**, magenta colors are observed in the combination RGB 654 Landsat 8 and RGB 543 Landsat 7, 5 and 4, grayish or cyan tones in RGB 564 L8 and RGB 453 L7-L5-L4, and greenish or violet blue tones in RGB 764 L8 and RGB 753 in Landsat 7, 5 and 4. The Texture is homogeneous, with low internal variability, associated with the orderly arrangement of the solar modules.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

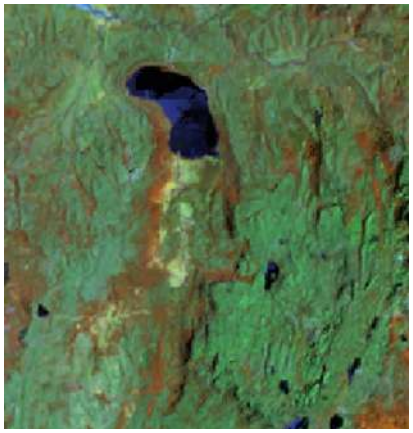
Google Earth	Landscape	MapBiomas

Location: Guadalajara de Buga, Valle del Cauca, Year: 2023, Scale: 200 m,
Coordinates: -76.30922 W, 3.93648 N.

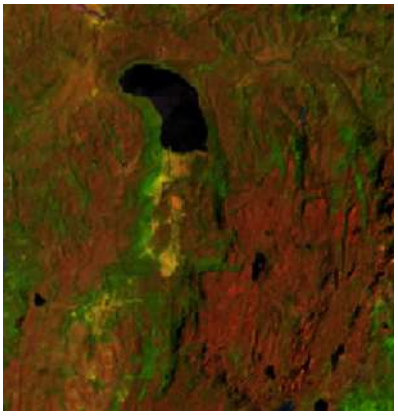
Figure 49 Spectral response Solar panel farm in the Andean region.

Andinean Herbaceous and Shrubby Vegetation (ID 81)

Natural vegetation cover restricted to the Andean region, located above the tree line, starting at approximately 2.900 m a.s.l., with its transition depending on local conditions, particularly edaphic and climatic factors. It is mainly dominated by herbaceous species, with a lower proportion of shrubs whose physiognomy and floristic composition vary widely. Among the most representative plant families are Poaceae, Asteraceae, Ericaceae, Melastomataceae, Rosaceae, and Orchidaceae, as well as Cyperaceae, Bromeliaceae, and Fabaceae, all of which contribute to the high diversity and endemism of the ecosystem. These communities are adapted to conditions of high humidity, frequent cloudiness, high rainfall, direct solar radiation, low temperatures, and soft soils. They constitute one of the most unique ecosystems and, at the same time, one of the most threatened by anthropogenic pressure



RGB 654 L8
RGB 543 L7 - L5 - L4

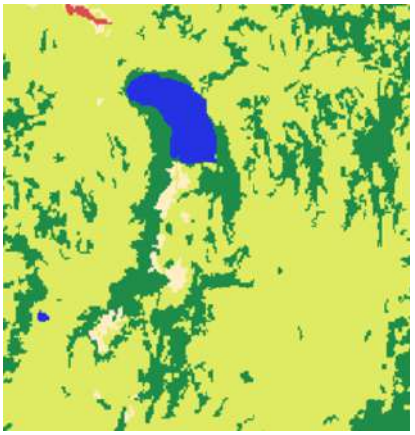


RGB 564 L8
RGB 453 L7 - L5 - L4

RGB 764 L8
RGB 753 L7 - L5 - L4

Google Earth

Landscape



MapBiomas

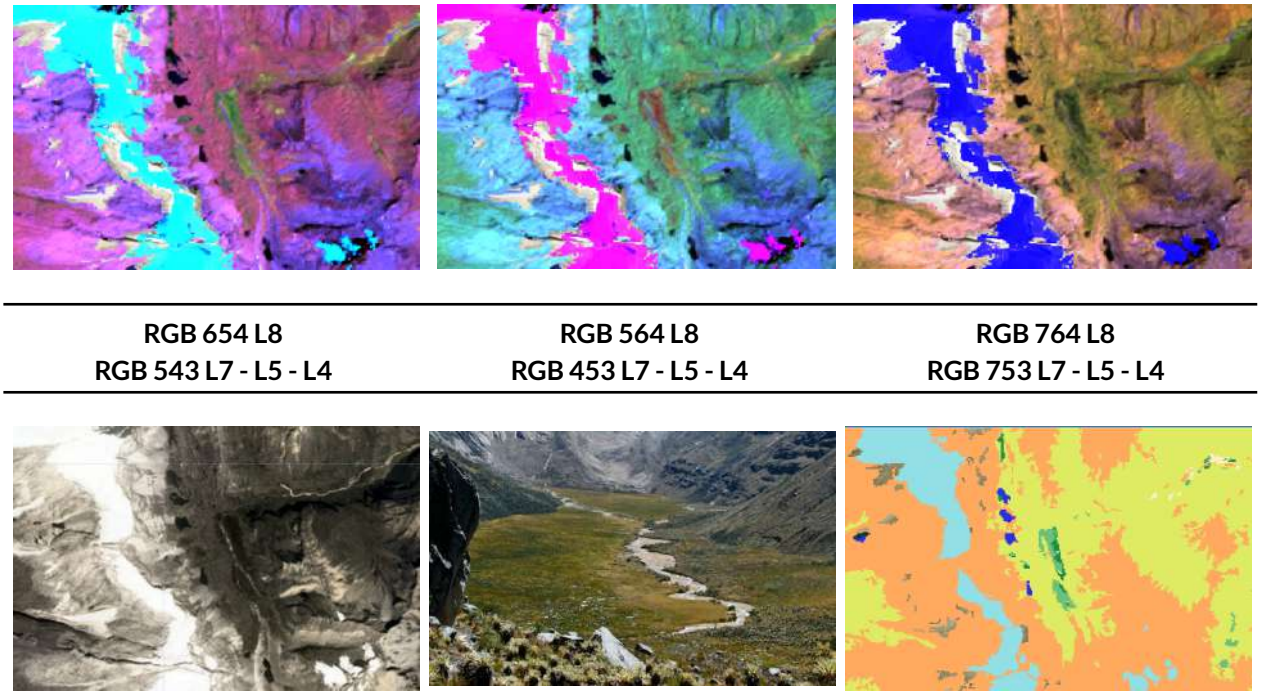
Location: Páramo de Chingaza- Cundinamarca, Year: 2024, Scale: 1 Km, Coordinates: 73.752 W, 4.529 N .

Figure 50 Spectral response Andinean Herbaceous and Shrubby Vegetation in the Andean region.

As shown in **Figure 50**, in the false color combination RGB 654 Landsat 8 and 9, and RGB 543 Landsat 7, 5 and 4, it appears purple to brown in opaque tones. In a combination of RGB 564 Landsat 8 and 9, and RGB 453 Landsat 7, 5 and 4, pale green tones are observed. In true color, a yellowish-brown tone is observed. It presents a heterogeneous texture and a pattern associated with areas with little anthropic intervention and rocky outcrops and hilly reliefs. Finally, in the MapBiomas legend it is represented with a lime green tone.

Flooded Andinean Herbaceous and Shrubby Vegetation (ID 82)

Natural vegetation cover is restricted to the Andean region, associated with freshwater lacustrine, palustrine, and fluvial systems, mainly dominated by herbaceous species and, to a lesser extent, by shrubs. It develops in alluvial plains, riparian zones, and swampy environments above 2.900 m a.s.l. It is characterized by vegetation adapted to conditions of high humidity, frequent cloudiness, high precipitation, direct solar radiation, low temperatures, and soft soils largely composed of mosses and decomposing organic matter that form peatlands. It also includes species that partially or completely cover the water surface in Andean lakes and lagoons undergoing eutrophication.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Boyaca, Sierra Nevada del Cocuy. Year: 2024. Scale: 1 Km.
Coordinates: 72.2788 W, 6.4769N.

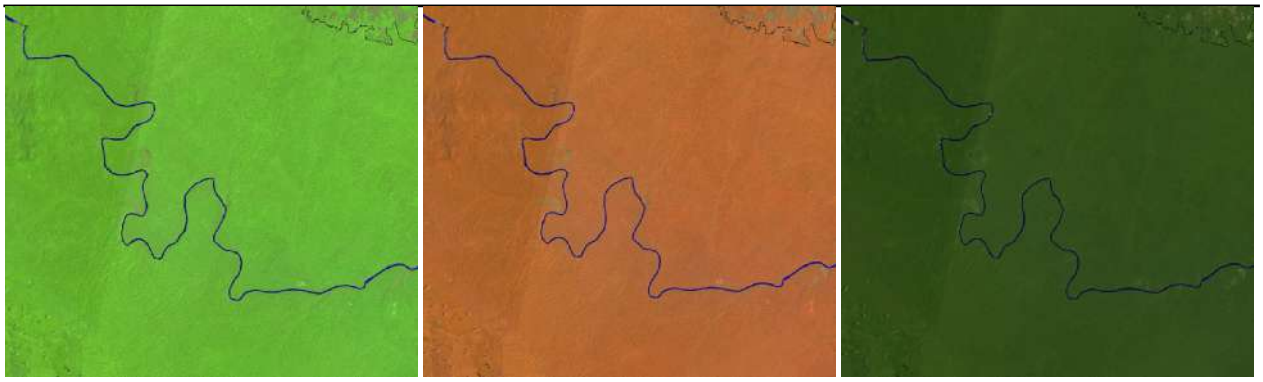
Figure 51 Spectral response Flooded Andinean Herbaceous and Shrubby Vegetation in the Andean region.

As shown in **Figure 51**, in the false color combination RGB 654 Landsat 8 and 9, and RGB 543 Landsat 7, 5 and 4, it appears purple with areas of darker tones in the areas of greatest flooding. In a combination of RGB 564 Landsat 8 and 9, and RGB 453 Landsat 7, 5 and 4, pale green tones are observed. In true color, a yellowish-brown tone is observed. It has a finer texture than Andean grasslands and shrublands since it is located in areas with more homogeneous reliefs and a pattern associated with areas with little anthropogenic intervention and rocky outcrops and hilly reliefs.

4.4.3.2 Amazon region legend

Forest (ID:3)

A vegetation cover consisting of a plant community dominated by typically arboreal elements, which form a generally continuous canopy layer (canopy) with an abundance of perennial woody plants and ecological associations with a predominance of native palms. For the Colombian land cover legend, this category includes dense forests and some open forests, as well as fragmented forests with secondary vegetation whose horizontal continuity is affected by the inclusion of other types of covers, such as a mosaic of agriculture and/or pasture, bare areas, or some type of transitional vegetation. As mentioned, other natural biological forms are found, such as different species of palm and guadua (Castellanos, 2010).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Caquetá - Amazonas boundary, Year: 2023, Scale: 5 Km, Coordinates: -72.9709 W, -0.1203

Figure 52. Spectral Response of Forest in the Amazon Region.

The species that dominate this cover include both native and exotic origins found in natural or semi-natural areas. These forests, in general, have not been disturbed, or their intervention has been selective in such a way that no alteration is evident in their original structure or functional

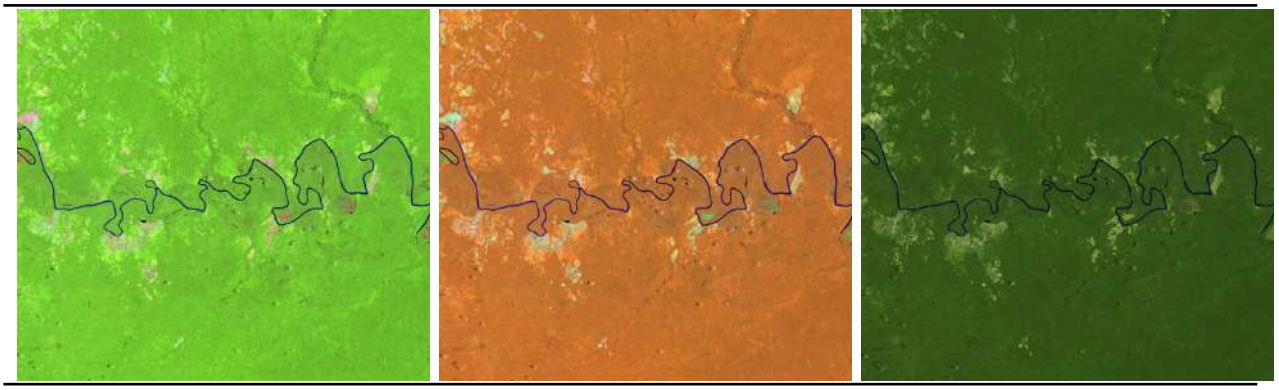
characteristics. Likewise, this class excludes plantations associated with monocultures of African palm or oil palm that have been anthropogenically established.

In general, this cover shows, in satellite imagery, a continuous pattern in terms of shape and physiognomy, with some secondary tree formations naturally regenerated that have reached the density and height of the original natural forest matrix. For gallery forests, the pattern is easily distinguishable as it borders watercourses and is therefore associated with different drainage patterns (dendritic and sub-dendritic).

As shown in **Figure 52,** in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4, dark and light green tones can be observed, with brown and violet hues depending on the successional stage, vegetation maturity, and image quality. In an RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, it appears as an intense red color with violet hues characteristic of vigorous vegetation. It presents a texture ranging from medium to coarse roughness, depending on the crown size and canopy height. Finally, in MapBiomas classification 3, it is represented in a dark green tone and is characterized as the most extensive cover in the Colombian Amazon territory (RAISG boundary).

Flooded forests (ID:6)

It refers to areas with vegetation generally of arboreal type adjacent to water bodies (lotic), which mainly correspond to meander belts and floodplains with periodic flooding processes and particular adaptations to these conditions (Lopez & Rodriguez, 2011), lasting more than two months(Rincon et al., 2009), It is characterized by a more or less continuous stratum whose tree cover represents more than 70% of the total area of the unit, with a canopy height exceeding 15 meters.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

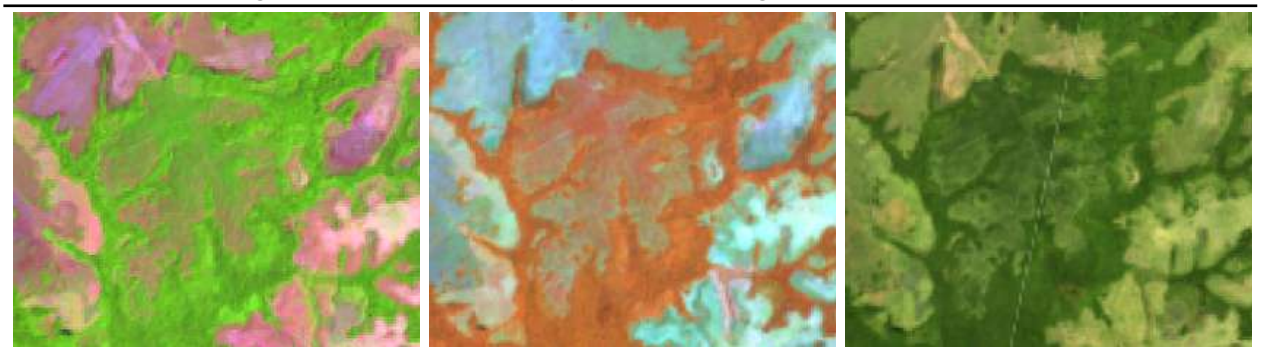
Location: Vaupés River - Guaviare, Year: 2023, Scale: 2km, Coordinates: -71.7748 W, 1.1892 N.

Figure 53 Spectral Response of Flooded forests in the Amazon Region.

In this type of cover, in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4, dark and light green tones with color hues can be observed, depending on the successional stage, vegetation maturity, and image quality. In an RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, reddish-brown coloration is evident, showing a spectral response similar to that of forest; however, its transition is quite noticeable since the texture of this cover is fine compared to the roughness of class 3, as shown in the example in **Figure 53**. The pattern corresponding to this cover is characterized by being associated with the alluvial plains and valleys of rivers, forming elongated strips of varying widths, ranging from narrow to wide, depending on the hydrographic network (Rincon et al., 2009).

Forest plantation (ID:9)

These covers consist of tree vegetation plantations, generally established for commercial purposes. In this process, forest stands are created, formed through planting or seeding during afforestation or reforestation, with the objective of producing timber. In satellite images, this cover is distinguished by a regular geometric pattern, characterized by arrangements designed to facilitate tree management, which are usually of the same age.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

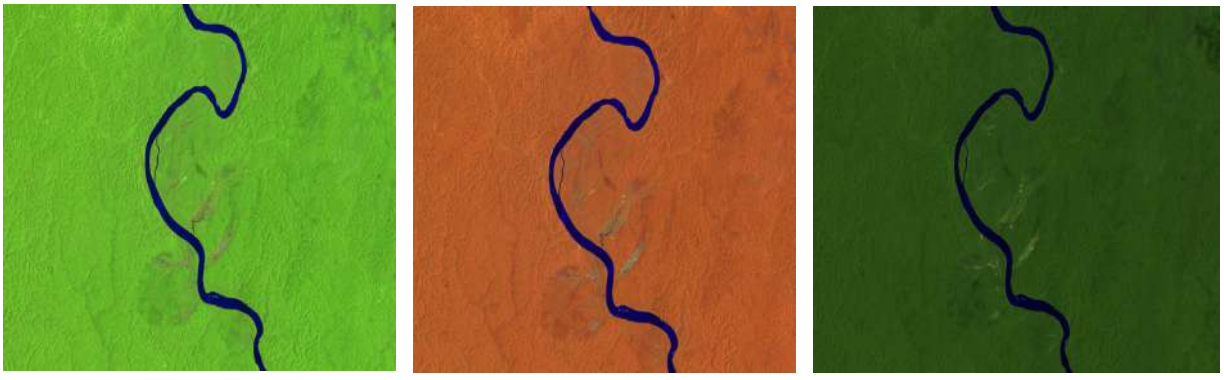
Location: Mapiripan - Meta, Year: 2023, Scale : 500 m, Coordinates: -72.43987 W, 3.11498 N.

Figure 54 Spectral Response of Forest plantation in the Amazon Region.

For the identification of this class, in the false-color combination RGB 654 Landsat 8 and 9, and RGB 543 Landsat 7, 5, and 4, green colorations similar to those of forests are observed: dark green for mature plantations and bright light greens with yellowish tones in the early stages. In RGB 564 Landsat 8 and 9, and RGB 453 Landsat 7, 5, and 4, reddish-orange tones predominate, while in the RGB 764 Landsat 8 and 9, and RGB 753 Landsat 7, 5, and 4 combinations, plantations display dark green tones easily confusable with natural forest formations. To distinguish between these classes, it is recommended to observe the distribution pattern; generally, plantations exhibit regular or square shapes.

Wetland (ID:11)

It corresponds to areas dominated by natural herbaceous vegetation with more than 70% cover, on permanently water-saturated soils, which during rainy periods (4–8 months per year, from April to November) may be covered by a thin layer of water.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

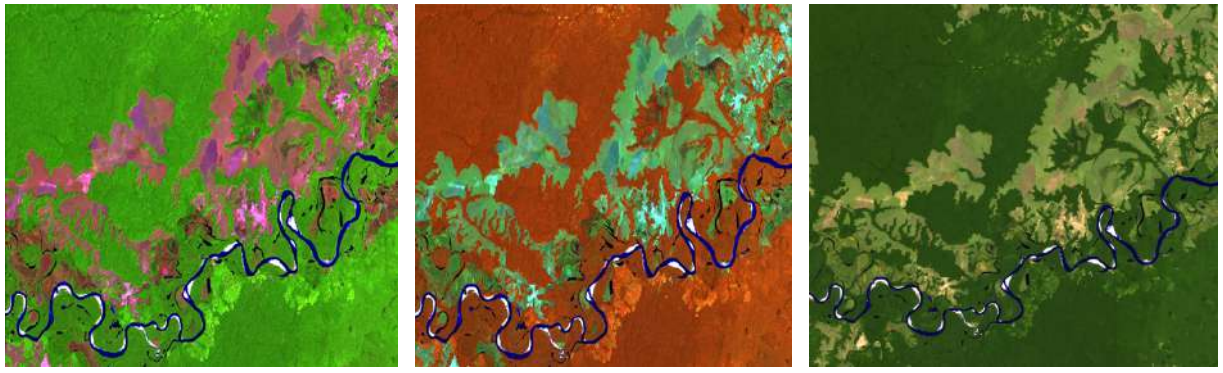
Location: Apaporis River – boundary between Vaupés and Amazonas, Year: 2023, Scale: 1 km, Coordinates: -70.91985 W, -0.16152 S.

Figure 55 Spectral Response of Wetland in the Amazon Region

Likewise, it is possible to find some tree individuals in the form of patches and areas with gregarious communities, such as palm groves or "morichales," which are scattered and never exceed 2%, and may be surrounded by riparian forest areas. (Rincon et al., 2009). As shown in **Figure 55**, for flooded grasslands, in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4, brown or coffee tones with dark orange combinations can be observed. In an RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, green coloration in different shades, mostly dark, is observed, with fine heterogeneous textures and no defined patterns. These can be easily found in oxbow lakes or rivers that have changed their course (Rincon et al., 2009).

Grassland (ID:12)

Natural cover composed mostly of herbaceous-type vegetation (grasses) on terra firme, with the presence of scattered or isolated tree and/or shrub elements. It is mainly located in areas with edaphic limitations and a climate similar to that of the soils of the Orinoco basin, within an altitudinal range between 300 and 800 m a.s.l.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Vichada River - near La Palometa (Cumaribo, Vichada), Year: 2023, Scale: 2km, Coordinates: -69.0575 W, 4.4042 N.

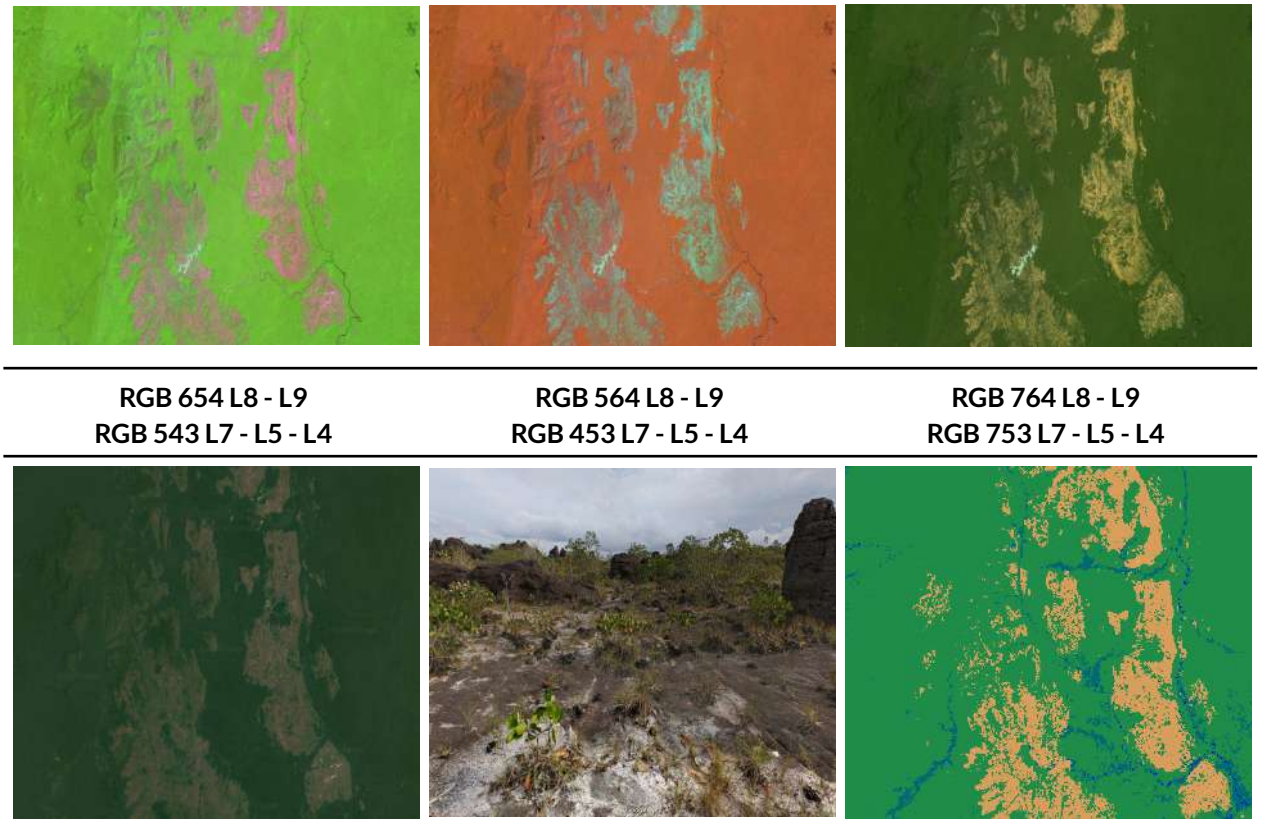
Figure 56 Spectral Response of Grassland in the Amazon Region.

This type of cover is generally surrounded by gallery forests and includes natural grasslands as well as some degraded areas (mining) or rocky outcrops (Rincon et al., 2009). As shown in **Figure 56**, the spectral response of this cover in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4 displays fuchsia tones with ochre hues, ranging from dark to light depending on seasonality (dry/wet seasons). In the RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, apple-green to emerald-green colors are observed. The visible or true-color spectral signature shows brown to yellowish-green tones due to the composition of natural grasses. In terms of texture, it exhibits a fine pattern with a dendritic configuration typical of the ridges formed in flat areas of the Colombian Amazon and the Orinoco basin. It is characterized by surrounding gallery forests.

Other non forest formation (ID:13)

Land cover consists of a plant community dominated by typically herbaceous elements that develop naturally, forming an open cover. These vegetative formations have not been disturbed, or their intervention has been selective and has not altered their original structure or functional characteristics (IGAC, 1999).

In general, it does not present tree elements in an isolated manner; it develops on rocky outcrops of low relief or altitude and in some areas with sandy soils that do not retain moisture significantly. Geomorphologically, this type of grassland develops on landforms composed of aeolian sands, rocky outcrops, and stony surfaces of the Guiana Shield. In the Colombian Amazon, its predominance is associated with the departments of Vaupés and Guainia.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Cunare - Caqueta, Year: 2023, Scale: 5km, Coordinates: -72.7532 W, 0.628 N.

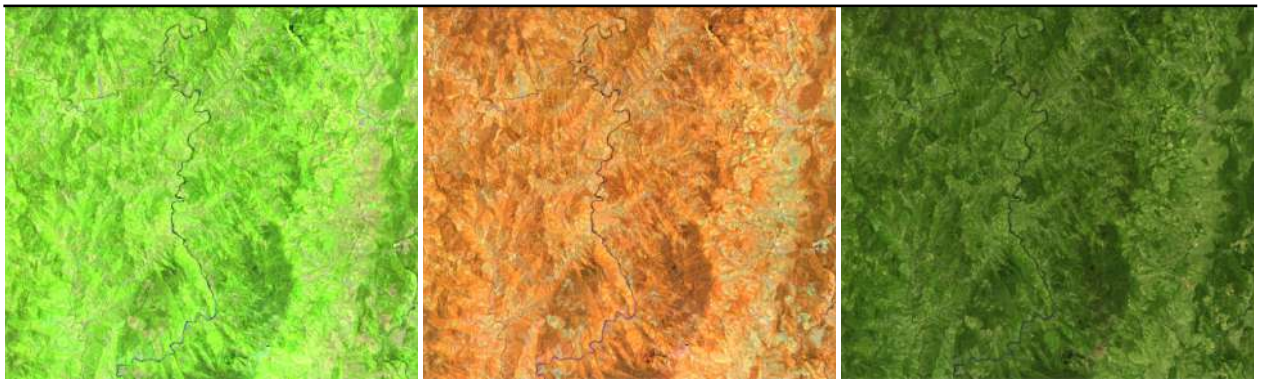
Figure 57 Spectral Response of Other Non Forest Formation in the Amazon Region.

This landcover is interpreted in the Colombian Amazon as low vegetation observed on some hilly terrains, rocky outcrops, or low-altitude tepuis. As shown in **Figure 57,** in the satellite image using the false-color combination RGB 654 Landsat 8 and 543 Landsat 7 and Landsat 5, low open vegetation or grasslands appear in fuchsia tones with ochre and brown hues, similar to grasslands; their differentiation lies in the landform, regular shapes, and the large number of shadows generated in the images. In the RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, it appears cyan in color. It presents a fine to medium heterogeneous texture with a pattern associated with hilly terrains, rocky outcrops, and shallow effective soils.

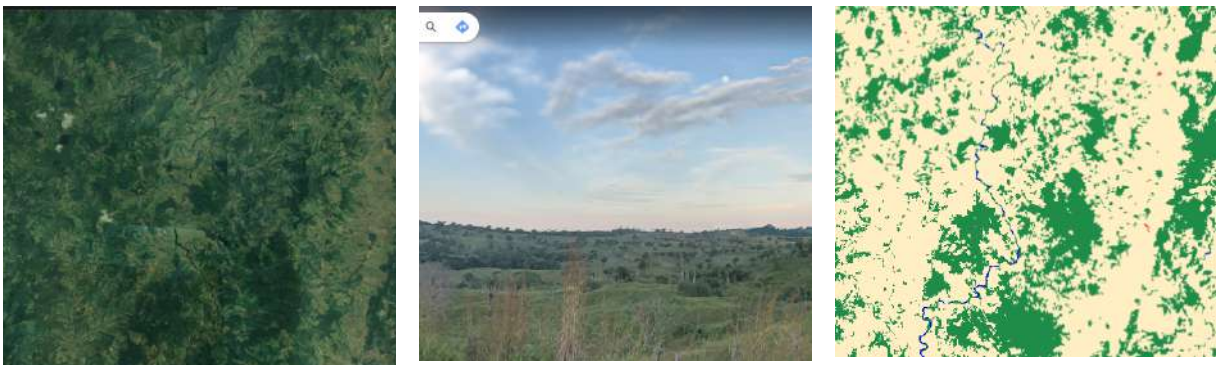
Mosaic of agriculture and pasture (ID:21)

It comprises an association of crops and pastures located in lands mainly dedicated to the production of food, fibers, and other industrial raw materials, whether they are under crops, with pastures, in rotation, and fallow or resting. Areas dedicated to permanent crops, transient crops, pasture areas, and heterogeneous agricultural zones are found, in which livestock uses can also occur in addition to agricultural ones. Transient crops are located in areas occupied with crops whose vegetative cycle is less than one year, even reaching only a few months, with the characteristic that after harvesting it is necessary to re-sow or plant to continue producing (Castellanos, 2010).

Permanent crops are related to territories dedicated to crops whose vegetative cycle is greater than one year, producing several harvests without the need to replant; they include: herbaceous crops, shrub crops like coffee and cocoa, and arboreal crops like fruit trees. It is worth mentioning that for this collection, Palm oil crops are excluded, as they are included as a differentiated class identified with code ID:35, (See Palm Oil in this section). Finally, prepared soils, post-harvest, and some burns are included. Regarding pastures, areas dedicated to permanent grazing for a period of two or more years are included, which may present temporary or permanent flooding when they are located in low areas or terrain depressions. A characteristic of this cover is that its presence, in a high percentage, is due to anthropic action, referred to especially to its planting, with the introduction of mainly non-native species. It should be clarified that this class of agriculture and/or pasture mosaics occurs because, in some areas, the sizes of the plots for both agriculture and pastures create difficulty in their differentiation and, therefore, in their classification due to the spatial resolution of the Landsat images.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4



Planet	Landscape	MapBiomas

Location: Norcasia - Caqueta, Year: 2024, Scala: 1 km, Coordinates: -75.49247 W, 1.77444 N.

Figure 58 Spectral Response of Mosaic of agriculture and pasture in the Amazon Region.

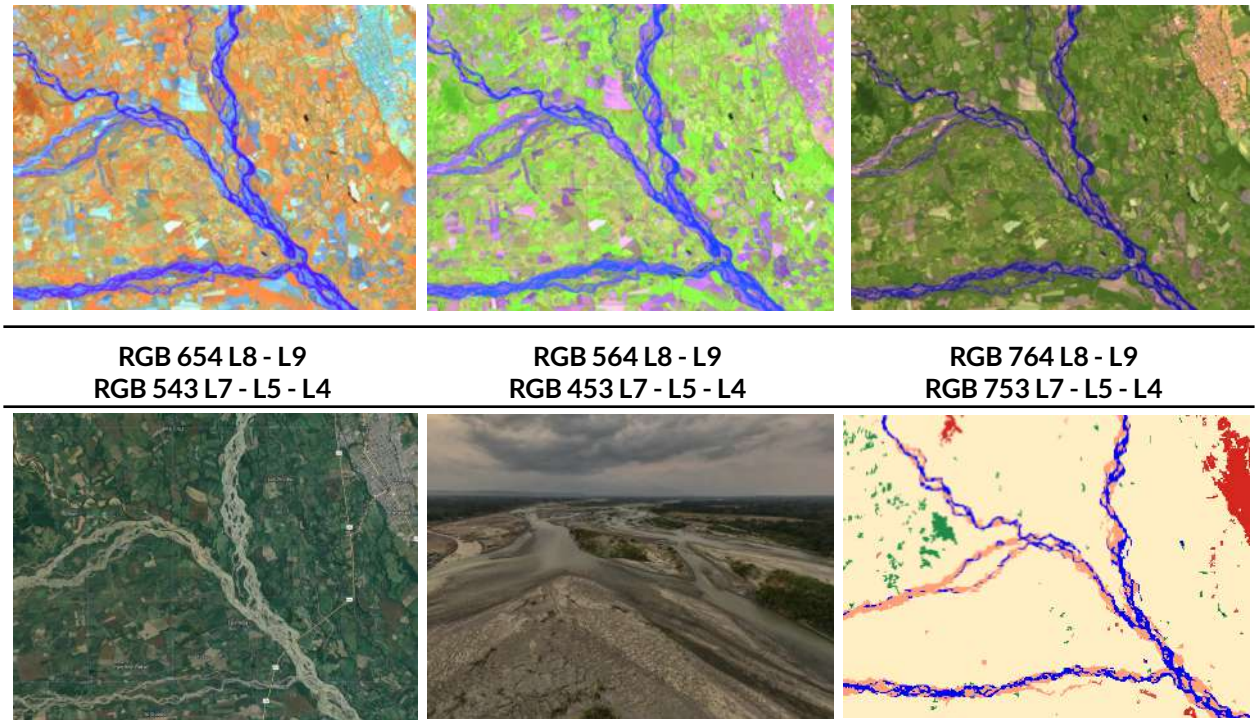
As observed in **Figure 58**, in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4, a matrix of intense green tones and yellow colors is observed, which correspond to prepared soils, crops in different phenological stages, and pastures, respectively. In

an RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, it appears as apple green, yellow, and very light orange colors.

It presents a fine homogeneous texture following a geometric pattern given by the parceling of the properties. Coffee crops located in Caqueta, Casanare, and Meta are observed in the satellite image in clearly defined geometric arrangements; the presence of relics of *guaduales*, road networks, and the high density of rural housing allow this cover to be identified. When areas covered by clean pastures are abandoned for long periods (six months to three years, depending on the region), the growth of shrubland and the development of early succession vegetation may occur, which can be confused with another type of non-forest natural formation or secondary or transitional vegetation.

Beach, dune and sand spot (ID:23)

Natural beaches and dunes are predominantly found in flood zones, such as riverine plains, mobile sandbanks, or abandoned meanders, and are characterized by sandy and stony soils.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Ariari River - Granada - Meta, Año: 2024, Scale: 500 m, Coordinates: -73.73353 W, 3.50406 N.

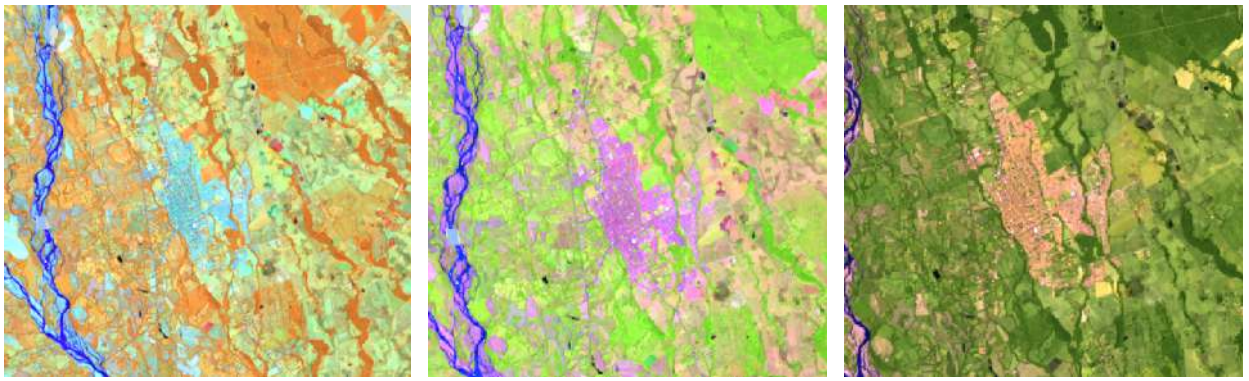
Figure 59 Spectral Response of Beach, dune and sand spot in the Amazon Region

In these areas, vegetation cover tends to be scarce or absent, showing variations in shape or size throughout the temporal series, mainly due to river flooding dynamics. The spectral response of this class shows a noticeable similarity across the three band combinations shown in **Figure 59**, exhibiting a fine texture and the absence of a clearly defined pattern. Specifically, in the RGB 654 and 764 combinations of Landsat 8 and 9, as well as in RGB 543 and 753 of Landsat 7, 5, and 4, lilac

and pink tones can be observed along the riverbanks. On the other hand, in RGB 564 of Landsat 8 and 9, and RGB 453 of Landsat 7, 5, and 4, light blue hues predominate. Finally, in MapBiomas, this class is represented in orange.

Infrastructure (ID:24)

It comprises areas of large and small urban centers (towns) and peripheral zones that are being incorporated into Infrastructures through a gradual process of urbanization or land-use change toward residential, commercial, industrial, service, and recreational purposes. Continuous urban centers can be found in Leticia (Amazonas), Florencia (Caqueta), Mocoa (Putumayo), Orito (Putumayo), Calamar (Guaviare), among others. Most large urban centers have aerial infrastructure (airports) and road connections with other cities..



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Granada - Meta, Year: 2023, Scale: 500 m, Coordinates: -73.7076 W, 3.5497 N.

Figure 60 Spectral Response of Infrastructure in the Amazon Region.

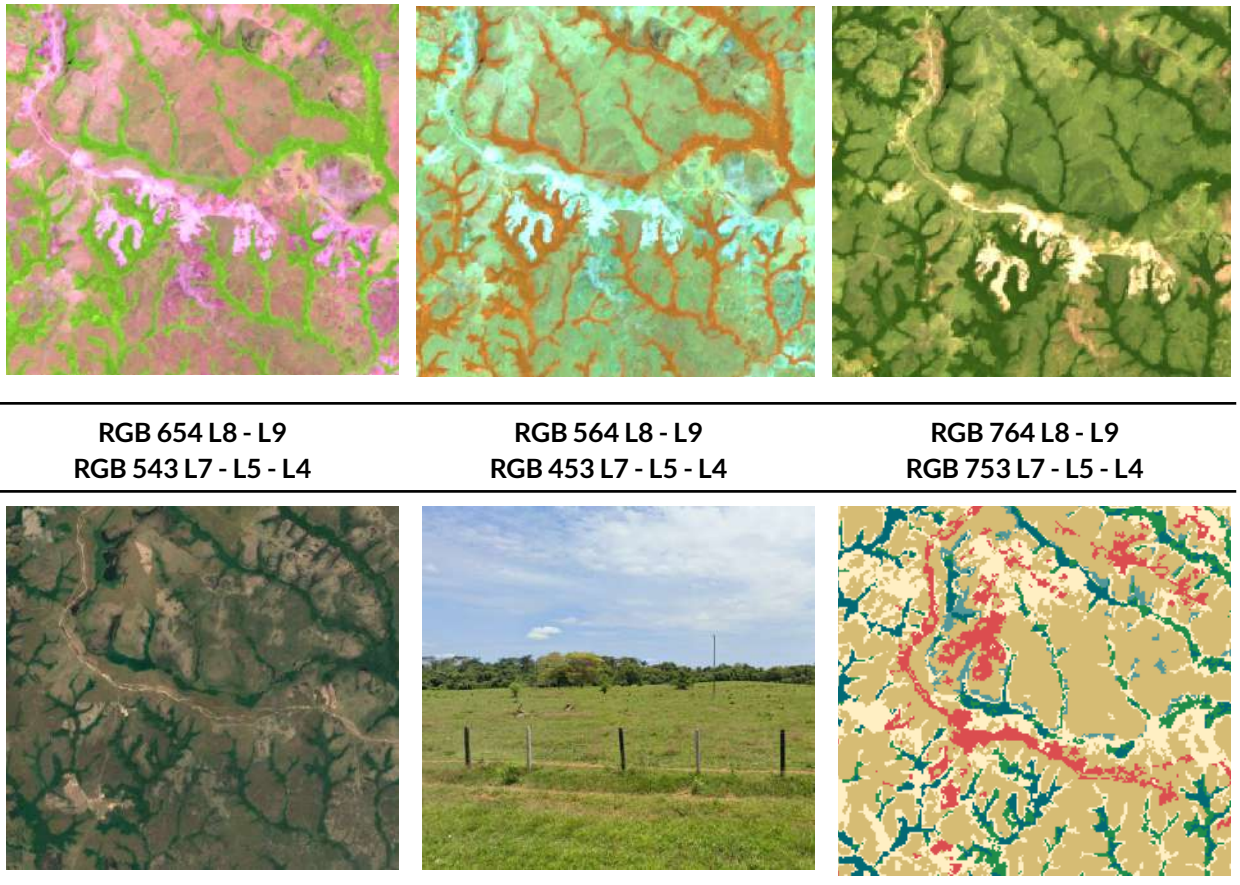
Similarly, small settlements can be found within the forest or around water bodies. Some of these settlements may have airstrips, as air transport often represents the only means of access for entry and exit. As shown in **Figure 60**, in the false-color combination RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4, this landcover is characterized by bright violet tones; likewise, in the false-color combination RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, it appears in light blue to white tones. It displays a fine to medium texture determined by the

size and density of the constructions. The homogeneous distribution of buildings and the road network gives it a geometric pattern resembling a grid.

Other non vegetated area (ID:25)

It comprises areas where vegetation cover is absent or scarce, consisting mainly of bare and burned soils, as well as sandy covers and rocky outcrops (Castellanos, 2010). It includes natural sandy areas on terrains composed mainly of sandy and stony soils, generally devoid of vegetation or covered by sparse shrub vegetation. In the Colombian Amazon, this class also includes exposed soils resulting from deforestation and burned areas.

Burned areas refer to zones affected by recent fires, where carbonized materials are still locally present, both in natural and semi-natural areas such as forests, crops, savannas, and shrublands.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Vda Calo Blanco - Guaviare, Year: 2023, Scale: 500 m, Coordinates: -72.3307 W, 3.08676 N.

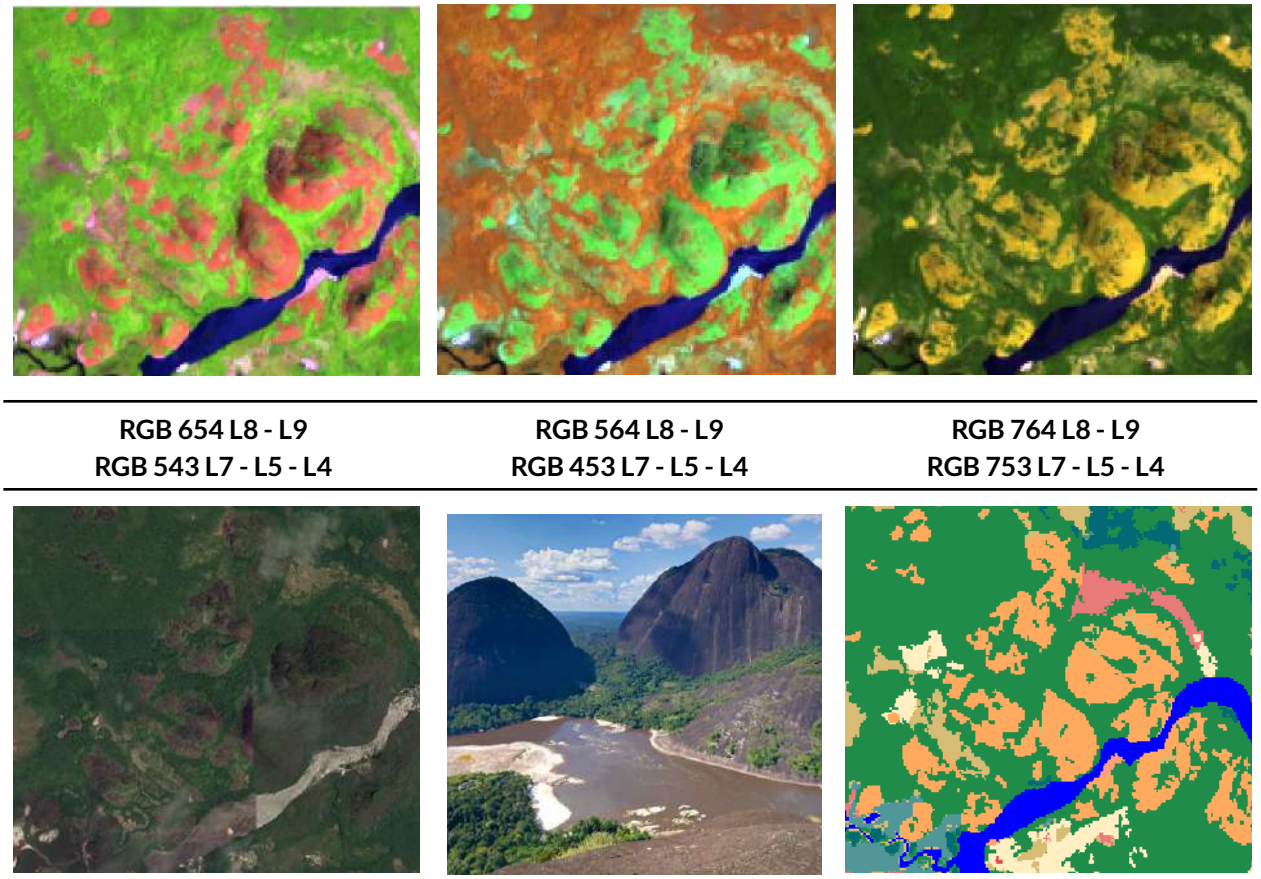
Figure 61 Spectral Response of Other Non-Vegetated Area in the Amazon Region.

As shown in **Figure 61**, the spectral response of other non-vegetated areas, in the RGB 654 Landsat 8 and RGB 543 Landsat 7, Landsat 5, and Landsat 4 combinations, displays bright fuchsia coloration, occasionally with some yellow hues. In the RGB 564 Landsat 8 and RGB 453 Landsat 7,

Landsat 5, and Landsat 4 combinations, mint-green or dark purple tones with bluish shades can be observed. In the RGB 764 Landsat 8 and RGB 753 Landsat 7, Landsat 5, and Landsat 4 combinations, pale yellow or dark brown tones with bluish hues can be seen. This landcover presents a very fine, homogeneous texture and generally continuous, uniform boundaries.

Rocky outcrop (ID:29)

It corresponds to areas composed of exposed rock layers, where erosion and rainfall processes have led to the exposure of the bedrock, with little or no vegetation present. These areas are generally located on steep slopes and rugged terrain. In the Amazon region, their representative location is found in the fluvial star of Inirida.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Puerto Inirida - Guainia, Year: 2023, Scale: 200m, Coordinates: -67.975284 W, 3.472212 N

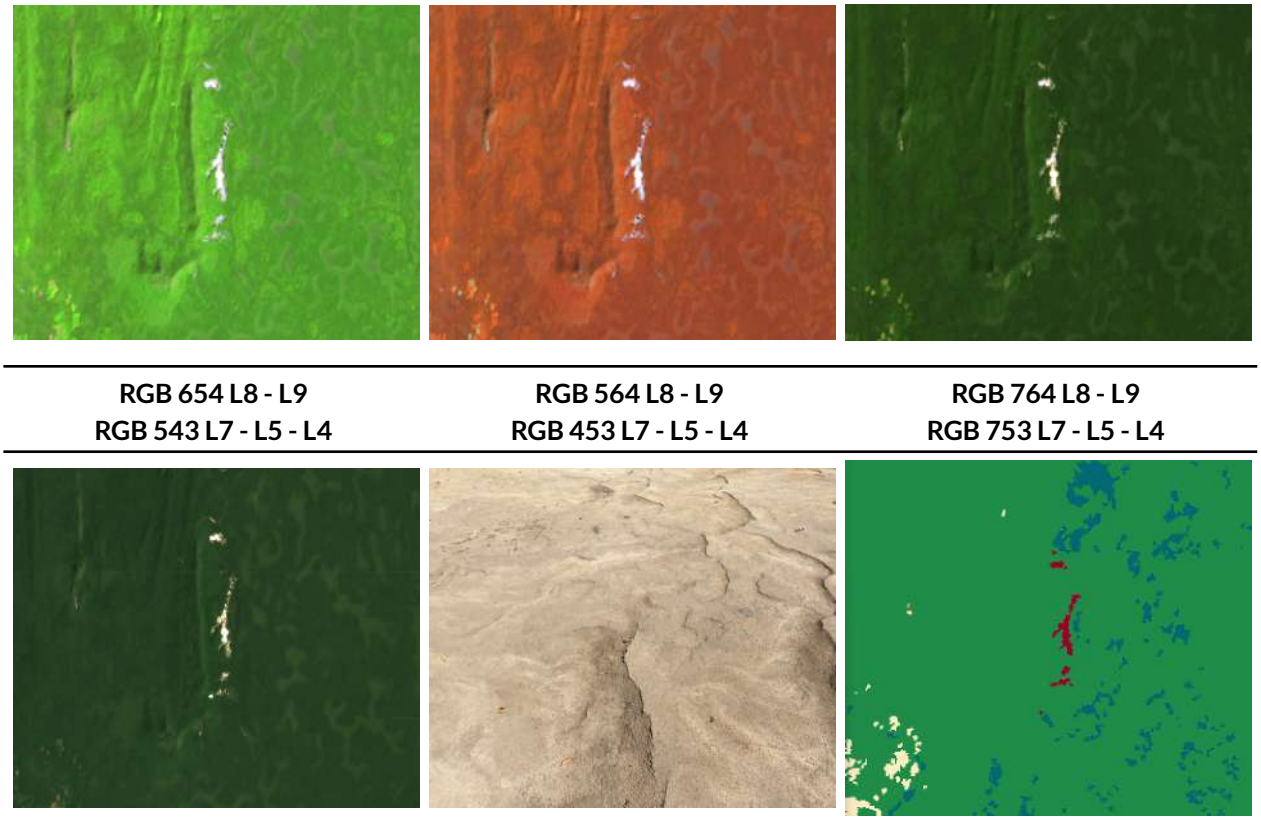
Figure 62 Spectral response of Rocky outcrop in the Amazon Region.

This cover type exhibits a homogeneous texture, and its spectral response, in the False Color RGB combination (Landsat 8 654 and Landsat 7, 5, and 4 543), varies between pink hues. Conversely, in the False Color RGB combination (Landsat 8 564 and Landsat 7, 5, and 4 453), it is visualized in green colors. Finally, in the RGB 764 (L8) combination, it appears in yellow hues.

Mining (ID:30)

Mining is found dispersed within the Forest (ID 3) and appears as small areas of bare soil dedicated to mineral extraction. These areas are located, for example, in the municipality of Taraira (Vaupés), distributed around the department of Guainia, among others. Likewise, a large cluster of mining areas can be identified in the department of Putumayo.

As observed in **Figure 63**, in the False Color RGB combination (Landsat 8 and 9 654, and Landsat 7, 5, and 4 543), and in an RGB combination (Landsat 8 and 9 564, and Landsat 7, 5, and 4 432), a forest spectral response is observed with patches of Magenta to purple coloration in the red combination, and blue patches in the green combination, which are characteristic of bare soil. These cover types differ from the others because they are generally immersed within the forest pattern and are in close proximity to generally small settlements. They exhibit a coarse heterogeneous texture.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Planet	**Landscape**	**MapBiomas**

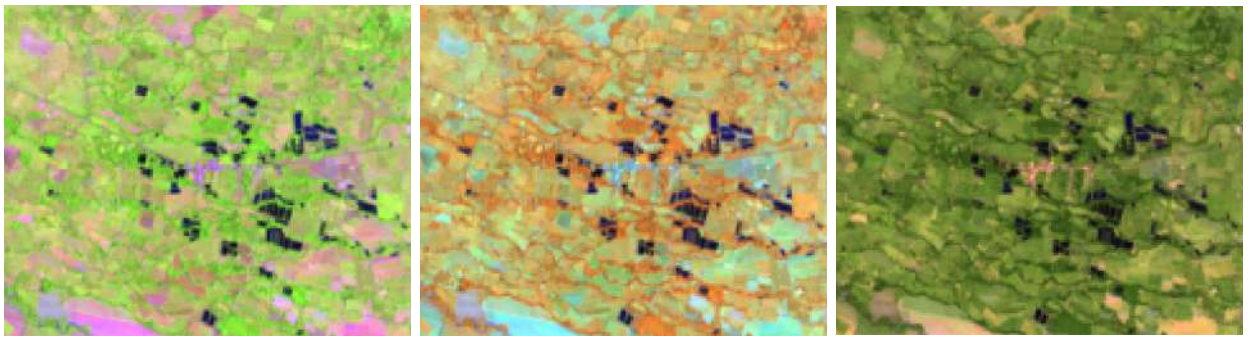
Location: Pana Pana, Guainía, Year: 2023, Scale: 500 m, Coordinates:-68.96314 W 1.90199 N

Figure 63 Spectral response of Mining in the Amazon Region.

Aquaculture (ID:31)

This class includes all artificial water bodies dedicated to the freshwater breeding of fish for consumption. The cover is composed of a series of adjacent ponds, which are distinguished by their regular geometric pattern.

The spectral response of aquaculture is similar to that of natural water bodies; being stagnant water, they tend to have a dark green to black coloration in high-resolution imagery. Likewise, the coloration is dark blue across the different band combinations used (RGB 654 Landsat 8 and 9, RGB 543 Landsat 7, 5, and 4). These features maintain a clearly distinguishable pattern associated with geometries that are almost always square to rectangular. For the classification of Collection 3, this class presents a dark blue coloration.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4

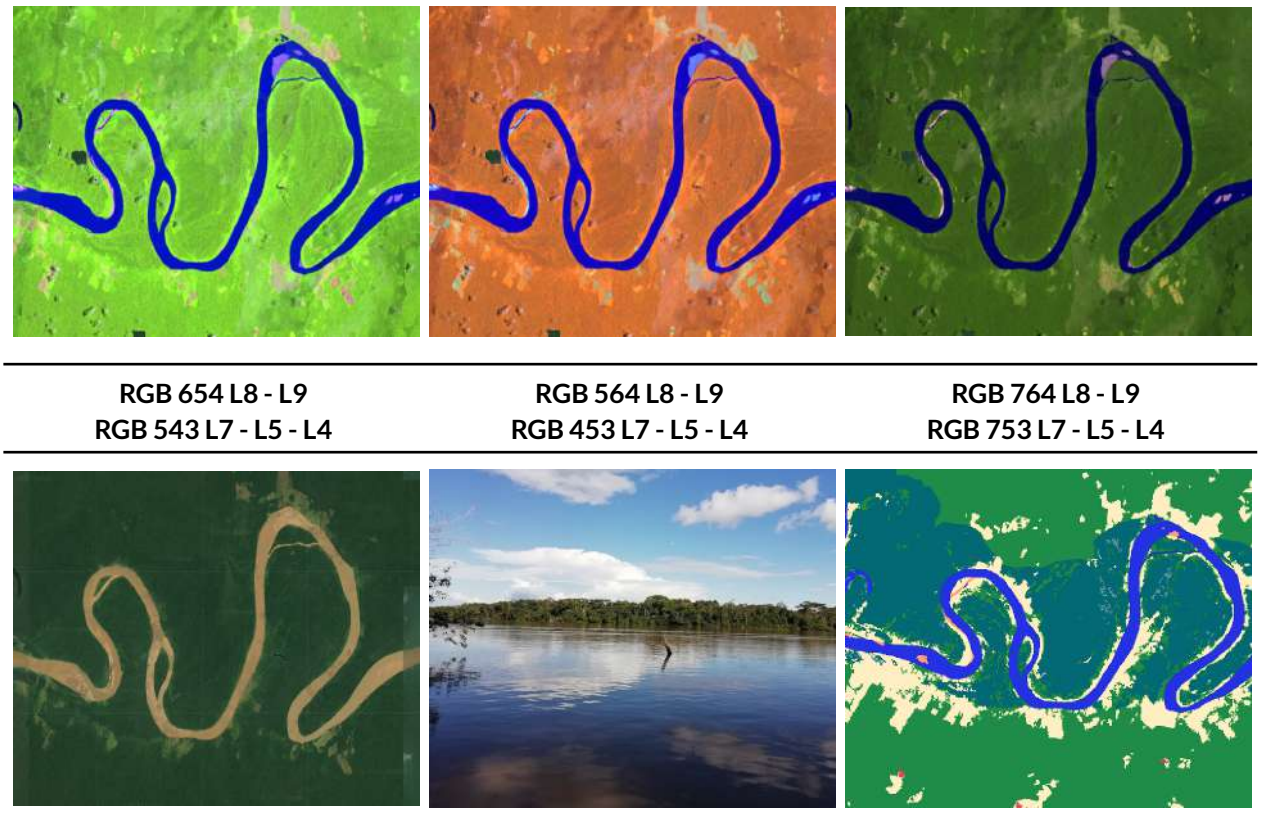
Google Earth	Landscape	MapBiomas

Location: Via Lejanías - Aguas Claras, Meta. Year: 2022, Scale: 200 m, Coordinates: -73.90554 W, 3.47541 S

Figure 64 Spectral response of Aquaculture in the Amazon Region.

River, lake and ocean (ID:33)

These are the permanent, intermittent, and seasonal water bodies which include lakes, lagoons, and natural or artificial freshwater ponds (non-saline) and moving water bodies.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

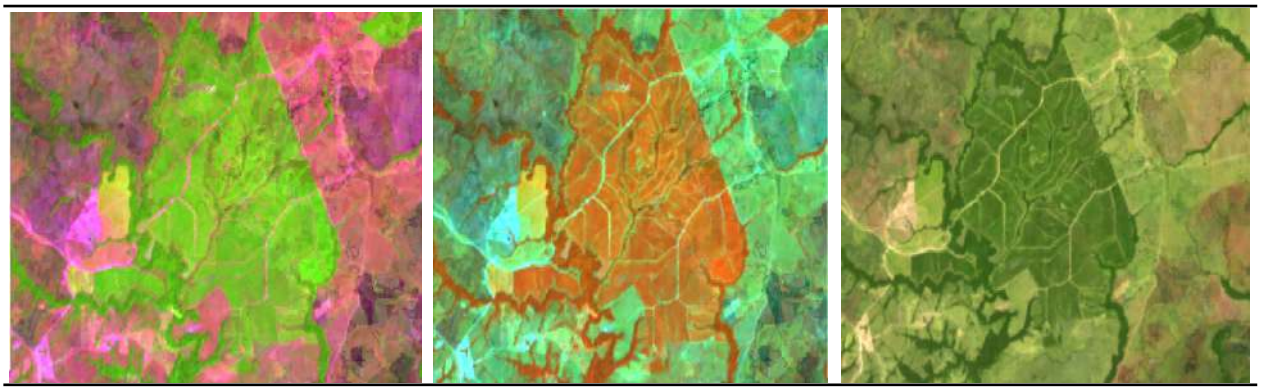
Location: Caqueta River, Year: 2021, Scale: 1 km, Coordinates: -74.490056 W -0.138241 S

Figure 65 Spectral response of River, lake or ocean in the Amazon Region.

The spectral response of water bodies depends on the suspended particle load. Rivers typically present a dark blue color due to sediment and organic matter content, and their color varies when their suspended particle loads are lower. In an RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combination, the coloration is the same across the different band combinations used. It exhibits a very fine homogeneous texture, as evidenced in **Figure 65**, with a drainage pattern that follows the different water courses, in some cases presenting a dendritic type.

Palm Oil (ID:35)

This class comprises symmetrical crops of Palm Oil, either transitory or permanent, where the plot sizes are considerably large compared to normal crops. They are generally implemented across large extensions and their exploitation is on an industrial scale.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

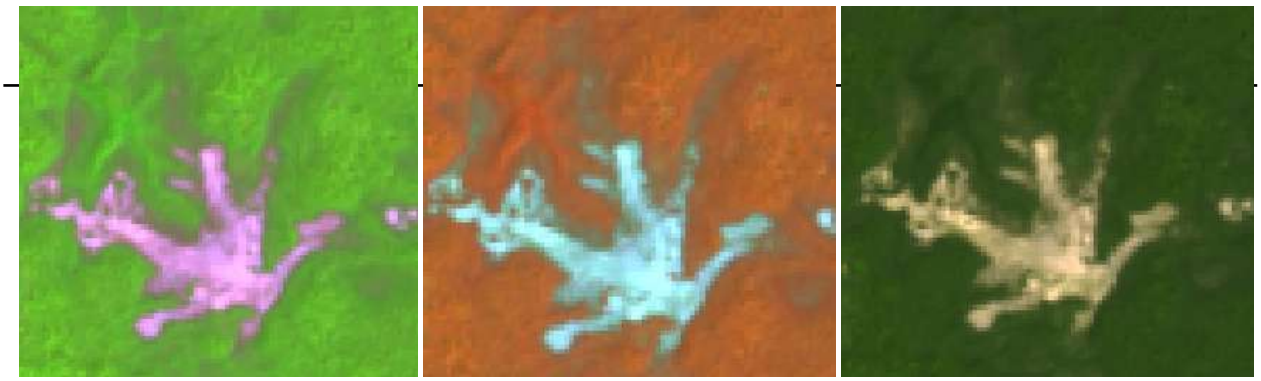
Location: Mapiripán, Meta, Year: 2021, Scale: 500 m, Coordinates: -72.08995 W, 2.9255 N.

Figure 66 Spectral response of Palm oil in the Amazon Region.

As evidenced in **Figure 66**, this crop adheres to a clear, regular geometric pattern, distributed in plots that are intertwined with internal roads serving as access networks for their care and exploitation. Its texture is fine and homogeneous with a geometric pattern defined by the parceling of the properties. In the False Color combination (Landsat 8 654 and Landsat 7, Landsat 5, and Landsat 4 543), and in an RGB combination (Landsat 8 563 and Landsat 7, Landsat 5, and Landsat 4 453), a spectral response similar to the forest is observed, displaying a green coloration. These cover types are differentiated by their symmetrical patterns in the mosaic, the degrees of intervention in the surrounding area, and the regularity of their boundaries.

Other natural non vegetated area (ID:68)

This class includes areas that are devoid of vegetation or have very sparse plant cover, resulting from natural erosive processes or other natural phenomena. In the Amazon region, it was used to map natural disturbances (such as landslides, water erosion, among others), as well as to classify certain areas with sparse vegetation on the tepuis.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Guainia, Year: 2022, Scale: 500 m, Coordinates: -67.51949 W, 3.52939 N.

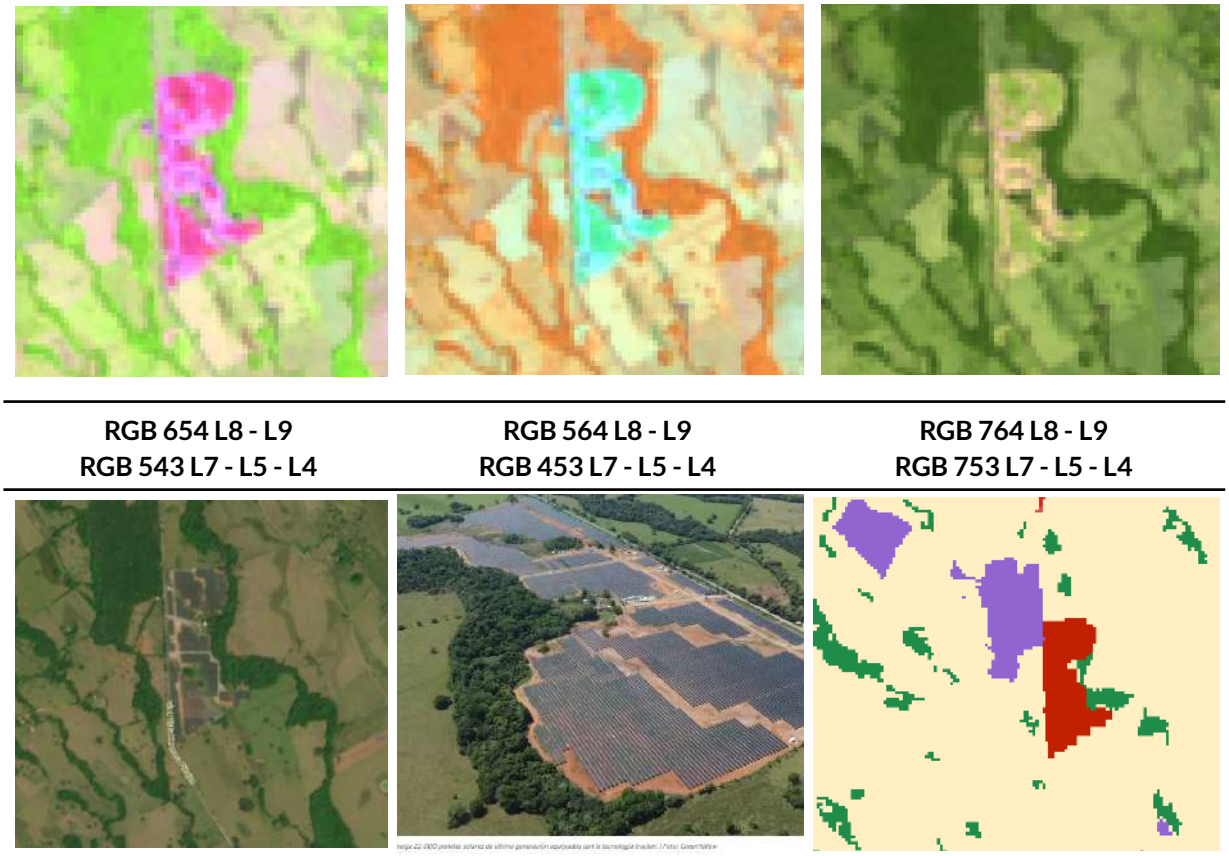
Figure 67 Spectral response of Other natural non vegetated area in the Amazon Region.

The spectral response is similar to Class 25. In the False Color RGB combination (Landsat 8 and 9 654 and Landsat 7, 5, and 4 543), a dark bluish-purple hue is observed, while in the RGB combination (Landsat 8 and 9 564 and Landsat 7, 5, and 4 453), pale mint green tones and yellowish hues with whitish undertones can be seen. Finally, in the True Color RGB (Landsat 8 and 9 764 and Landsat 7, 5, and 4 753), the pixels exhibit opaque pink hues. In the MapBiomas legend, it is represented by an intense fuchsia tone, as evidenced in **Figure 67.**

Solar panel farm (ID:75)

It includes all those areas designated for the installation of photovoltaic modules capable of converting sunlight into electrical energy. These spaces comprise sets of solar panels mounted on fixed structures or equipped with solar tracking systems, as well as substations, internal connection networks, and other infrastructures necessary for the transmission, distribution, and

management of the generated energy. While they commonly cover large areas —such as the *Corredor del Jaguar Project* in Guaviare or the *Dinamarca Solar Park* by GreenYellow in Meta—, smaller-scale installations have also been identified, aimed at facilitating access to energy in isolated communities and reducing dependence on fossil fuels.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

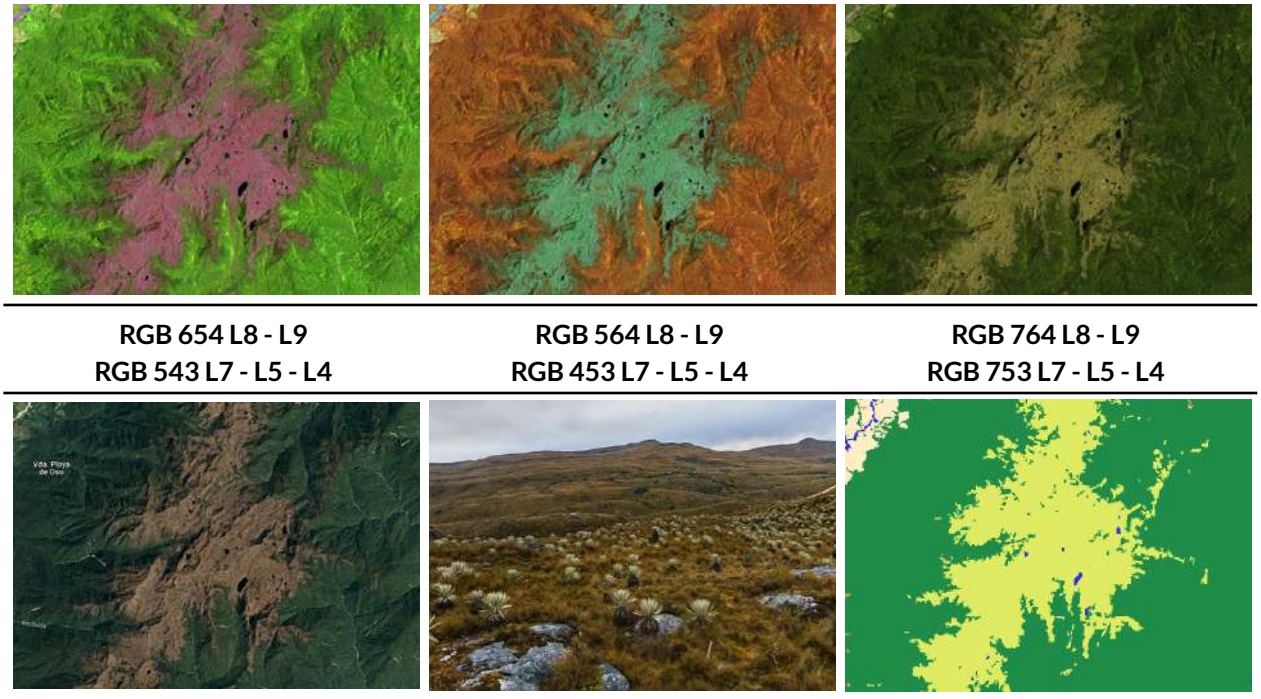
Location: San Juan de Arama - Meta. Year: 2024, Scale: 500 m, Coordinates: -73.8738, 3.35012

Figure 68 Spectral Response of Solar Panel farm in the Amazon region

Its spectral response is highly distinctive. In the false color combination RGB 654 of Landsat 8 and 9, and RGB 543 of Landsat 7, 5, and 4, it displays magenta tones with some light pink hues. In the RGB 564 combination of Landsat 8 and 9, and RGB 453 of Landsat 7, 5, and 4, vivid mint-green pixels can be observed. It shows fine, homogeneous textures arranged in well-defined geometric patterns, as illustrated in **Figure 68**. Finally, in the MapBiomas legend, this class is represented in red.

Andinean Herbaceous and Shrubby Vegetation (ID 81)

Natural vegetation cover restricted to the Andean region, located above the tree line, starting at approximately 2.900 m a.s.l., with its transition depending on local conditions, particularly edaphic and climatic factors. It is mainly dominated by herbaceous species, with a lower proportion of shrubs whose physiognomy and floristic composition vary widely. Among the most representative plant families are Poaceae, Asteraceae, Ericaceae, Melastomataceae, Rosaceae, and Orchidaceae, as well as Cyperaceae, Bromeliaceae, and Fabaceae, all of which contribute to the high diversity and endemism of the ecosystem. These communities are adapted to conditions of high humidity, frequent cloudiness, high rainfall, direct solar radiation, low temperatures, and soft soils. They constitute one of the most unique ecosystems and, at the same time, one of the most threatened by anthropogenic pressure.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

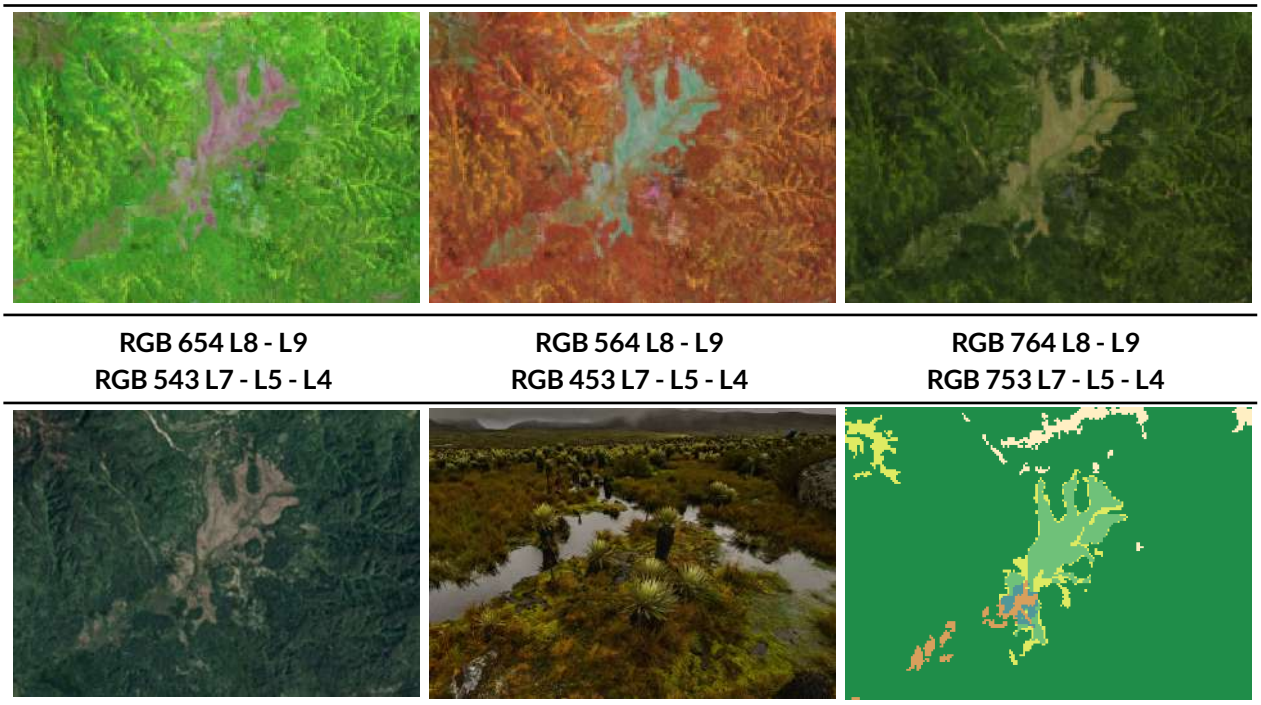
Location: Paramo sumapaz - Meta, Year: 2024, Scale 1 km, Coordinates:-74.248694 W, 3.653077 N

Figure 69 Spectral response Andinean Herbaceous and Shrubby Vegetation- in the Amazon region.

As shown in **Figure 69**, in the false color combination RGB 654 Landsat 8 and 9, and RGB 543 Landsat 7, 5, and 4, it appears in shades ranging from purple to brown with opaque tones. In the RGB 564 Landsat 8 and 9, and RGB 453 Landsat 7, 5, and 4 combinations, pale green hues are observed. In true color, it appears yellowish-brown. It exhibits a heterogeneous texture and a pattern associated with areas of low anthropogenic intervention, rocky outcrops, and hilly reliefs. Finally, in the MapBiomas legend, it is represented with a lime green tone.

Flooded Andinean Herbaceous and Shrubby Vegetation (ID 82)

Natural vegetation cover is restricted to the Andean region, associated with freshwater lacustrine, palustrine, and fluvial systems, mainly dominated by herbaceous species and, to a lesser extent, by shrubs. It develops in alluvial plains, riparian zones, and swampy environments above 2.900 m a.s.l. It is characterized by vegetation adapted to conditions of high humidity, frequent cloudiness, high precipitation, direct solar radiation, low temperatures, and soft soils largely composed of mosses and decomposing organic matter that form peatlands. It also includes species that partially or completely cover the water surface in Andean lakes and lagoons undergoing eutrophication.



RGB 654 L8 - L9 RGB 543 L7 - L5 - L4	RGB 564 L8 - L9 RGB 453 L7 - L5 - L4	RGB 764 L8 - L9 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Pasto - Nariño, Year: 2024, Scale; 500 m, Coordinates: -77.11389 W, 1.00599 N

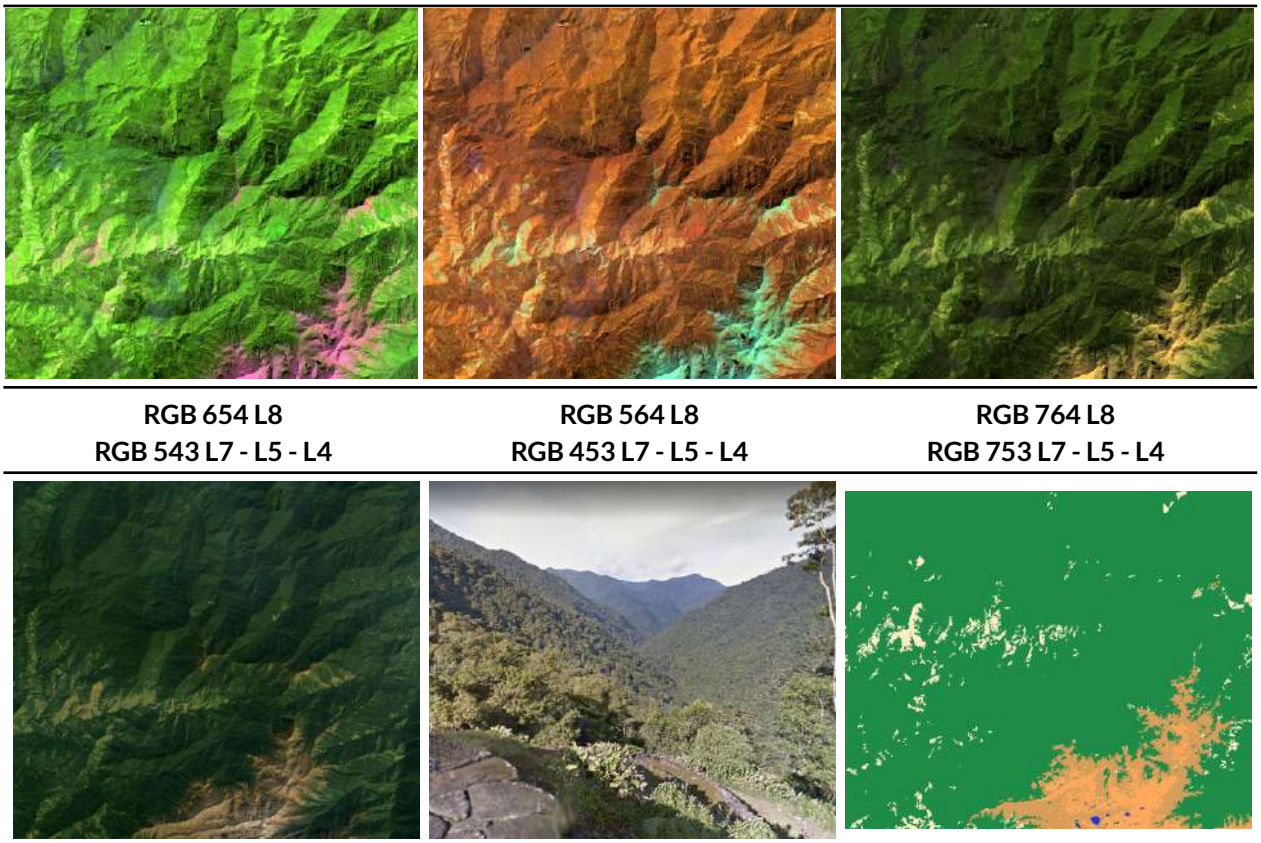
Figure 70 Spectral response Flooded Andinean Herbaceous and Shrubby Vegetation- in the Amazon region.

As shown in **Figure 70**, in the false color combination RGB 654 Landsat 8 and 9, and RGB 543 Landsat 7, 5, and 4, this land cover appears in purple tones, with darker areas corresponding to zones of greater flooding. In the RGB 564 Landsat 8 and 9, and RGB 453 Landsat 7, 5, and 4 combinations, pale green tones are observed. In true color, it appears yellowish-brown. It exhibits a finer texture than the Andean herbaceous and shrub formations, as it is located in areas with more homogeneous reliefs and a pattern associated with low anthropic intervention, rocky outcrops, and hilly terrain.

4.4.3.3 Caribbean Legend

Forest (ID: 3)

This class corresponds to natural areas dominated by arboreal or shrubby elements forming a more or less continuous canopy with heights exceeding 5 meters. It includes dense upland forests, dense shrublands, riparian and gallery forests, as well as secondary vegetation in advanced stages of succession where part of the structural attributes have already been recovered. In the Caribbean region, different forest types can be found according to altitudinal gradients and climatic conditions, such as the tropical humid forest of the Middle Magdalena Valley, characterized by a tall stratum and continuous canopy with evergreen vegetation; the tropical dry forest of the Caribbean Lowlands, subject to drought periods and extreme temperatures, featuring deciduous and thorny vegetation; and the montane forests of the Serrania del Perija and the Sierra Nevada de Santa Marta (IDEAM, 2010; IDEAM, IGAC & Instituto Humboldt, 2017).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Sierra Nevada de Santa Marta-Magdalena,**Year:** 2021, Scale: 2000 m,
Coordinates: -73.9136 W, 10.9809 N

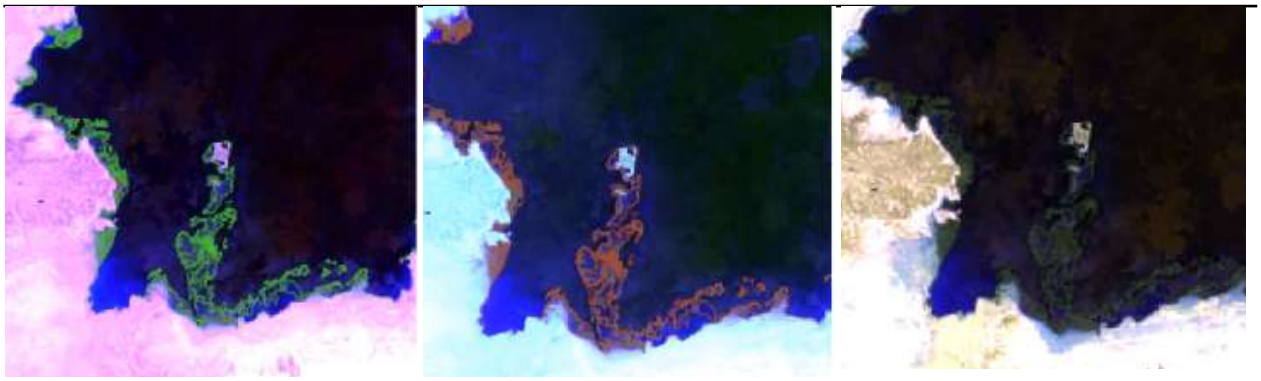
Figure 71. Spectral response of the Forest in the Caribbean region.

In dense forests with a high degree of conservation, identification through satellite imagery is feasible due to their continuity in shape and physiognomy. These forests display darker tones compared to some naturally regenerated secondary tree formations. In the case of riparian or gallery forests, the pattern is easily distinguishable as it borders watercourses, following various drainage patterns (from dendritic to sub-dendritic).

Regarding the Landsat imagery used, in the false-color combinations RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4), this class is identified by dark to light green tones, which—as mentioned earlier—depend on its successional stage and maturity. For the combinations RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4), the class appears in dark red to orange hues. Finally, for band combinations RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4), the forest reflects in dark green tones (**Figure 71**). The texture ranges from medium to coarse roughness depending on canopy density.

Mangrove (ID: 5)

Natural formations of dense, evergreen forests located in coastal zones, occupying a transitional area between the continent and the ocean (Fundación Gaia Amazonas, 2022). These ecosystems develop on flat, muddy soils that may be permanently or seasonally flooded due to tidal influence. Mangroves occur in estuarine zones, bays, inlets, coastal lagoons, and tidal channels, among others, where they receive inputs from continental runoff and the influence of marine or brackish waters (Gaxiola, 2011). According to Murcia & Castillo (2018), mangroves in the Caribbean region extend from the Gulf of Uraba (Antioquia) to the Bahia Tukakas in the Upper Guajira. Their floristic composition includes five species belonging to the genera *Rhizophora*, *Avicennia*, *Laguncularia*, *Pelliciera*, and *Conocarpus*. Due to the influence of brackish water, these ecosystems have developed specific morphological adaptations that enable them to survive under such conditions, including elongated and flexible roots that colonize unstable substrates, anatomical structures known as *lenticels* on stems, branches, and roots that allow gas exchange with the atmosphere, and reproductive strategies such as buoyant seeds capable of floating for extended periods (Villalba, 2006).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

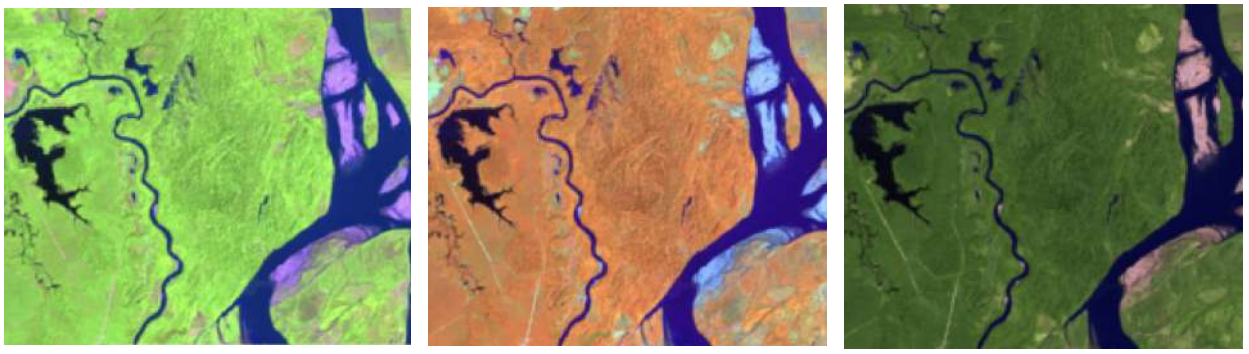
Location: Uribia- La Guajira , Year: 2021, Scale: 2000 m, Coordinates: −71.92896 W, 12.152619 N

Figure 72. Spectral Response of the Mangrove in the Caribbean Region.

At the top of **Figure 72**, the combinations used for identifying this land cover are shown. In the false-color combinations RGB 654 (Landsat 8) and RGB 543 (Landsat 7–5–4), mangrove areas are characterized by grayish dark-green tones in shrub-dominated formations and brighter green tones in taller vegetation, typically with smooth textures. For RGB 564 (Landsat 8) and RGB 453 (Landsat 7–5–4), the spectral response ranges from dark red to brown, with higher intensity in vigorous vegetation. Finally, in RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4), mangroves appear as opaque dark-green tones.

Flooded forest (ID: 6)

Flooded forests are wooded land covers composed of vegetation with multiple strata, dominated by woody or tree species with heights starting from approximately 3 meters. These formations typically establish along the banks of temporary or permanent rivers, swamps, wetlands, valleys, or alluvial plains. Owing to the relatively flat topography, this type of vegetation is also referred to as *gallery forest*; however, not all gallery forests necessarily correspond to this class.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

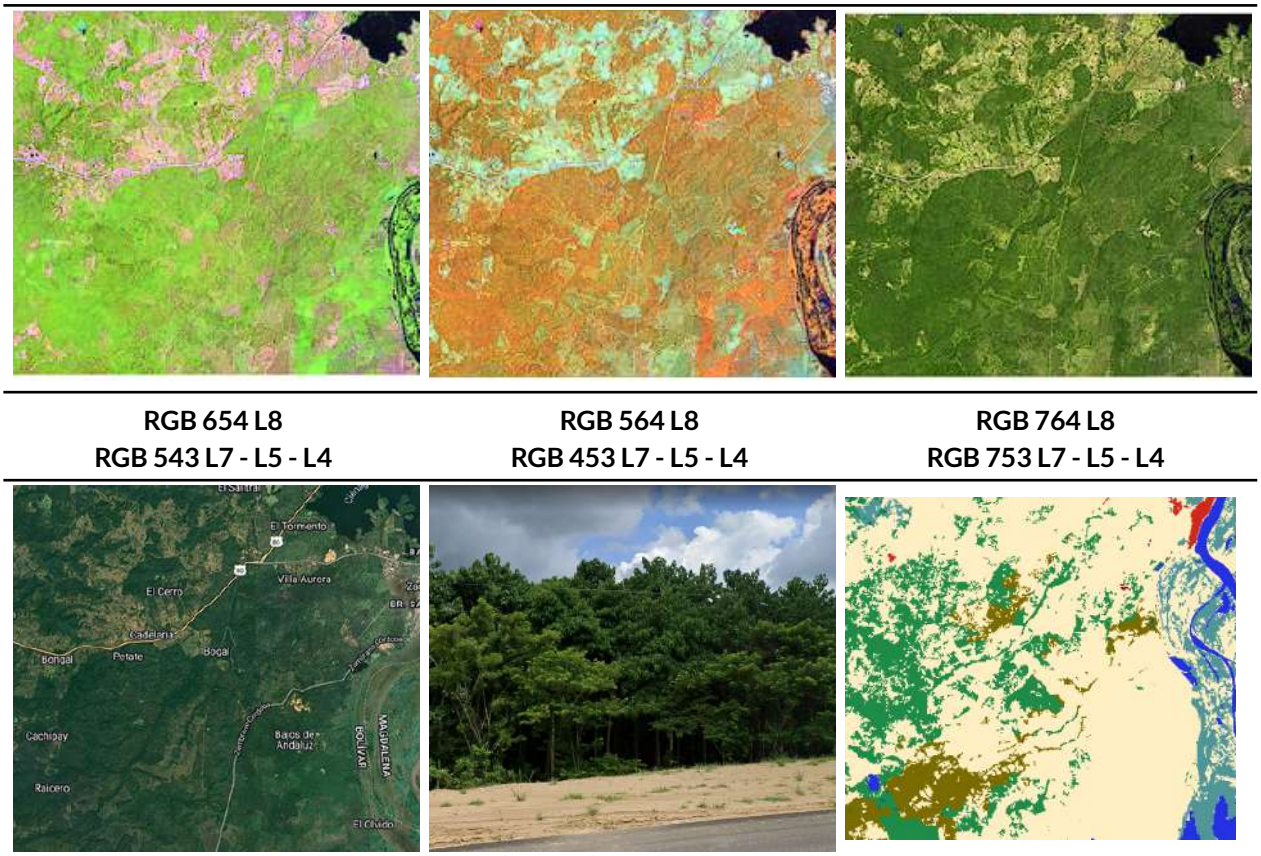
Location: Magdalena River – Bolivar/Santander, Year: 2022 , Scale: 200 m,
Coordinates: −73.82262 W, 7.76953 N

Figure 73. Spectral Response of the Flooded Forest in the Caribbean Region.

In the Colombian Caribbean, flooded forests typically occur behind mangrove zones, where the flood level is lower. These areas may include some *terra firme* species tolerant to periodic flooding, as well as palms that are characteristic of inundated environments. As shown in **Figure 73**, under the false-color combinations RGB 654 (Landsat 8) and RGB 543 (Landsat 7–5–4), these covers are distinguished by bright light-green tones. In the RGB 564 (Landsat 8) and RGB 453 (Landsat 7–5–4) combinations, coloration varies from red to brown with intense orange hues, differing from upland forest by their finer texture, in contrast to the rougher canopy of Class 3. Lastly, in RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4), this class displays tones ranging from dark to light green.

Forest Plantation (ID: 9)

This land cover corresponds to an anthropogenic class, consisting exclusively of tree vegetation established in pure stands through planting or sowing for afforestation or reforestation processes with commercial purposes. In the Caribbean region, the species with the largest planted areas are *Tectona grandis* (teca) and *Gmelina arborea* (melina). Most of these plantations are located in lowland areas with gentle slopes.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

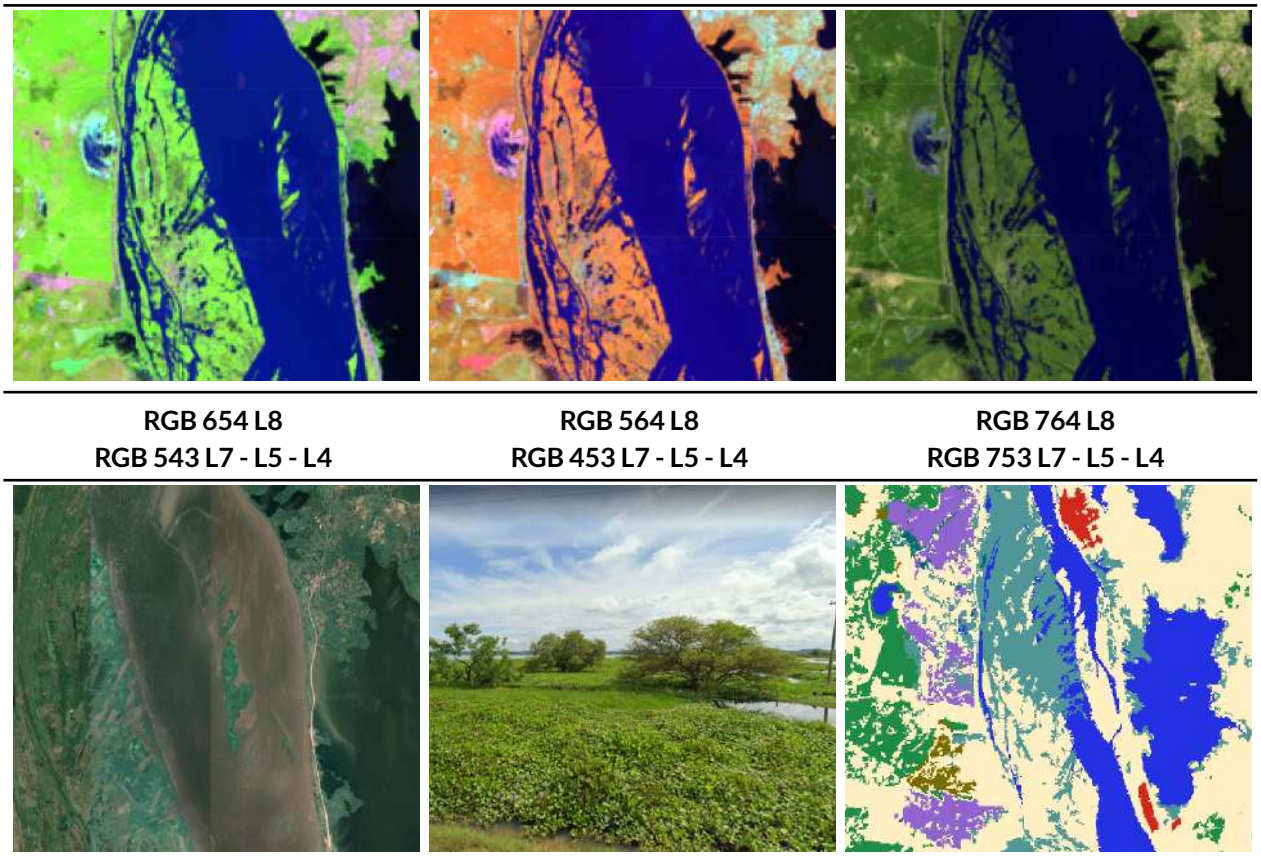
Location: Zambrano, Magdalena, **Scale:** 1000 m, **Year:** 2021, **Coordinates:** −74.88476 W, 9.73087 N

Figure 74. Spectral Response of Forest Plantation in the Caribbean Region.

In satellite imagery, this class is characterized by continuous coverage with a regular geometric pattern, reflecting rows of trees typically of the same age. In the false-color combinations RGB 654 (Landsat 8) and RGB 543 (Landsat 7–5–4), forest plantation appear in green tones—dark green for mature plantations and bright yellowish-green for younger stages. In RGB 564 (Landsat 8) and RGB 453 (Landsat 7–5–4), the dominant colors range from orange in young plantations to reddish hues as the stands mature. Finally, in the RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4) combinations, plantations appear in dark-green tones, which can be easily confused with natural forest formations; however, silvicultural areas exhibit more homogeneous and less rugged textures compared to those of Class 3 (**Figure 74**).

Wetland (ID: 11)

This type of land cover consists mainly of herbaceous vegetation and, to a lesser extent, shrubs, located in areas associated with river deltas, estuaries, swamps, coastal lagoons, and marine floodplains, as well as in *madres viejas* (oxbow lakes or abandoned river channels).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

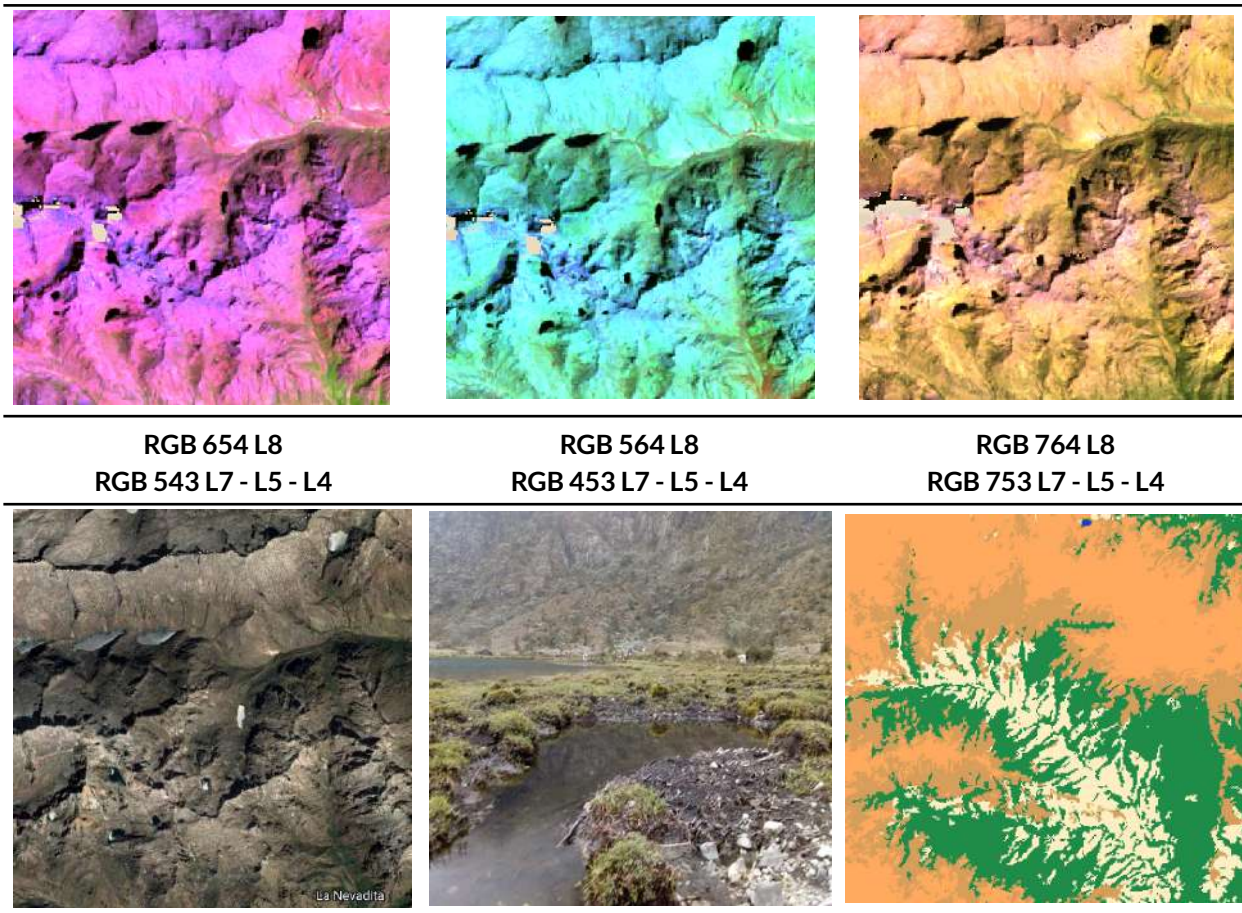
Location: Ciénaga Zurra-Tenerife, Magdalena, Scale: 500 m, Year: 2022,
Coordinates: −74.85062 W, 9.86896 N

Figure 75. Spectral Response of Wetland in the Caribbean Region.

These covers can also be found in low coastal areas where vegetation has adapted to brackish environments due to tidal influence (IDEAM, 2010). The spectral response of this class is highly variable. As shown in **Figure 75**, along the edges of the swamp, in the false-color combinations RGB 654 (Landsat 8) and RGB 543 (Landsat 7–5–4), the class displays bright neon-green tones but may also appear brownish to dark brown. In RGB 564 (Landsat 8) and RGB 453 (Landsat 7–5–4), the class shows orange tones with vivid pink and light ochre-green hues in some marshy areas. Finally, in RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4), vivid green tones are predominant. This class presents a fine, heterogeneous texture without defined spatial patterns.

Other non forest formation (ID: 13)

In the Caribbean region, this class includes a set of natural vegetation formations that have not been significantly influenced by human activity. They are composed mainly of dispersed shrubs and grasslands that develop in areas not subject to flooding (IDEAM, 2010).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Valledupar - Cesar, Scale: 500 m, Year: 2021, Coordinates: −73.453367 W, 10.846723 N

Figure 76. Spectral Response of the Other Non Forest Formation Class in the Caribbean Region.

This class is mainly composed of natural grasslands and high-mountain shrublands (*paramo*) found in the Serrania del Perija and the Sierra Nevada de Santa Marta, generally above 3.300 m a.s.l. It is associated with areas of low anthropogenic intervention and the presence of rocky outcrops, characterized by fine, slightly rough textures, especially in steep terrains. As shown in **Figure 76**, the spectral response of this cover in the RGB 654 (Landsat 8) and RGB 543 (Landsat 7–5–4) combinations appears in strong fuchsia and pink tones. In RGB 564 (Landsat 8) and RGB 453 (Landsat 7–5–4), it exhibits light emerald-green hues with blueish tones, and finally, in RGB 764 (Landsat 8) and RGB 753 (Landsat 7–5–4), the pixels display a cream-yellow coloration.

Mosaic of Agriculture and Pasture (ID:21)

In the Caribbean region, this land cover is mainly represented by temporary crops, seasonally flooded crops located adjacent to water bodies, some permanent crops, and mosaics of pastures. In most cases, these are difficult to represent individually due to their small parcel size and intricate spatial patterns. Agriculture in the region is primarily associated with crops such as rice, maize, plantain, some legumes, and other small-scale family farming systems. Pasture mosaics, on

the other hand, are mainly used for livestock activities, including clean pastures, weedy pastures, and pastures interspersed with natural vegetation. This cover presents a wide range of tones due to the different phenological stages and varied management practices across parcels, which may cause confusion with other classes. Its main characteristic is the regular and irregular geometric pattern of the plots (IDEAM, 2018).

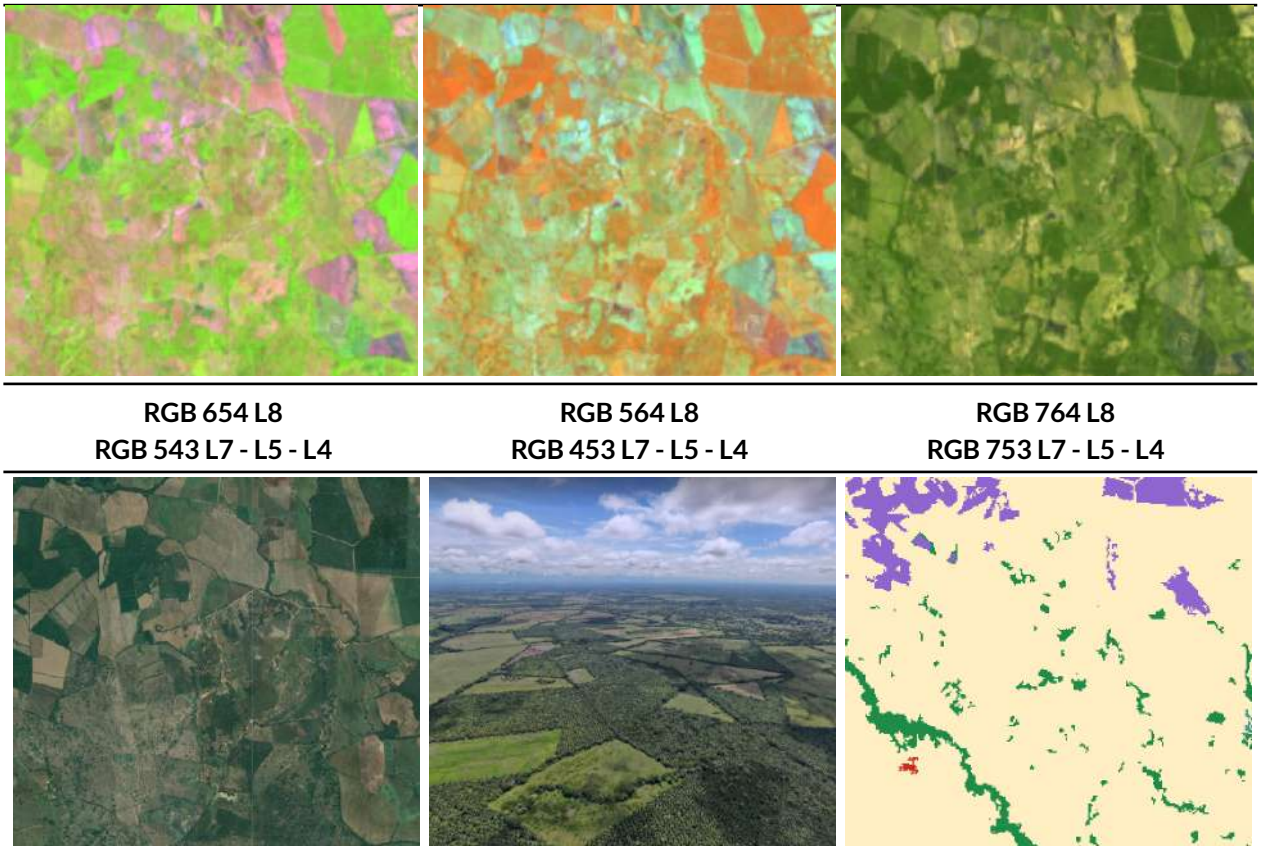


Figure 77. Spectral Response of the Mosaic of Agriculture and/or Pasture class in the Caribbean region.

In general, this cover is characterized by well-defined geometric patterns resulting from parcel delimitation, with a smooth and homogeneous texture. In false color composite RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4), a variety of tones can be observed, ranging from bright green, light pink, pale purple, light brown, and yellowish-green. In false color composite RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4), the color matrix includes light reds, oranges, and bright sky blues. In true color composites, light green, pale purple, and soft cream tones predominate. Flooded crops tend to appear in darker tones with bluish to purplish hues.

Beach, dune and sand spot (ID:23)

In the Caribbean region, these natural formations are associated with several environments. Firstly, they are found along the shores and coasts of the Caribbean Sea and are characterized by a distinctive spectral response due to their high albedo or light reflectance.

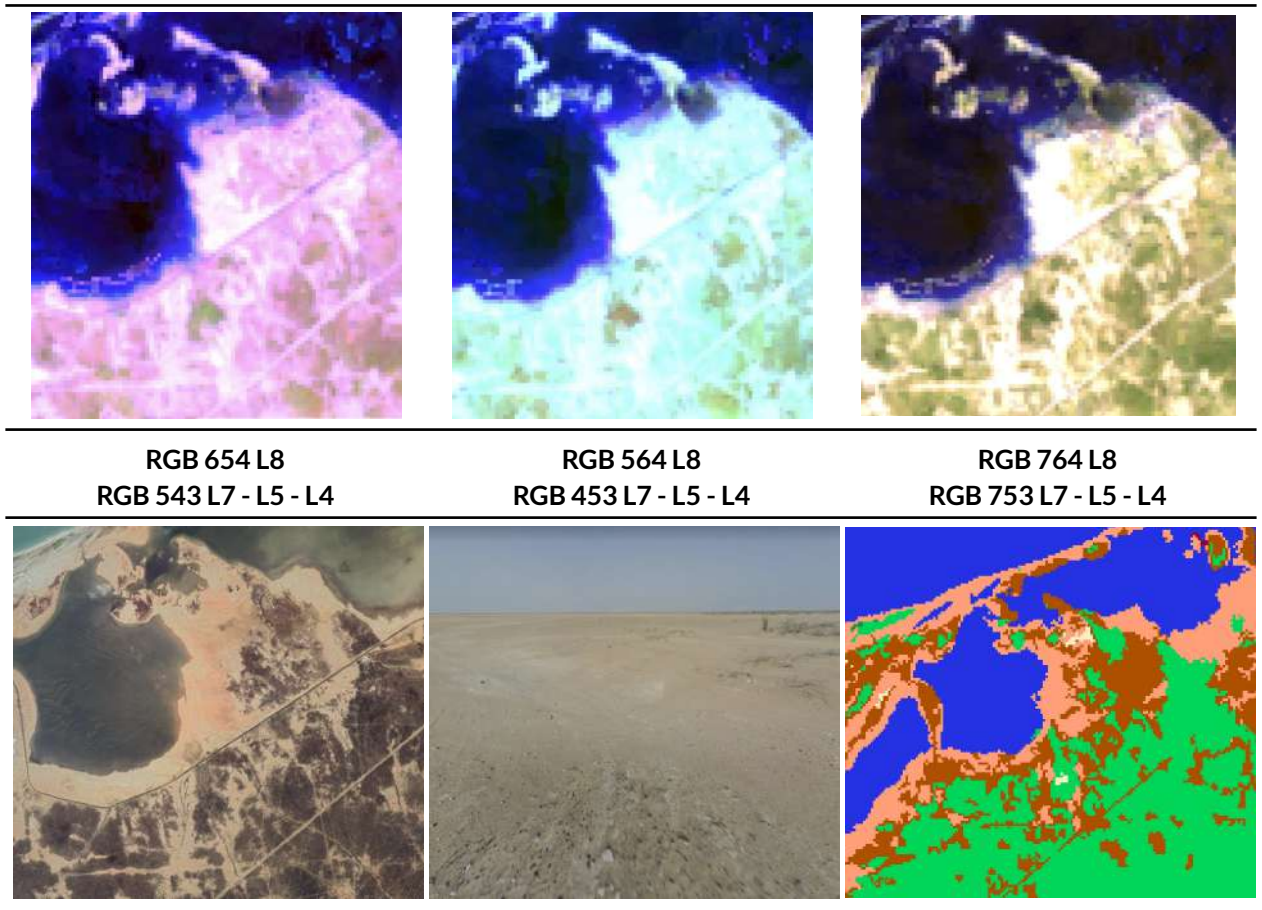


Figure 78. Spectral Response of the Beach, dune and sand spot in the Caribbean region.

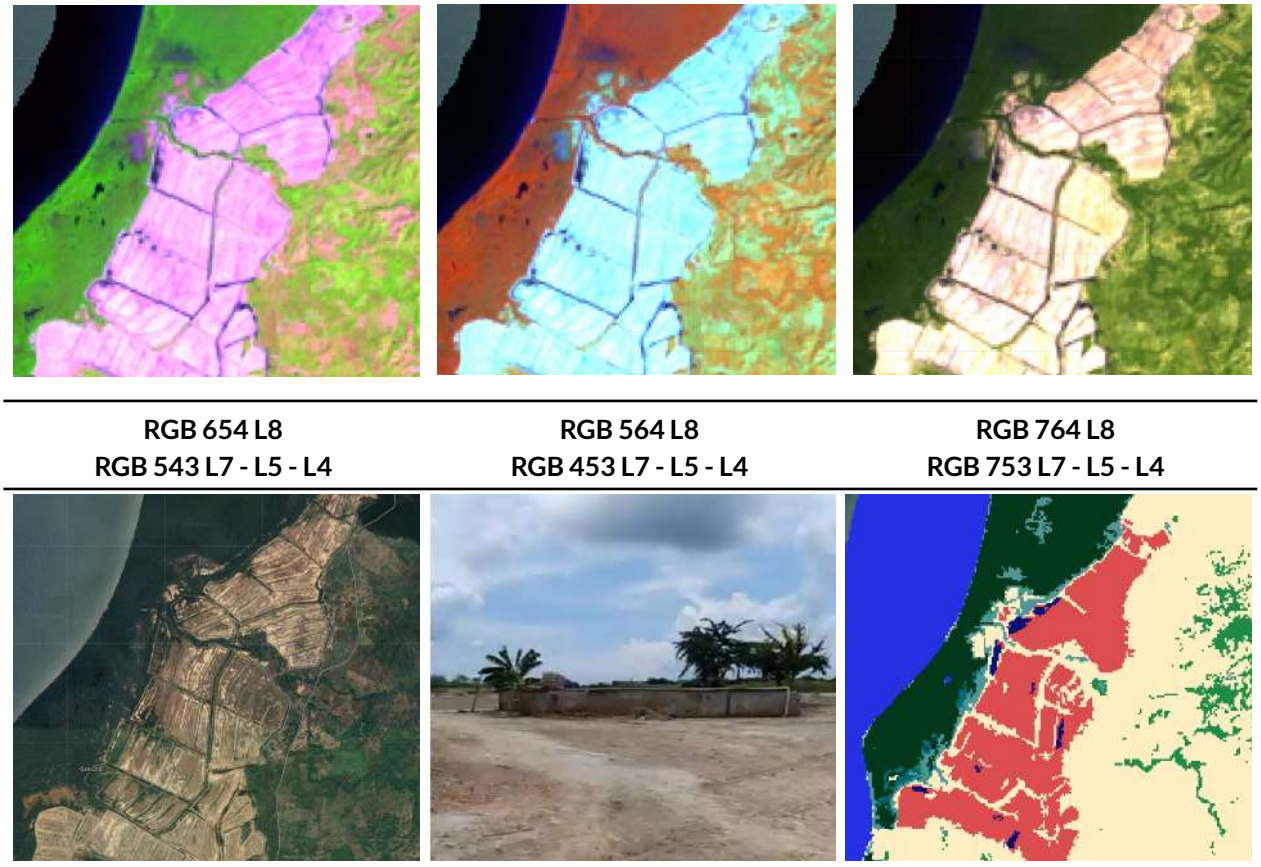
These covers occur in sandy and rocky soils located in the Upper Guajira area and the Sierra Nevada de Santa Marta, corresponding to desert or xerophytic formations with sparse vegetation (less than 20%) or areas completely devoid of it, where they form hills or dunes. They are also found in sandbanks formed from remnants of former mobile banks and abandoned meanders.

Their spectral response is very similar across the three band combinations shown in **Figure 78**, characterized by bright white pixels where vegetation is scarce. In the RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4) composites, lilac and pink hues can be observed at the edges, while

in RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4), light blue tones predominate. This class presents a fine texture and lacks a defined spatial pattern.

Other non vegetated areas (ID:25)

This class includes all anthropogenically disturbed areas (infrastructure, urban expansion, or mining) that are not mapped within their specific classes, as well as soils devoid of vegetation or with very sparse vegetation cover.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

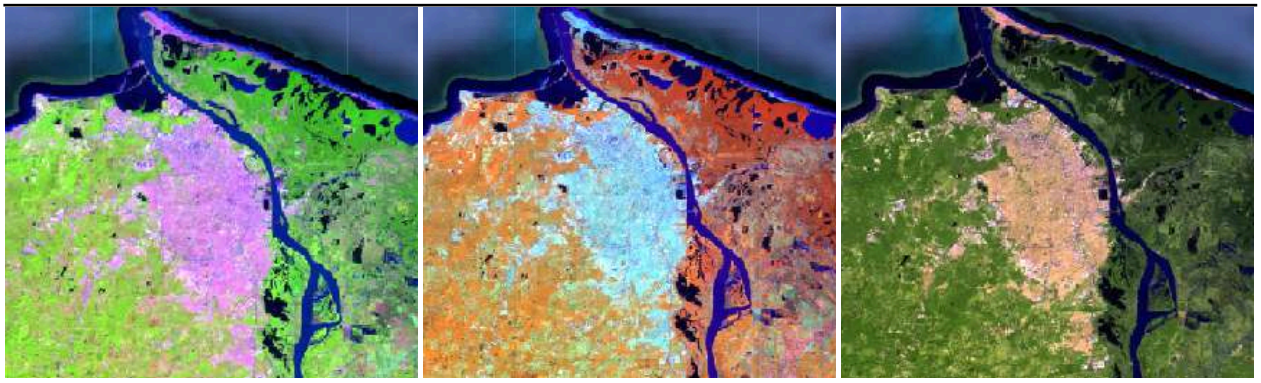
Location: San Onofre -Sucre, Scale: 200 m, Year: 2013, Coordinates: -75.56994 W, 9.93887 N,

Figure 79 Spectral Response of the Other non vegetated areas in the Caribbean region.

This category also includes burned areas, croplands under preparation or fallow, and areas previously used for aquaculture that have been abandoned, as exemplified in **Figure 79** by an area corresponding to a former shrimp farm. Regarding its spectral signature, the class is identified by light pink to magenta tones in the upper left image corresponding to the RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4) composites; light blue with greenish hues in RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4); and yellowish-cream tones in RGB 764 (Landsat 8) and RGB 753 (Landsat 7, 5, and 4). It presents a heterogeneous texture.

Infrastructure (ID:24)

As in the other biogeographic regions (Andean, Pacific, Orinoquia, and Amazon regions), this class encompasses structures and buildings associated with human settlements, such as urban centers (towns), road and railway networks and their adjoining lands, as well as other artificial areas including hydrocarbon exploitation sites, hydroelectric plants, military bases, airports, port zones, and non-agricultural green areas such as recreational facilities within cities, urban lawns, road medians, and unconventional airstrips in rural areas. Peripheral areas undergoing gradual urbanization processes for residential and/or industrial purposes are also included.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

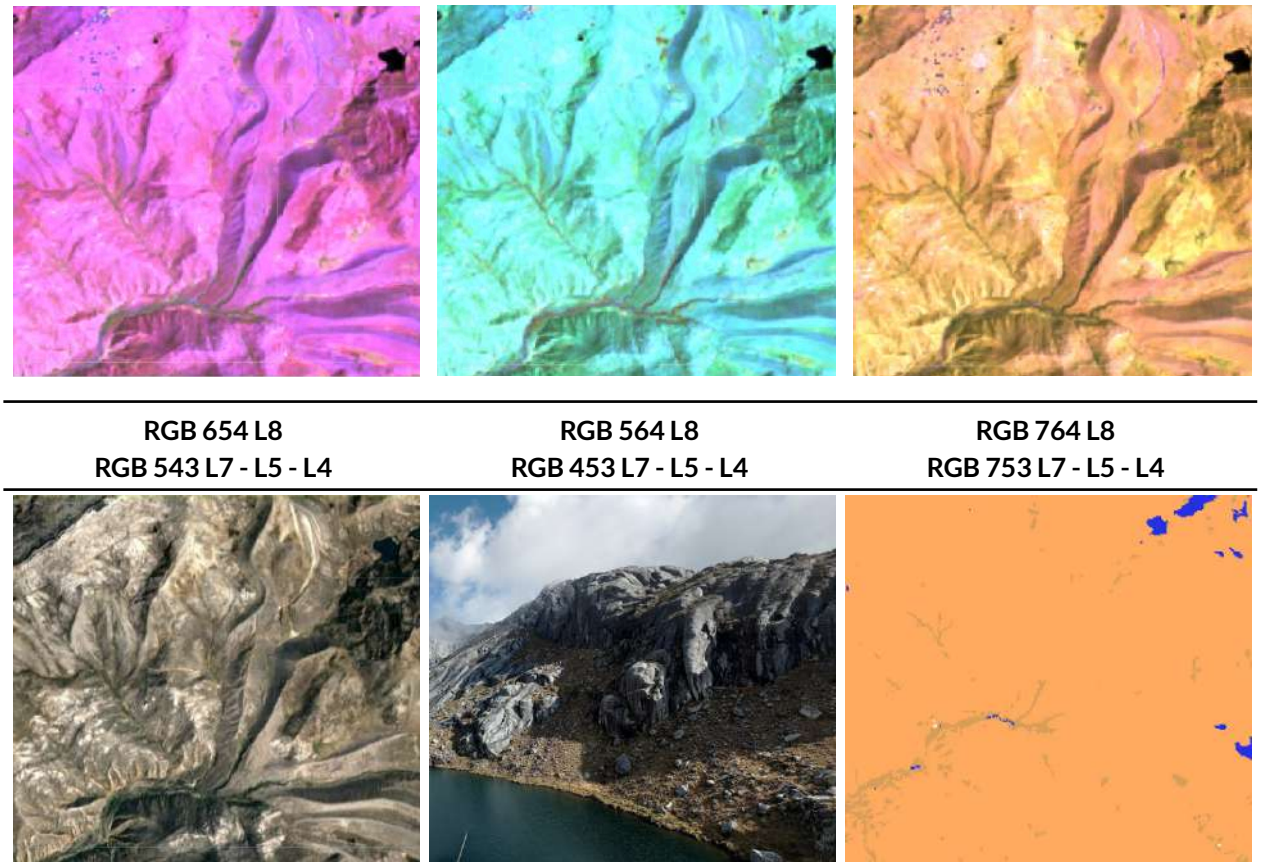
Location: Barranquilla - Atlántico, Scale: 2000 m, Year: 2021, Coordinates: -72.2377 W, 10.4525 N

Figure 80 Spectral Response of the Infrastructure class in the Caribbean region.

The covers within this class present a heterogeneous texture and a spectral response characterized by lavender to lilac tones in the RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4) composites, while in RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4), lighter colorations predominate, and in RGB 764 (Landsat 8) and RGB 753 (Landsat 7, 5, and 4) a yellowish-cream hue is observed.

Rock outcrop (ID:29)

This class corresponds to areas composed of exposed rock layers, where erosion processes have led to the exposure of bedrock, with low or null vegetation cover. These areas are generally located on steep slopes associated with mountain glaciers, volcanoes, faults, and geological deformations (IDEAM, 2010).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Ciénaga- Magdalena, Scale: 1000 m, Year: 2022, Coordinates: -73.877725 W, 10.862282 N

Figure 81 Spectral Response of the Rock outcrop in the Caribbean region.

With a slightly rough texture, the RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4) composites shown in Figure 80 display a violet spectral response. The RGB 564 (Landsat 8), RGB 453 (Landsat 7, 5, and 4), RGB 764 (Landsat 8), and RGB 753 (Landsat 7, 5, and 4) composites show bluish tones with light green, greenish-brown, or burnt yellow hues, respectively.

Mining (ID:30)

This class refers to areas where materials are extracted or accumulated from open-pit or alluvial mining activities, where soil exposure is evident. It includes industrial, artisanal, riverine, and

illegal mining. Likewise, it encompasses areas used for material extraction (sand pits, gravel pits, and quarries), and zones for coal, gold, and other mineral exploitation (IDEAM, 2010). According to Diaz et al. (2017), mining in the Colombian Caribbean is mainly focused on two products: coal—one of the main economic activities in the departments of Cesar and La Guajira—and ferronickel.

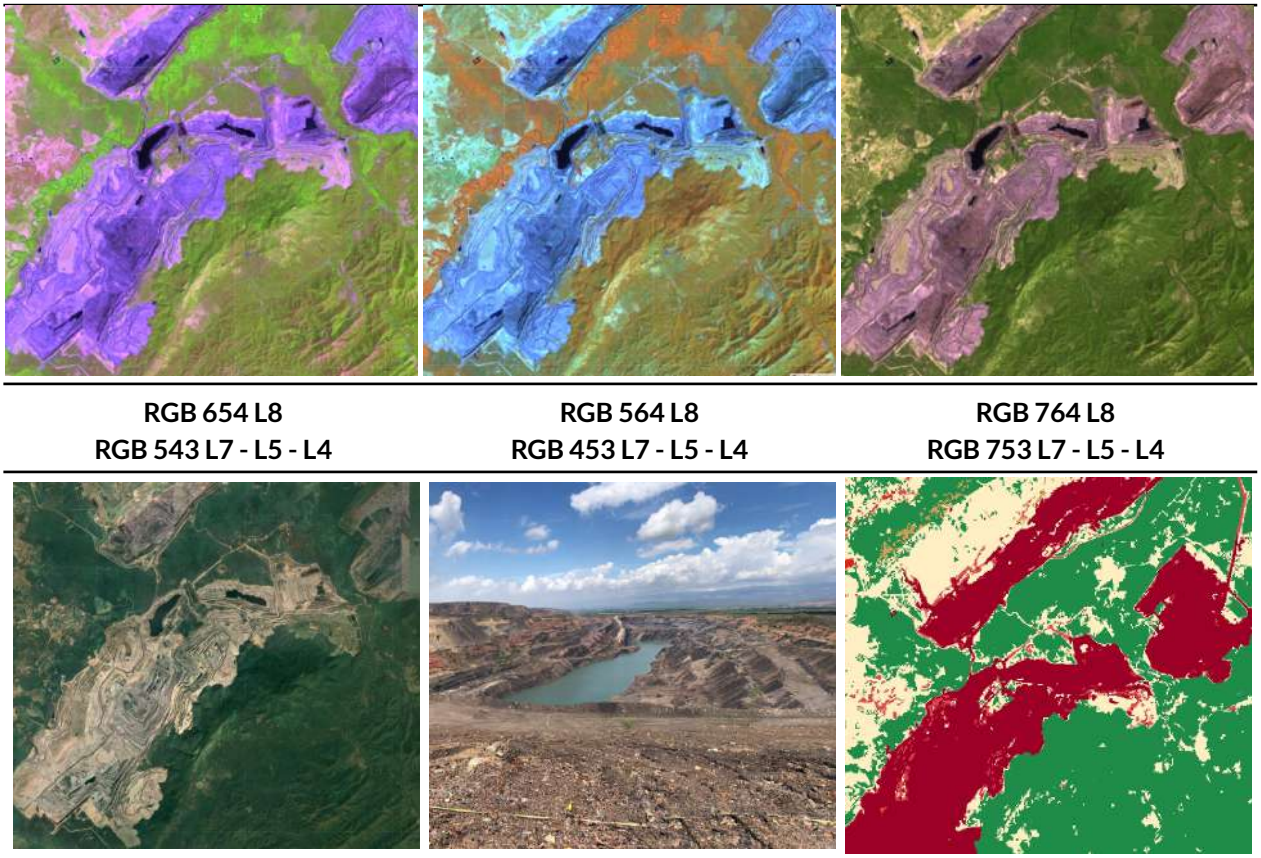


Figure 82 Spectral Response of the Mining class in the Caribbean region.

In terms of its identification through the various band combinations used during mapping (as shown in **Figure 82**), this class exhibits dark purple to light violet tones in false color composites (RGB 654 Landsat 8 and RGB 543 Landsat 7, 5, and 4); deep indigo blue hues in RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4); and dark purple tones in RGB 764 (Landsat 8) and RGB 753 (Landsat 7, 5, and 4). In quarries and some gold mining areas, the spectral response resembles that of Class 25 ("Other non vegetated area"), but differs in the satellite imagery due to the distinctive terraced or stepped exploitation patterns and the presence of "mining ponds."

Aquaculture (ID:31)

This class includes all artificial water bodies dedicated to the breeding of crustaceans, shrimp, and freshwater or saltwater fish. This cover type is composed of a series of adjacent ponds, characterized by a regular geometric pattern.

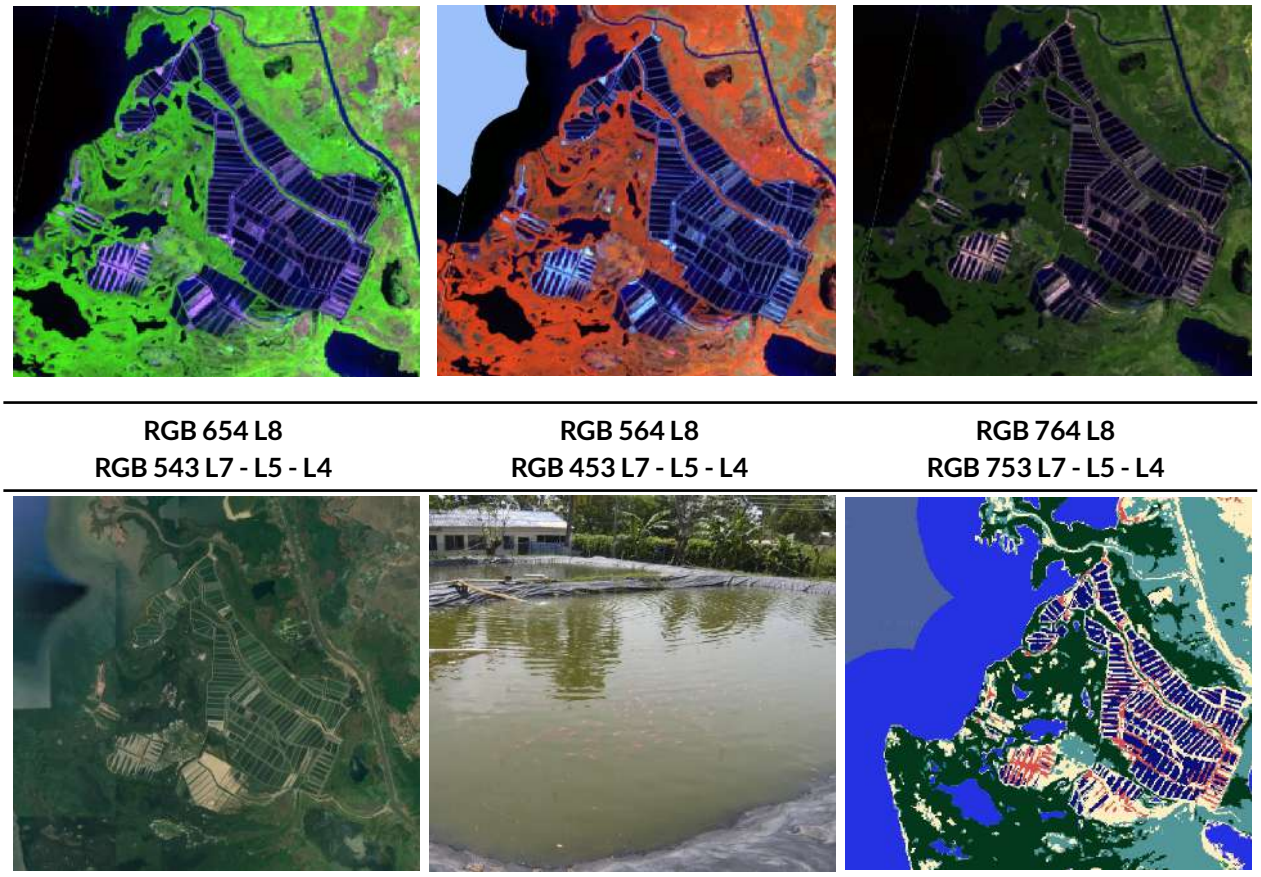


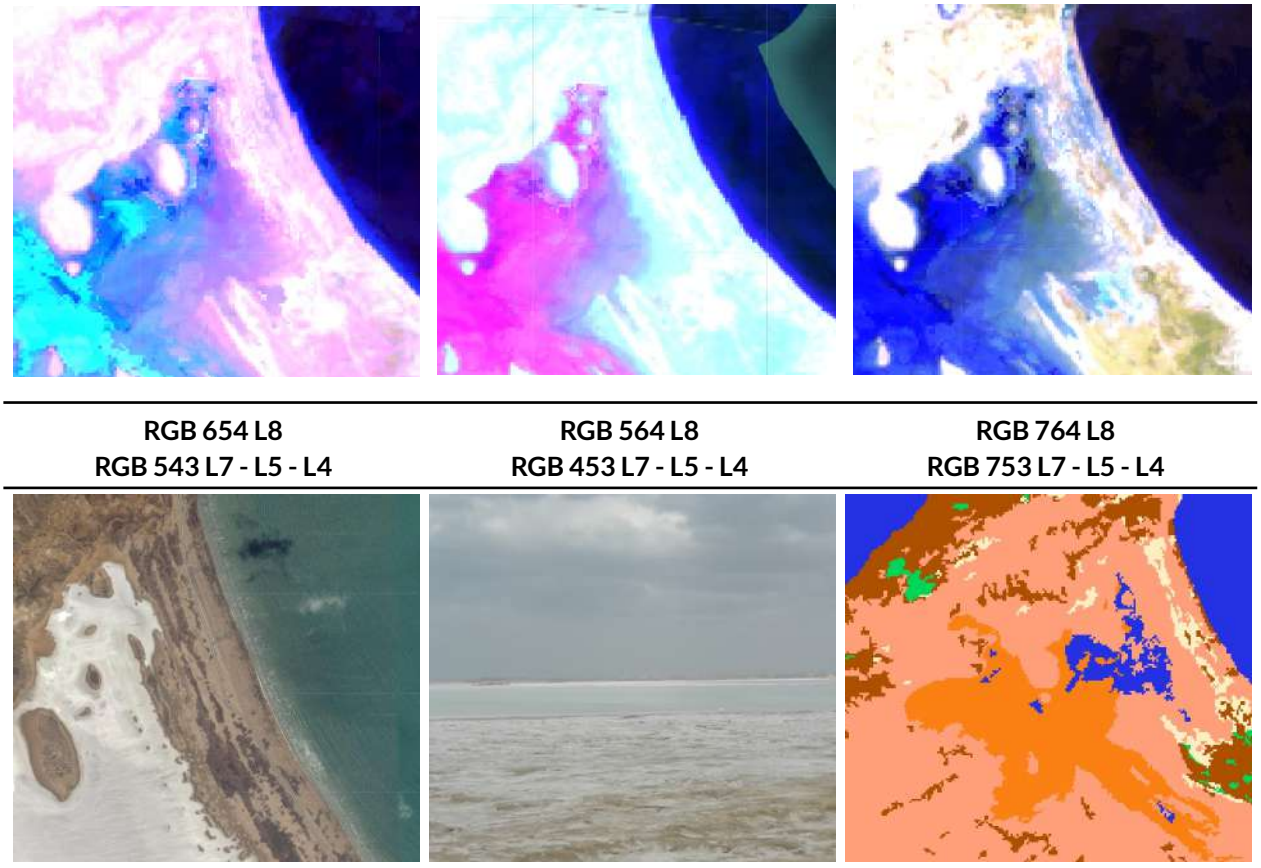
Figure 83 Spectral Response of the Aquaculture in the Caribbean region.

This class presents a high degree of similarity in its spectral response when compared to Class 33 ("River, Lake and Ocean"). In both cases, the color tones across the three band combinations used range from dark blue to black, with a fine and homogeneous texture. However, aquaculture areas can be clearly distinguished by the visible boundaries between ponds.

Hypersaline tidal flat (ID:32)

Stationary natural cover characterized by the accumulation of salts resulting from seawater evaporation and/or infiltration processes. It may be either disturbed or undisturbed; in the former case, disturbance occurs through land parceling without reaching an industrial-scale extractive process. Climatically, these areas occur under arid or semi-arid conditions, which favor their active

state. Due to their composition, they host extremophile microorganisms capable of surviving in high-salinity environments. (Torres, 2003).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Uribia - La Guajira, Scale: 100 m, Year: 2021, Coordinates: -71.83909 W, 12.32699 N

Figure 84 Spectral response of the Hypersaline Tidal Flat in the Caribbean region.

Hypersaline tidal flats display a fine, smooth, and homogeneous texture with a distinctive spectral response. In RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4 configurations, they appear in light royal blue to cyan blue tones with lilac hues. In RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, they show fuchsia and light purple tones with light blue nuances. In RGB 764 Landsat 8, the coloration is cobalt blue with some areas of grayish green, and similarly for RGB 753 in Landsat 7, Landsat 5, and Landsat 4 (**Figure 84**).

River, lake or ocean (ID:33)

This class includes all permanent or seasonal surface water bodies, either naturally formed or anthropogenic, generally for energy production or water supply purposes. It encompasses rivers, lakes, lagoons, oceans, seas, reservoirs, swamps, canals, and ponds (IDEAM, 2010).

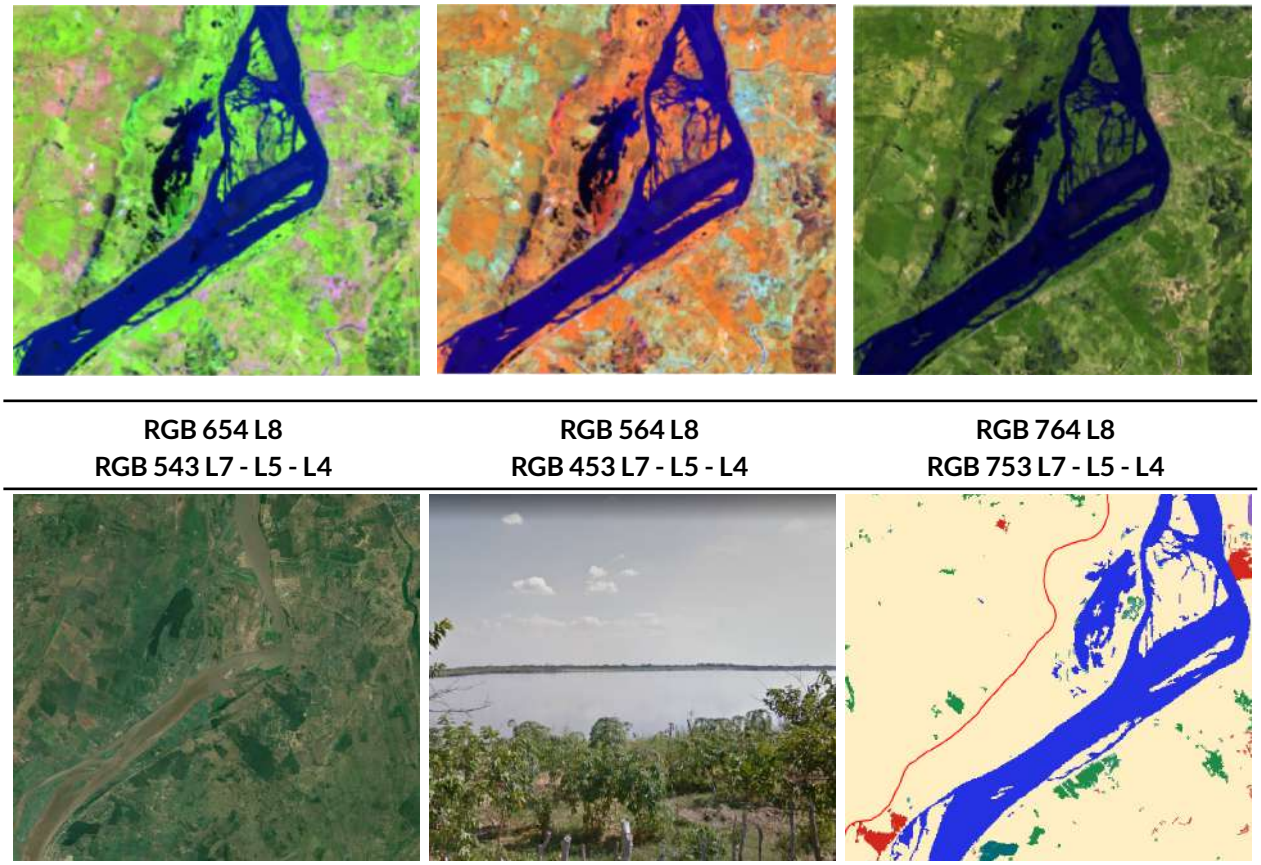
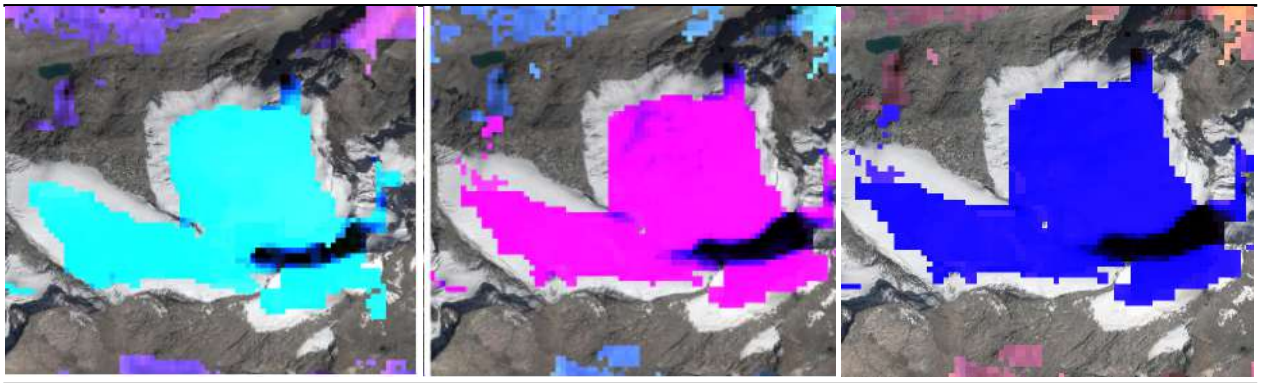


Figure 85 Spectral response of the River, lake or ocean in the Caribbean region.

This class exhibits a fine and smooth texture. The color tones appear in the dark blue range across all band combinations (RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4; RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4; RGB 764 Landsat 8 and 753 in Landsat 7, Landsat 5, and Landsat 4). Variations in tone correspond to differences in suspended particle load, such as sediments and organic matter (Fundación Gaia Amazonas, 2022).

Glacier (ID:34)

This class represents areas covered by permanent ice masses and/or constant snow in accumulation or ablation zones (Serrano & Gonzalez, 2004). In the Caribbean region, these areas occur at the summits of the Sierra Nevada de Santa Marta, descending between 5100 and 4900 m a.s.l., surrounded by rocky outcrops and small glacial lakes formed over time by melting processes. These glaciers are predominantly located on the southern slopes of the mountain range, where the gradient favors snow accumulation (IDEAM, 2012).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

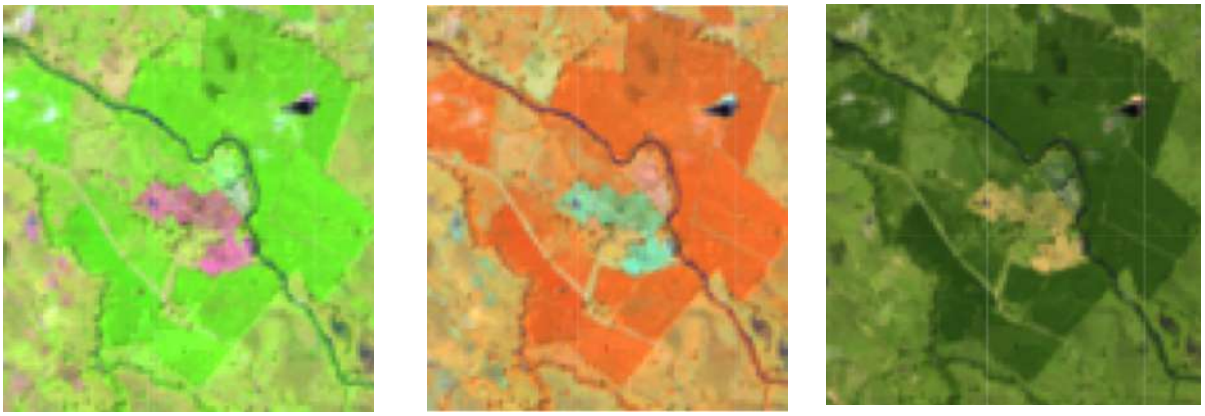
Location: Sierra Nevada de Santa Marta, Scale: 200 m, Year: 2022, Coordinates: -73.71262 W, 10.84418 N

Figure 86 Spectral response of the Glacier in the Caribbean region.

Glacial ice, representing the permanent ice cover, displays vivid color tones and a fine, homogeneous texture. In contrast, snow layers exhibit misty textures with bluish hues, marking the transition to adjacent zones dominated by rocky outcrops. In RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4 combinations, the pixels appear cyan blue; in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 they appear fuchsia with purple hues; and in RGB 764 Landsat 8 and 753 in Landsat 7, Landsat 5, and Landsat 4, they appear royal blue (**Figure 86**).

Palm oil (ID:35)

This class includes extensive areas of plantations with symmetrical and regular patterns of palm oil (*Elaeis guineensis*), either transient or permanent. These plantations are significantly larger than traditional crops and are developed on an industrial scale. They thrive in volcanic, alluvial, and marine clay soils located in lowlands (below 500 m a.s.l.), characterized by good permeability and drainage (Aguilera, 2002).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: San Alberto - Cesar, Scale: 200 m, Year: 2022, Coordinates: -73.56295 W, 7.72705 N

Figure 87 Spectral response of the Palm oil in the Caribbean region..

Oil palm plantations exhibit a homogeneous and smooth texture. In satellite imagery, the star-shaped crown structure and planting rows are distinguishable, along with a characteristic bright reflectance in Landsat images. In RGB 654 Landsat 8 and 543 Landsat 7, Landsat 5, and Landsat 4 combinations, the color tones are bright green (almost neon); in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, they show vivid colors with orange hues; and in RGB 764 Landsat 8 and 753 in Landsat 7, Landsat 5, and Landsat 4, they appear pine green (**Figure 87**).

Wooded sand vegetation (ID: 49)

Sub-xerophytic forest formations located below 800 m a.s.l. on sandy soils, mainly corresponding to the very dry and arid xerophytic ecosystems of La Guajira, within temperature ranges exceeding 24°C. They are characterized by sclerophyllous vegetation with hard, deciduous leaves (MEC, 2017; IDEAM, 2010).This class encompasses the semi-desert scrublands of La Guajira, dominated

by low-stature vegetation with sparse, scattered elements and deciduous foliage; thorny shrubs not exceeding 5 m in height with open canopies; and stunted forests reaching up to 8 m, where genera such as *Opuntia*, *Prosopis*, and *Erythrina* are prominent (Rangel, 2012).

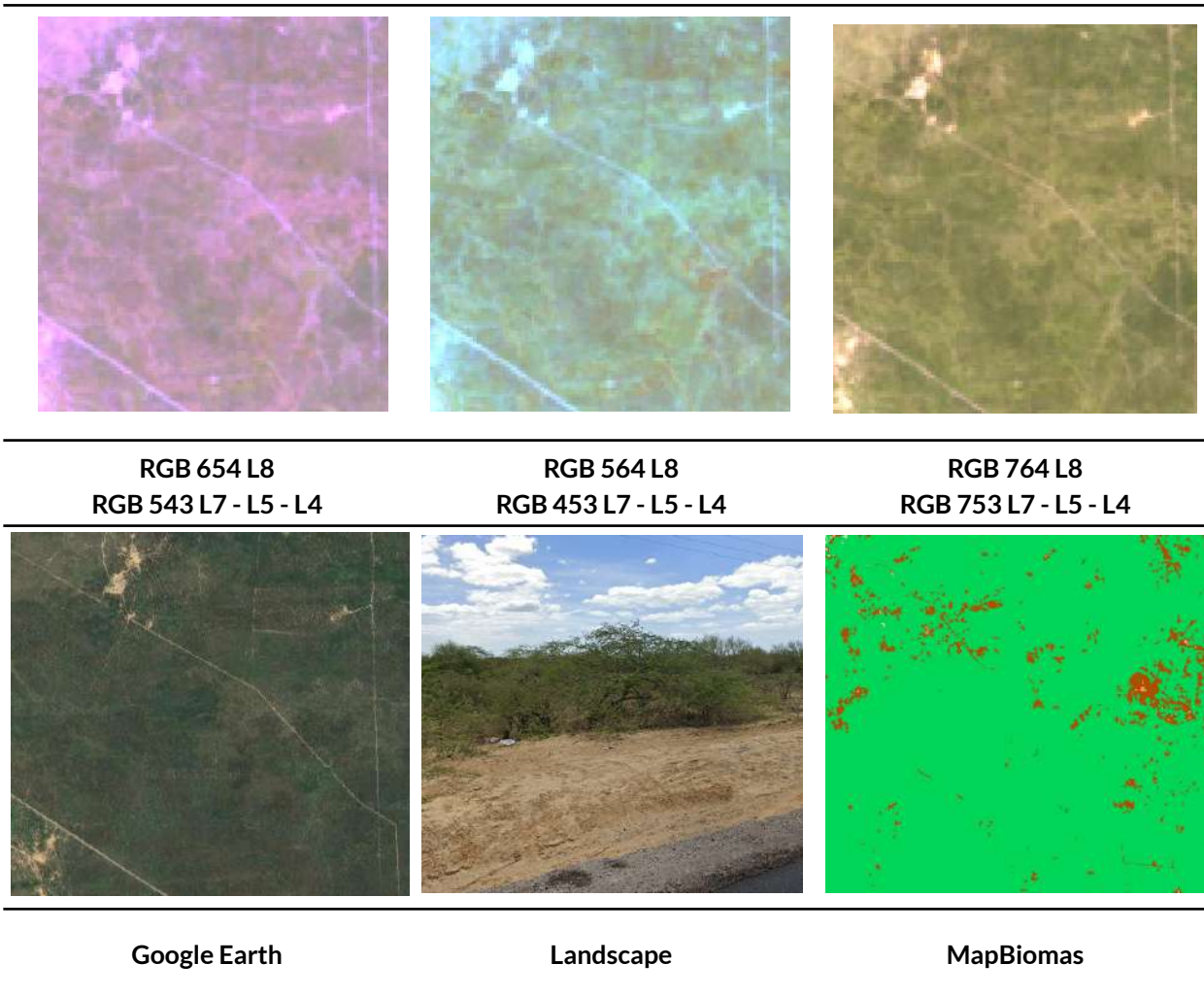


Figure 88 Spectral Response of the Wooded sand vegetation in the Caribbean Region.

In false color composites, this cover displays lilac tones with gray to dark green hues. In the RGB 564 (Landsat 8) and RGB 453 (Landsat 7, 5, and 4) combinations, its spectral response is characterized by brown to jade green shades with light blue tinges. In true-color composites, the pixels exhibit pale to grayish-green tones. The texture is fine and heterogeneous.

Herbaceous sand vegetation (ID: 50)

Herbaceous vegetation located below 800 m a.s.l. in arid and very dry environments, predominantly in the upper and middle Guajira, within temperature ranges above 24°C (MEC, 2017; IDEAM, 2010). This class includes low-lying herbaceous strata developed on sandy soils, low

succulent vegetation with occasional scattered trees, open and sparse prostrate shrublands, and herbaceous communities with poor ground cover (Rangel, 2012).

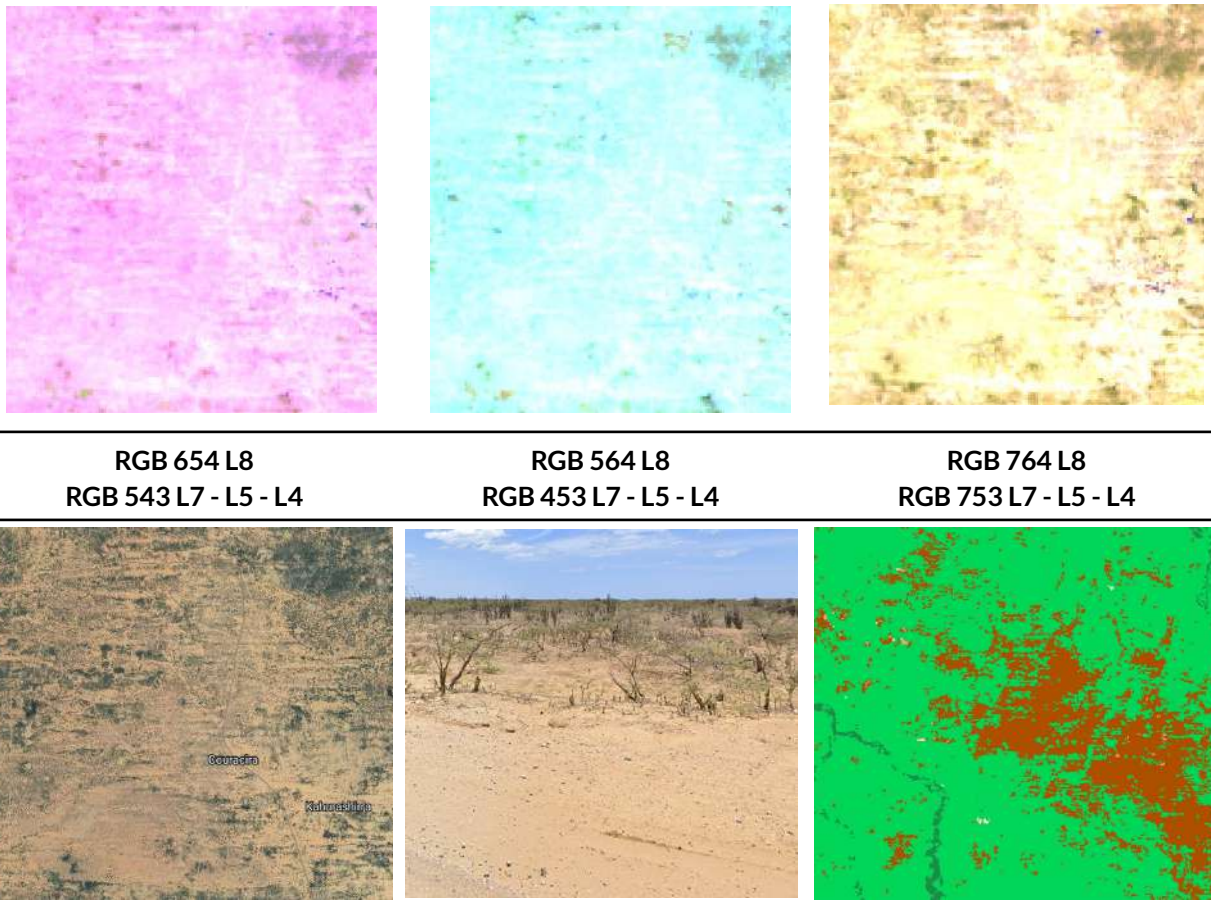
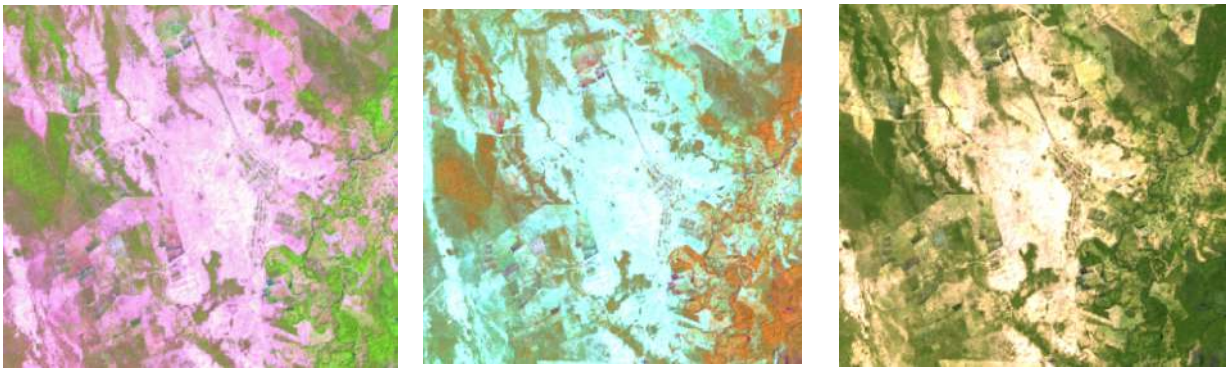


Figure 89 Spectral Response of the Herbaceous sand vegetation in the Caribbean Region.

It exhibits a fine to medium, heterogeneous texture, with some dispersed white pixels due to the high reflectance of sandy soils. In RGB 654 (Landsat 8) and RGB 543 (Landsat 7, 5, and 4) combinations, pale pink colorations are observed; light blue tones in RGB 564 (L8) and RGB 453 (L7–L5–L4); and pastel or cream yellow tones in RGB 764 (L8) and RGB 753 (L7–L5–L4) (**Figure 89**).

Other natural non vegetated area (ID: 68)

Includes areas devoid of vegetation or with very sparse plant cover, resulting from natural erosive processes or other natural phenomena.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

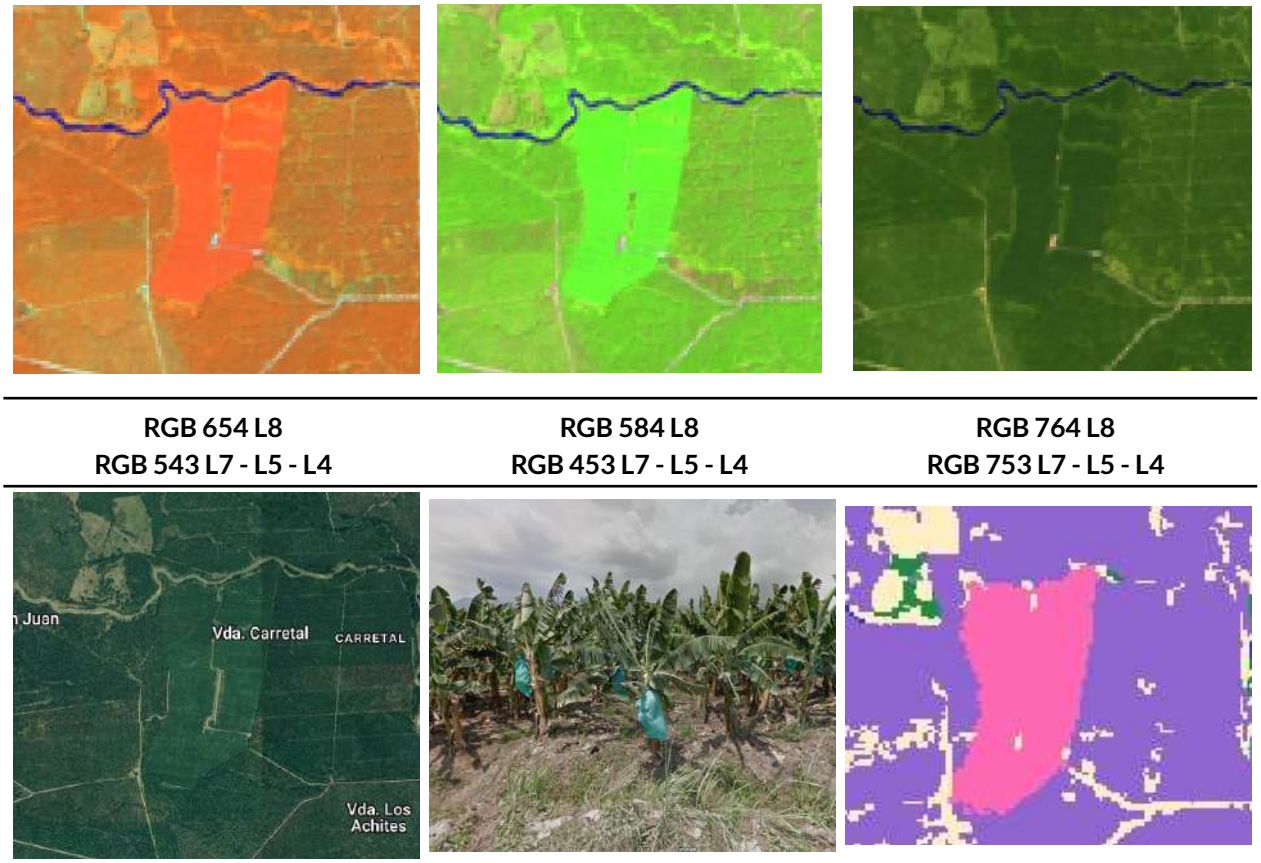
Location: Via Los Venados Guaimaral – Cesar, Scale: 500 m, Year: 2021,
Coordinates: -71.83909 W, 12.32699 N

Figure 90 Spectral Response of Other natural non vegetated area in the Caribbean Region.

It shows a fine, homogeneous texture, with pixels of similar tones grouped into patches associated with mountain slopes. In RGB 654 (L8) and RGB 543 (L7–L5–L4), intense pink hues are observed; cyan tones appear in RGB 564 (L8) and RGB 453 (L7–L5–L4); and very light yellow coloration predominates in RGB 764 (L8) and RGB 753 (L7–L5–L4) (**Figure 90**).

Banana (ID: 74)

Area dedicated to intensive and technified cultivation of *Musa* species, primarily banana (*Musa spp.*), established under large-scale agricultural systems for commercial purposes. This land cover class represents areas continuously occupied by perennial plantations, managed in a specialized and sustained manner over time.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 584 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

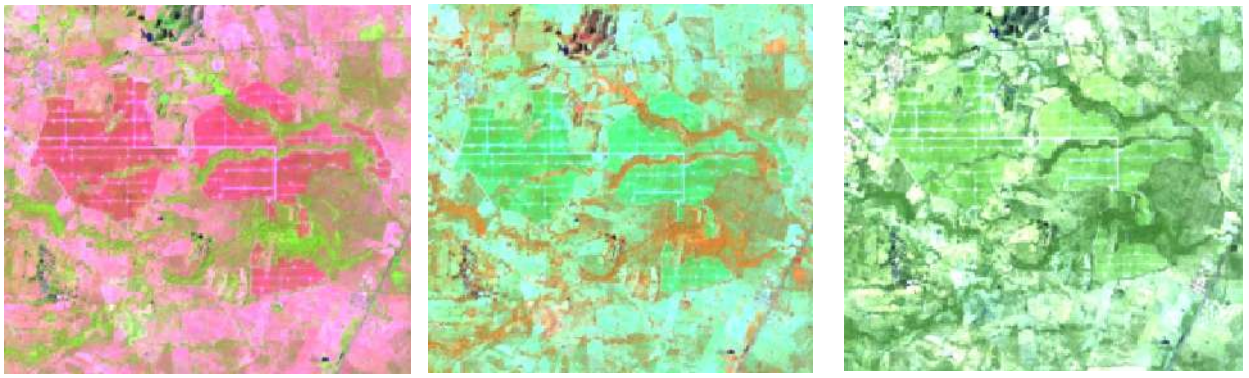
Location: Cienaga- Magdalena, Escala: 1000 m, Año: 2023, Coordenada: -74.1935W, 10.97068N

Figure 91 Spectral Response of Banana in the Caribbean Region

This class is identified by high vegetation density, regular crop distribution, and persistent cover over several years without evident rotation, as well as distinctive tonalities in various RGB combinations. In **Figure 91**, magenta colors appear in RGB 654 (L8) and RGB 543 (L7–L5–L4), intense reddish tones in RGB 564 (L8), and vivid green hues in RGB 453 (L7–L5–L4). The texture is homogeneous, with low internal variability, associated with the ordered layout of the plantations.

Solar panel farm (ID: 75)

Includes areas occupied by facilities for solar energy generation, characterized by modular structures (solar panels) arranged in a regular pattern, typically over flat, cleared surfaces. These areas have a clearly defined anthropogenic origin and are not confused with other types of urban or industrial infrastructure.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 584 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Ponedera – Atlántico, Scale: 1000 m, Year: 2024, Coordinates: -74.80166 W, 10.61049 N

Figure 92 Spectral Response of Solar panel farm in the Caribbean Region.

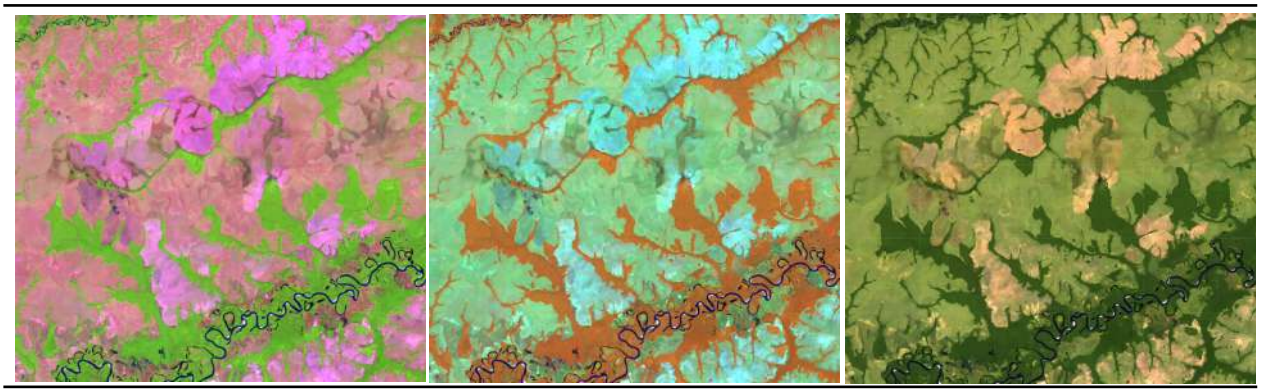
They are identified by their regular geometric pattern and distinctive tonalities across RGB combinations. In **Figure 92**, magenta colors are observed in RGB 654 (L8) and RGB 543 (L7–L5–L4); grayish or cyan tones in RGB 564 (L8) and RGB 453 (L7–L5–L4); and greenish to bluish-violet hues in RGB 764 (L8) and RGB 753 (L7–L5–L4). The texture is homogeneous, with low internal variability, associated with the ordered arrangement of the solar modules.

4.4.3.4 Orinoquin region legend

Forests formation (ID:3)

Natural land cover consisting mainly of arboreal elements, with the presence of some natural palm associations, which form a more or less regular canopy of more than 5 m in height. In a large part of the region, this cover is found bordering the natural savannas of the Orinoco, following the course of rivers and natural drainages. It includes terra firme gallery forests, low and high dense forests,

and secondary vegetation in an advanced state of succession, where part of its attributes have already been recovered. (IDEAM, 2010,IDEAM, IGAC e Instituto Humboldt, 2017).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Cumaribo - Vichada, Year: 2023, Scale: 1000 m, Coordinates: -68.3183 W, 5.1058 N.

Figure 93 Spectral Response of Forests formation in the Orinoquia Region.

This natural formation, in the RGB 654 band combination, shows reflectance in intense green tones with slight light brown hues and a mixed texture. In savanna areas, these formations can be distinguished because they are associated with water margins and contrast with the tones of the herbaceous formation. In the RGB 564 band combination, they usually display dull orange tones with faint reddish or reddish-green hues, maintaining the same heterogeneous texture. In the RGB 764 band combination, they exhibit strong dark green shades with olive-green nuances. Likewise, in this visualization, the contrast with the herbaceous formation is reflected in the intensity of the greens and the texture.

Flooded forests (ID:6)

Coverage present along most riverbanks, where tree vegetation taller than 3 meters can be observed. It is characterized by being established near river and stream channels. These are

known as gallery forests, although not all gallery forests are necessarily floodable. Likewise, plant associations such as morichales can also be found within these floodplain formations.

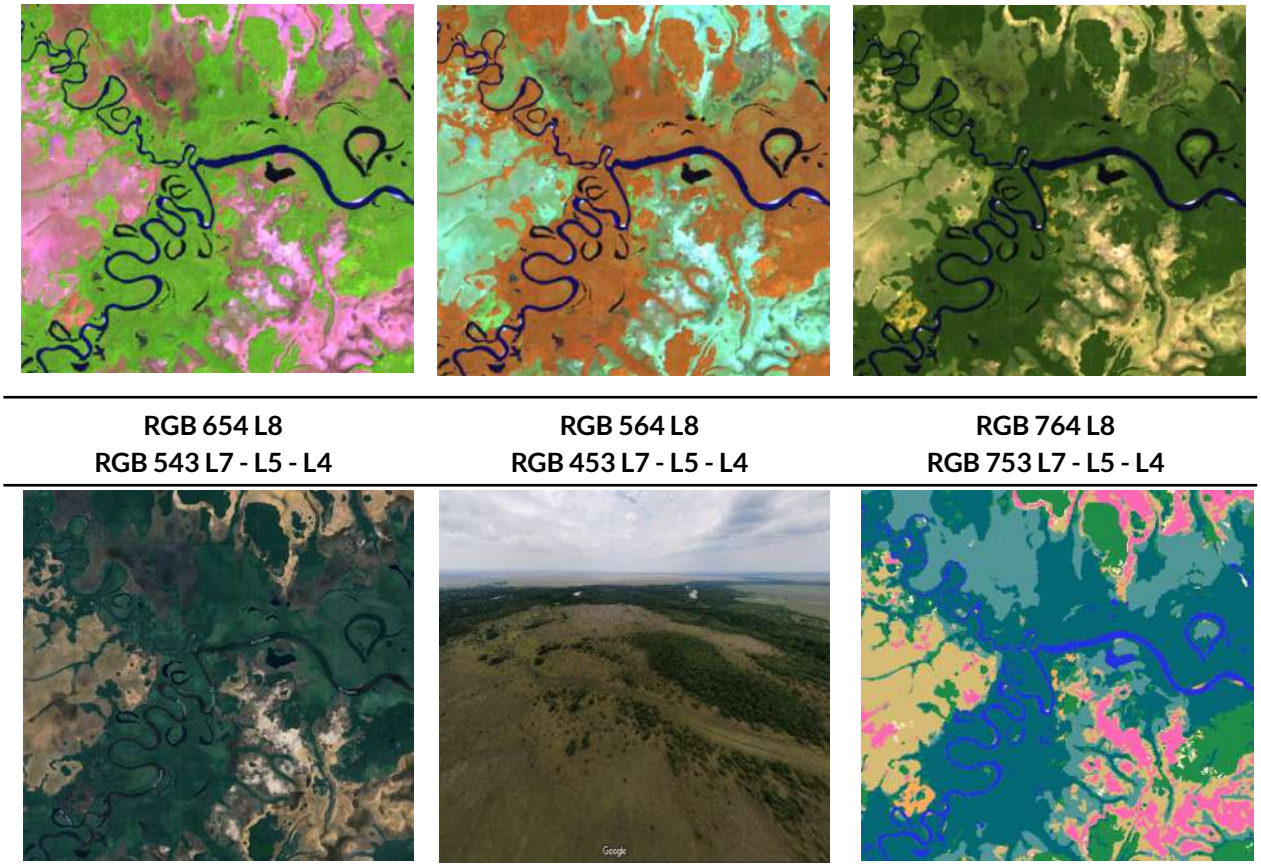


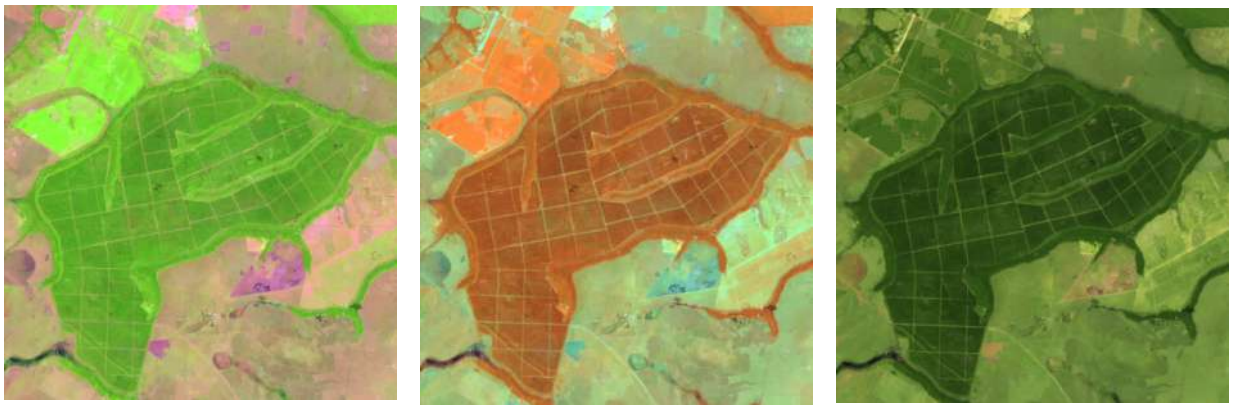
Figure 94 Spectral Response of Flooded Forests in the Orinoquia Region.

This natural formation, in the RGB 654 band combination, exhibits reflectance in opaque green tones with brown hues and a mixed texture. In savanna areas, it can be distinguished by its association with water margins. In the RGB 564 band combination, it usually displays opaque orange tones with slight opaque green or greenish-brown hues, maintaining the same heterogeneous matrix. In the RGB 764 band combination, it shows dark opaque green tones with pale yellowish-green shades.

This formation maintains a spectral response similar to that of forest cover; however, its transition is quite noticeable since the texture of this cover is finer compared to the roughness of class 3, as illustrated in **Figure 94**. The pattern corresponding to this cover is characterized by its association with the alluvial plains and valleys of rivers, forming elongated bands of varying widths, from narrow to wide, depending on the hydrographic network (Rincon et al., 2009).

Forest Plantation (ID:09)

These covers consist of tree vegetation plantations established through direct human intervention for forest management purposes. In this process, forest stands are created through planting and/or seeding during afforestation or reforestation activities for timber production (commercial plantations). In satellite imagery, this cover displays a regular geometric pattern formed by rows of trees, generally of the same age. In the Orinoquia region, Vichada is the department with the largest planted area, mainly with pine (*Pinus caribaea*) and acacia (*Acacia mangium*)(MADR, 2022), Most of these plantations are bordered by the region's gallery forests and are established in areas that were previously occupied by natural or improved pastures.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location:Cumaribo - Vichada,Year: 2023, Scale: 500 m, Coordinates: -70.9799 W, 4.64385 N.

Figure 95 Spectral Response of Forest Plantations in the Orinoquia Region

The reflectance of this type of formation tends to vary depending on the stage of establishment of the forest plantation, as well as on whether the cultivated species are coniferous or broad-leaved. Its identification is usually facilitated by the geometric patterns present in the formation (lines or grids), which are generally arranged in rectangular or square shapes.

In the early stages of the plantation, in the RGB 654 band combination, it displays light green tones with some yellowish hues. In the RGB 564 combination, it appears in soft red tones with some opaque aquamarine-green hues, while in the RGB 764 combination, it tends to show slightly dark green tones with pale yellow shades.

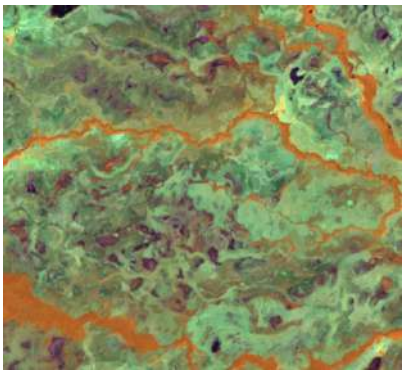
Once the plantation is fully established, in the RGB 654 band combination, it exhibits intense green tones that may appear slightly dark; in the RGB 564 combination, it shows intense orange-red tones; and in the RGB 764 combination, it appears as strong dark green tones. In general, it maintains a uniform texture once established. In some cases, particularly with native species, its reflectance may closely resemble that of natural forest formations, displaying a coarse and uniform texture.

Wetland (ID:11)

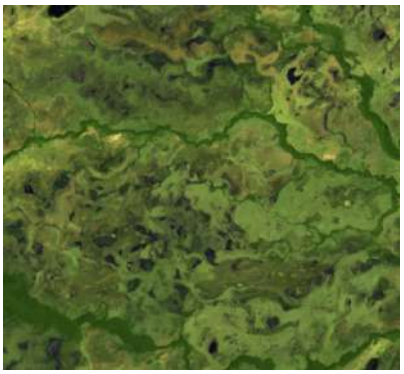
Herbaceous vegetation, mostly grasses, subject to permanent or temporary flooding (at least once a year) according to natural flood pulses, generally located in low areas, which may be constituted by watercourse diversion zones, flood plains, old diversion meadows and natural depressions where the water table rises permanently or seasonally. It may present some scattered arboreal and/or shrubby elements. (IDEAM,2010, Fundación Gaia Amazonas, 2022).

This natural formation, in the RGB 654 band combination, shows opaque pink tones within which opaque green and cyan hues can be observed, along with grayish and moderately muted purple tones, depending on the level of flooding of the cover. In the RGB 564 band combination, it displays darker aquamarine-green tones with grayish and pale bluish-green shades. In the RGB 764 combination, it appears in opaque olive-green tones with yellowish and light brown hues. The texture of this formation is generally coarse, and areas of water accumulation can be observed, displaying soft grayish and light blue tones.

RGB 654 L8
RGB 543 L7 - L5 - L4



RGB 564 L8
RGB 453 L7 - L5 - L4



RGB 764 L8
RGB 753 L7 - L5 - L4

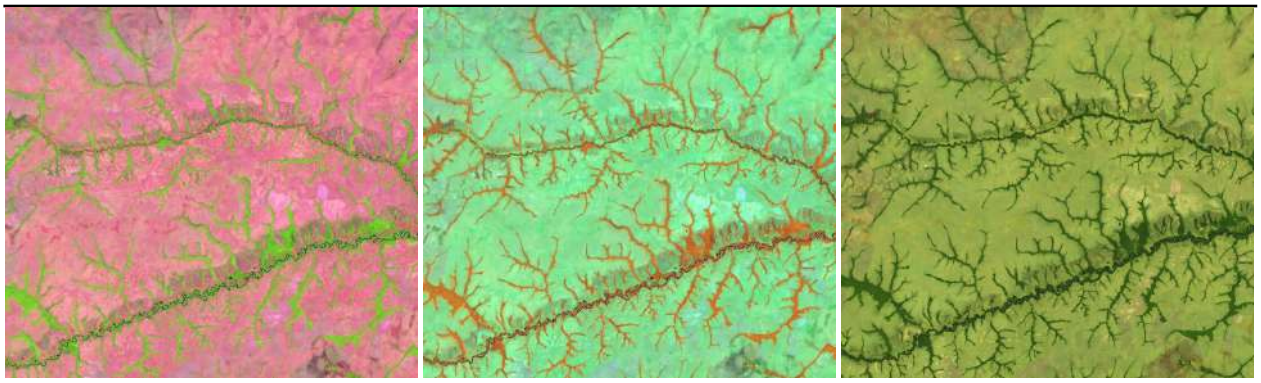
Google Earth	Landscape	MapBiomas

Location: Paz de Ariporo, Casanare, Year: 2023, Scale: 500 m, Coordinates: -70.4163 W 5.9446 N

Figure 96 Spectral Response of Wetland in the Orinoquia Region.

Grassland (ID:12)

Geomorphologically flat land covered by natural vegetation, mainly grasses and subxerophytic species, with abundant shrubs and few or scattered trees. In the Colombian Orinoquia, this vegetation type characterizes the savanna ecosystem, and its predominance reflects edaphic factors such as nutrient deficiency and high soil permeability, which favor rapid drying during the dry season and leaching during the rainy season.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

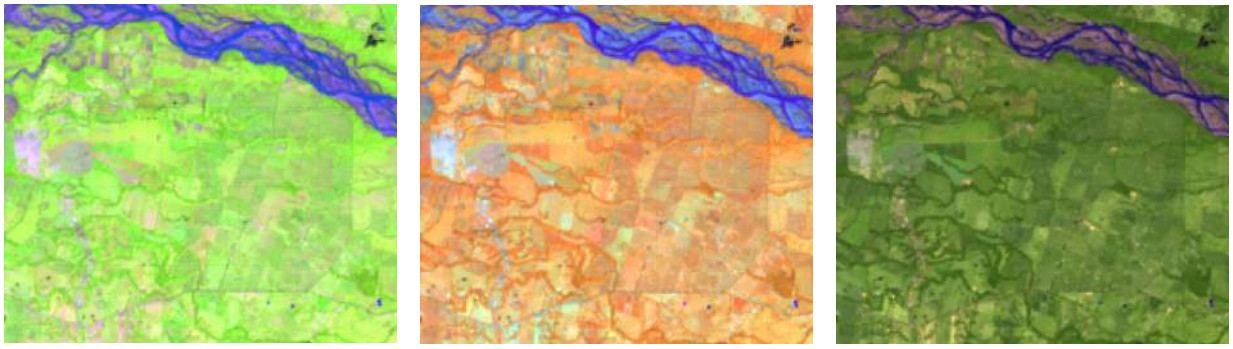
Location: Cumaribo, Vichada, Year: 2022, Scale: 2000 m, Coordinates: -68.4675 W, 5.2161 N.

Figure 97 Spectral Response of Grassland in the Orinoquia Region.

The continuity of this vegetation is interrupted by the presence of gallery forests that cover the courses of rivers and streams, as well as by grazing activities and periodic burns that serve a regenerative function for the savanna, these latter being evidence of the expansion of anthropogenic activities into these natural areas (Cuatrecasas, 1989). The spectral response of the herbaceous formation, in the RGB 654 band combination, appears in intense dark pink tones; in some cases, a few pixels with green hues can be observed scattered within the pink matrix, corresponding to isolated trees. In the RGB 564 band combination, it shows reflectance in dark aquamarine-green tones, with some red-toned pixels corresponding to isolated trees. In the RGB 764 band combination, it exhibits opaque yellowish-green tones with muted yellow shades, and some pixels in opaque olive-green tones, also corresponding to isolated trees. Overall, the formation presents a mixed texture and contrasts with the adjacent forest formation.

Mosaic of agriculture and pasture (ID:21)

In the Orinoquia region, this cover is mainly represented by a mosaic of temporary and permanent crops, along with a significant presence of pastures, which may sometimes be confused with grassland and flooded formations (classes 12 and 11). Agriculture is primarily associated with crops such as rice, corn, soybeans, cocoa, cassava, beans, citrus fruits, sugarcane, and small-scale family farming. The pasture mosaics mainly include clean, wooded, and weedy pastures, as well as natural grasslands, primarily used for livestock production activities such as extensive cattle ranching.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Villavicencio - Meta, Year: 2024, Scale: 500 m, Coordinates: -73.47174 W, 4.1310 N.

Figure 98 Spectral Response of Mosaic of agriculture and pasture in the Orinoquia Region

In some cases, these activities are rotated depending on the level of flooding in the natural grasslands found in the region. Therefore, this class is not static in certain areas and exhibits a wide range of tones due to different phenological stages and varied management practices. Its main characteristic is the regular or irregular geometric pattern of the plots (IDEAM,2018) (ADR,2019).

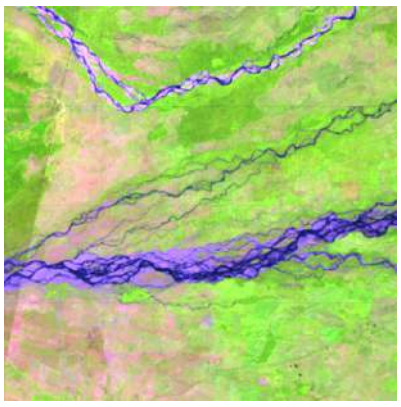
Among the anthropogenic classes, this one tends to be the most variable, as it depends on the growth stage of the crop or pasture, as well as the type of crop, which can produce a reflectance different from the rest of the matrix. In the RGB 654 band combination, it may display light pink, light green, or yellowish-green tones. In some cases, such as rice cultivation, it can show dark purple tones due to flooding stages or periods typical of this crop. Pastures generally exhibit bright green reflectance, while crops such as pineapple may appear in red or lilac tones. In the RGB 564 band combination, these areas often display yellow tones mixed with mint-green or soft orange shades. Orange tones with soft yellow hues can also appear. Rice crops reflect blue tones, sometimes with purple hues, while pastures show very bright mint-green or pale yellow tones. Pink shades with soft brown hues may also be detected.

In the RGB 764 band combination, green tones range from yellowish-green to intense green, with pale yellow hues also visible. In this combination, pastures generally show the least intense or softest greens. Overall, this formation presents fine and very uniform textures, characterized by rectangular or square geometries, often divided by live fences that exhibit reflectance similar to forest formations. These areas are typically found near urban centers in smaller patches, while in rural zones they cover large tracts of land.

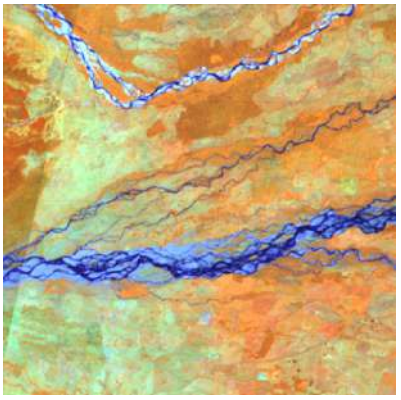
Beach, dune and sand spot (ID:23)

In the Orinoquia region, natural beaches and dunes are mainly found in flood zones, river valleys, mobile sandbanks, or abandoned meanders. These areas consist of sandy and rocky soils, and the cover usually hosts little to no vegetation, mainly small shrubs or weeds, with vegetation cover generally below 2%. Some of these areas show variations in shape or size over time, mainly due to the flooding dynamics of the rivers.

This natural formation, in the RGB 654 band combination, shows intense or medium purple tones, sometimes with vivid pink hues. In the RGB 564 combination, it displays light blue tones with grayish-blue shades, and in some cases, steel-blue tones can be observed. In the RGB 764 band combination, it presents opaque pink tones with muted purple hues, occasionally showing mauve-pink shades. This cover is usually found along river margins or riparian zones, as well as in river meanders and beaches. It is highly variable throughout the temporal series and is characterized by a medium texture, coarser in river beach areas and smoother in floodplain zones.



RGB 654 L8
RGB 543 L7 - L5 - L4



RGB 564 L8
RGB 453 L7 - L5 - L4

RGB 764 L8
RGB 753 L7 - L5 - L4

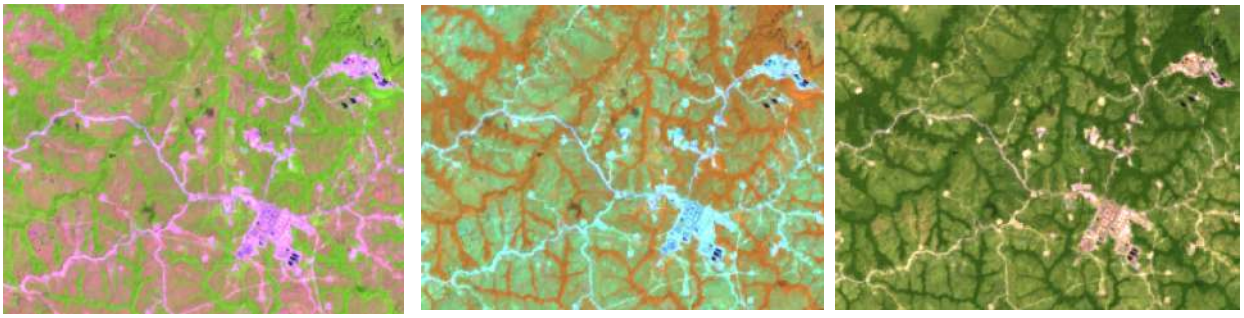
Google Earth	Landscape	MapBiomas

Location: Rio Casanare - Hato corozal, Casanare, Year: 2024, Scale: 1000m,
Coordinates: -71.74183 W, 6.19308 N.

Figure 99 Spectral Response of beach, dune and sand spot in Orinoquia Region.

Infrastructure (ID:24)

Human settlement areas associated with large and small urban centers (towns), featuring built-up infrastructure such as road and railway networks and associated lands. This class also includes other artificial areas such as hydrocarbon exploitation sites, hydroelectric plants, military bases, airports, port zones, and non-agricultural green areas, including recreational facilities, urban lawns, road dividers, and unconventional airstrips in rural zones. Peripheral areas undergoing a gradual urbanization process for residential and/or industrial purposes are also included.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Puerto Gaitán - Meta, Year: 2024, Scale: 500 m, Coordinates: -71.45086 W,3.78272 N.

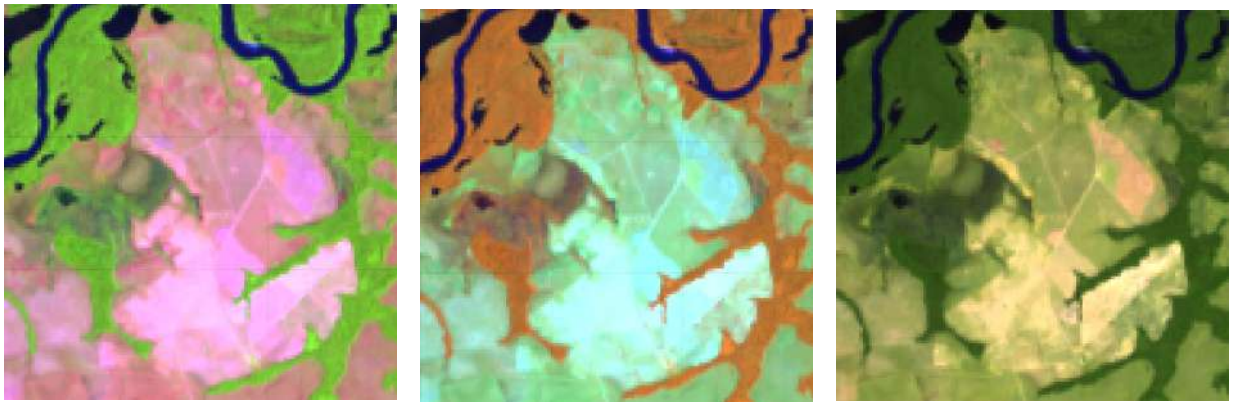
Figure 100 Spectral Response of Infrastructure in Orinoquia Region.

This anthropogenic formation, in the RGB 654 band combination, displays a matrix of magenta, pink, violet, lilac, and lavender tones. In the RGB 564 band combination, cyan-turquoise, sky blue, aqua, and aquamarine hues can be observed, while roads appear in indigo-blue tones. In the RGB 764 band combination, yellow ochre and bright yellow tones are evident, and roads tend to show mauve hues with brownish shades.

This cover is characterized by distinctive geometric patterns such as grids and straight lines associated with avenues and streets. It presents a coarse and heterogeneous texture, as well as mixed reflectance values, particularly in large urban centers.

Other non vegetated areas (ID:25)

Areas altered by anthropogenic activities (infrastructure, urban expansion, or mining) that are not mapped under their specific classes, as well as soils lacking vegetation or with sparse plant cover. This category also includes burned areas and croplands under preparation or fallow.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

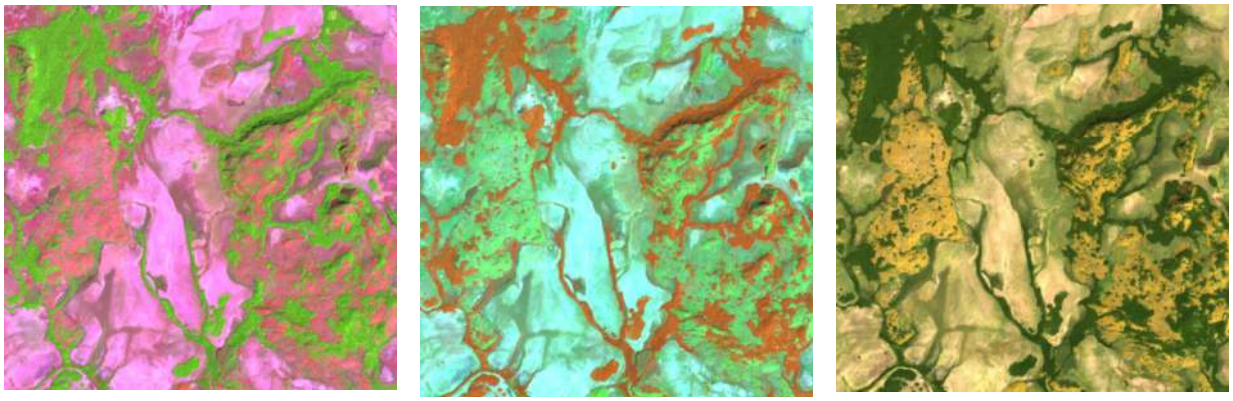
Location: Cumaribo - Vichada, Year: 2023, Scale: 200 m, Coordinates:-69.52735 W, 4.92194 N.

Figure 101 Spectral Response of Other non vegetated areas in the Orinoquia Region.

This anthropogenic formation, in the RGB 654 band combination, displays a mixture of purple, mauve, violet, fandango, and violine tones. In the RGB 564 band combination, a mix of emerald green, teal green, petroleum green, Persian green, and some light blue hues can be observed. In the RGB 764 band combination, olive green, brown, caramel, dark brown, sepia, and coral tones are present. The texture of this cover tends to be coarse, with irregular geometries, and it is commonly found in areas with herbaceous formations or agricultural and pasture mosaics. This cover is highly dynamic throughout the temporal series; generally, pastures or crops are established after it, and vice versa. It is characterized by a medium texture when associated with vegetation burns, while sandy or bare areas tend to have a slightly finer texture.

Rocky outcrop (ID:29)

It corresponds to areas composed of exposed rock layers, where erosion processes and rainfall have caused the exposure of the bedrock, with low or no vegetation cover. These areas are generally located on steep slopes or rugged terrains. In the Orinoquia region, this cover is associated with the landscapes of hills and rocky outcrops of the Guayanes Shield. (IDEAM,2010) (Lopez et al., 2006).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

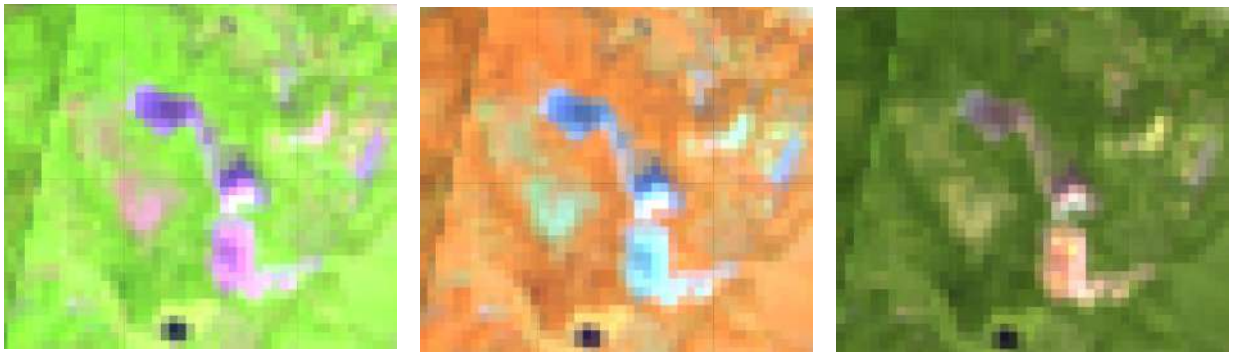
Location:Cumaribo - Vichada,Year: 2024, Scale: 1000 m, Coordinates: -67.59041 W, 5.56764 N.

Figure 102 Spectral response of Rocky outcrop in the Orinoquia Region.

This natural formation, in the RGB 654 band combination, exhibits shades of fuchsia and light to deep pink. In the RGB 564 combination, predominant tones include cyan green, mint green, and very light green. In the RGB 764 band combination, a mixture of golden yellow, sunflower yellow, and some ochre hues can be observed. This cover type is characterized by a medium texture and remains quite stable throughout the entire time series.

Mining (ID:30)

It comprises areas where materials are extracted or accumulated from open-pit or alluvial mining activities, with clear soil exposure. No distinction is made between industrial, artisanal, riparian, or illegal mining. This class includes areas dedicated to material extraction (sand pits, gravel pits, quarries) and zones for the exploitation of coal, gold, among others (IDEAM,2010). In the Orinoquia region, the departments of Meta and Casanare are the main crude oil producers, primarily in the municipalities of Acacias and Puerto Gaitan.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

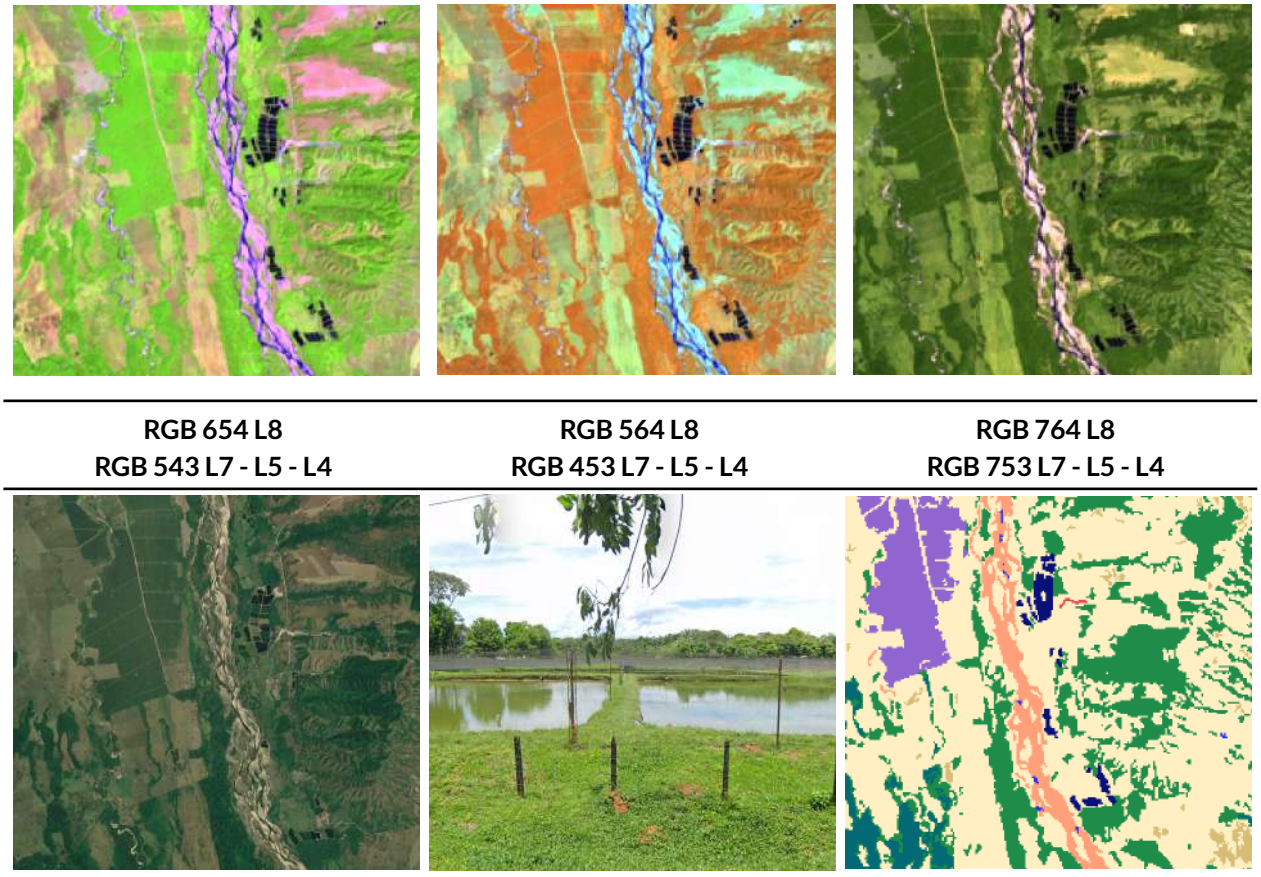
Location: Acacias - Meta, Year: 2024, Scale: 100m, Coordinates: -73.78067 W, 4.02660 N.

Figure 103 Spectral Response of Mining in the Orinoquia Region.

This anthropogenic formation in the RGB 654 band combination displays a mixture of rosewood, fuchsia, French pink, white, and shades of purple. In the RGB 564 combination, a blend of sky blue, electric blue, cyan, and white tones can be observed. In the RGB 764 combination, mixtures of lemon yellow, banana yellow, cream, and pastel yellow tones are present. Generally, this formation tends to cover small to medium-sized areas, which are connected by roads and often have nearby artificial water bodies (chemical ponds). The texture of this cover is coarse and is characterized by a highly varied mixture of the tones described above.

Aquaculture (ID:31)

Artificial water surfaces intended for the rearing of fish, shrimp and crustaceans in freshwater or saltwater environments. They are composed of a series of adjacent pools that present a regular geometric pattern, characteristic of aquaculture production systems.



Location: Villanueva, Casanare, Year: 2022, Scale: 500 m, Coordinates: -72.90423 W, 4.79612 N.

Figure 104 Spectral Response of Aquaculture in Orinoquia Region

This coverage is characterized by very deep dark blue tones in all three RGB combinations (654, 564, and 764). Shades such as midnight blue and dark blue can be observed, which is due to these being lentic water bodies with a high sediment load. The texture of this coverage ranges from medium to fine.

River, lake or ocean (ID:33)

It includes all extensions of permanent or seasonal water surfaces, of natural or anthropogenic formation, mainly associated with the supply of aqueducts and energy production. Includes rivers, lakes, lagoons, oceans, reservoirs, swamps, canals and ponds. (IDEAM,2010)

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

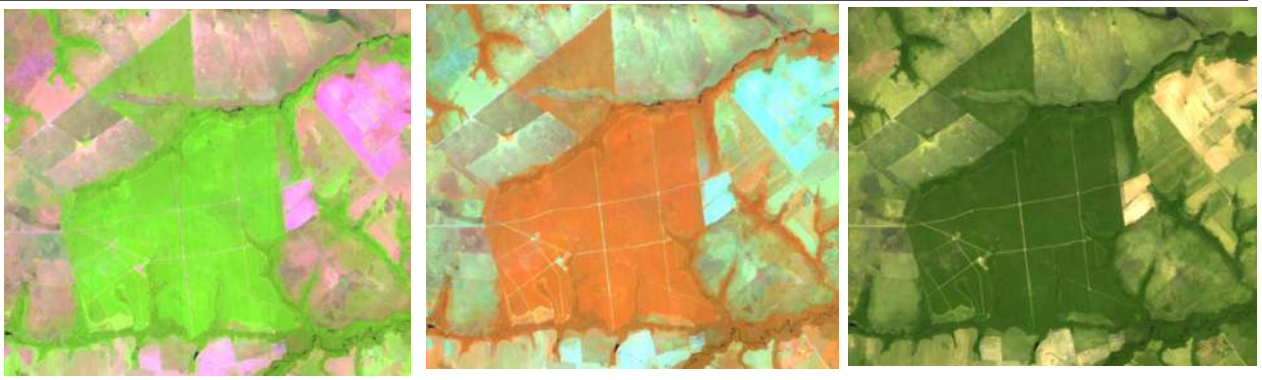
Location: Puerto Lopez - Meta, Year: 2024, Scale: 1000 m, Coordinates: -73.01369 W, 3.9603 N.

Figure 105 Spectral Response of River, lake or ocean in Orinoquia Region.

This natural formation is characterized by dark blue and navy-blue tones in the RGB 6-5-4 and 5-6-4 band combinations. In bay areas, some purplish hues with blue undertones may also be observed. In the RGB 7-6-4 combination, Oxford blue, midnight blue, and deep medium-blue tones predominate. This cover type is characterized by a very fine texture with smooth contrasts among the blue shades.

Palm oil (ID:35)

This coverage is characterized by extensive cultivation areas with symmetrical and regular oil palm (*Elaeis guineensis*) plantations, whether temporary or permanent. These plantations are developed in considerably larger plots compared to traditional crops, and their production is carried out on an industrial scale. Palm oil cultivation thrives in volcanic soils as well as alluvial and marine clays found in lowland areas (below 500 m a.s.l), which are well-drained and highly permeable (Aguilera, 2002). Palm oil has shown significant growth across the national territory; in the Orinoquia region, particularly in the departments of Meta and Casanare, palm oil production has been highly important, representing up to 37% of the national total. (Rojas, 2016)



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location:Maní - Casanare, Year: 2022, Scale: 500 m, Coordinates: -72.15985 W, 4.63359 N.

Figure 106 Spectral Response of Palm oil in Orinoquia Region.

This anthropogenic cover is characterized by bright lawn green and apple green tones in the RGB 654 combination. In the RGB 564 band combination, it shows vivid orange tones, while in the RGB 764 combination, it presents pine green shades. The texture of this cover is fine and very homogeneous, and it is also characterized by exhibiting geometric patterns.

Solar panel farm (ID 75)

It includes areas occupied by facilities for solar energy generation, characterized by the presence of modular structures (solar panels) arranged in a regular pattern, generally over flat and open surfaces. These areas have a clearly defined anthropogenic origin and are not confused with other types of urban or industrial infrastructure.

They are recognized by their regular geometric pattern and distinctive tonalities across different RGB combinations. In **Figure 107**, magenta colors can be observed in the RGB 654 combination of Landsat 8 and RGB 543 of Landsat 7, 5, and 4; grayish or cyan tones in RGB 564 (L8) and RGB 453 (L7–L5–L4); and greenish or bluish-violet hues in RGB 764 (L8) and RGB 753 (L7–L5–L4). The texture is

homogeneous, with low internal variability, associated with the orderly arrangement of the solar modules.

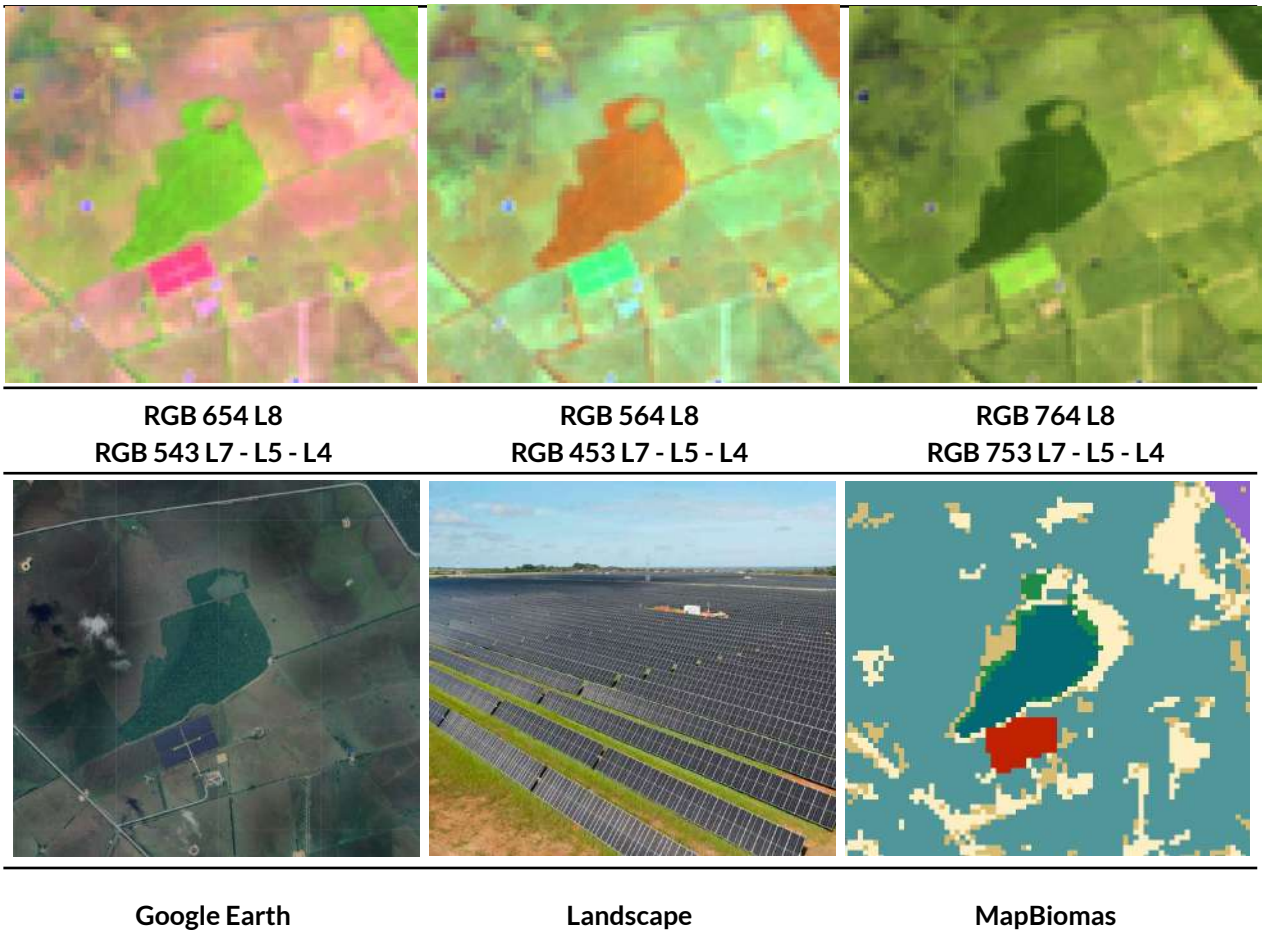
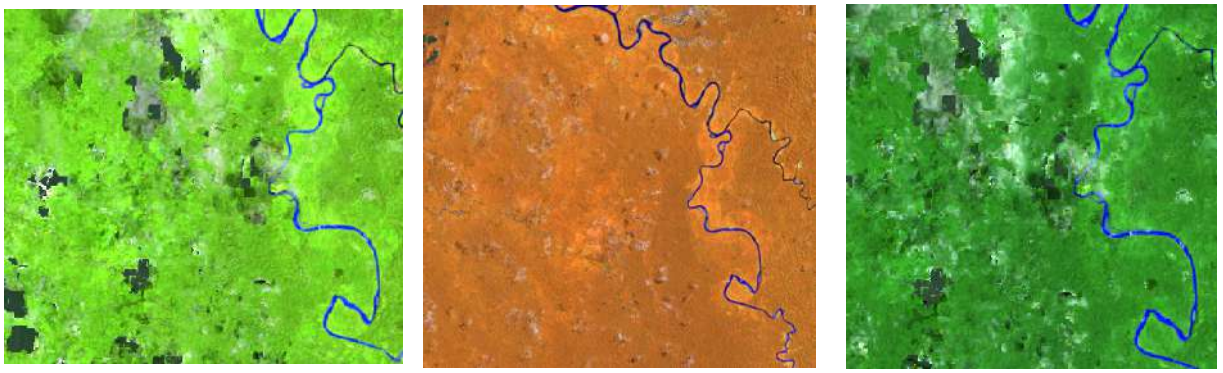


Figure 107 Spectral Response of Solar panel farms in Orinoquia Region.

4.4.3.5 Pacific region legend

Forest (ID:3)

In the Colombian Pacific region, this class corresponds to natural areas dominated by arboreal elements that form a continuous canopy with a height greater than 5 m. This class includes dense terra firme forests, dense shrublands, riparian and gallery forests, and tall secondary vegetation; located between the coasts of the Pacific Ocean and the western flank of the Western Cordillera. Due to its geographic, climatic, and edaphic configuration, this area is considered the most biodiverse in the world. Likewise, according to diversity and richness studies, it is the second region with the greatest floristic diversity after the Amazon. (Galeano et al., 1998; Rangel, 2010).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Sipi River, Chocó, Year: 2022, Scale: 1 km, Coordinates: -76.67134 W, 4.56063 N.

Figure 108 Spectral Response of Forest in the Pacific Region.

The forests of the region exhibit distinctive characteristics, such as evergreen vegetation with a great variety of species and growth habits, including trees, lianas, vines, incandescent plants, shrubs, and others (Gentry, 1986). In dense forests with a high degree of conservation, it is possible to identify them through satellite imagery due to their continuity in shape and texture, where darker tones are observed compared to some naturally regenerated secondary arboreal formations. In the case of riparian or gallery forests, the pattern is easily distinguishable as it borders watercourses, following different drainage patterns (from dendritic to subdendritic).

Regarding the Landsat images used, in the false color combinations RGB 654 for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, the class in question is identified by dark and light green tones, which, as mentioned earlier, depend on its successional stage and maturity. For the RGB 564 combination in Landsat 8 and RGB 453 in Landsat 7, Landsat 5, and Landsat 4, it shows dark red to orange hues. Finally, for images using the RGB 764 combination in Landsat 8

and RGB 753 in Landsat 7-5-4, the forest appears in dark green tones (**Figure 108**). The texture varies from medium to coarse roughness depending on canopy density.

Mangrove (ID:5)

Mangroves are strategic coastal ecosystems that, from an ecological point of view, serve as the habitat for various groups of organisms such as mollusks, crustaceans, fish, birds, among others. This forest cover is found in coastal areas (Casas-Monroy, 2000) and is composed of arboreal vegetation with heights not exceeding 8 meters. Its cover includes gregarious species, meaning they grow in groups.

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Patía River – Nariño, Year: 2022, Scale: 5 km, Coordinates: -78.26470 W, 2.55340 N.

Figure 109 Spectral Response of Mangrove in the Pacific Region.

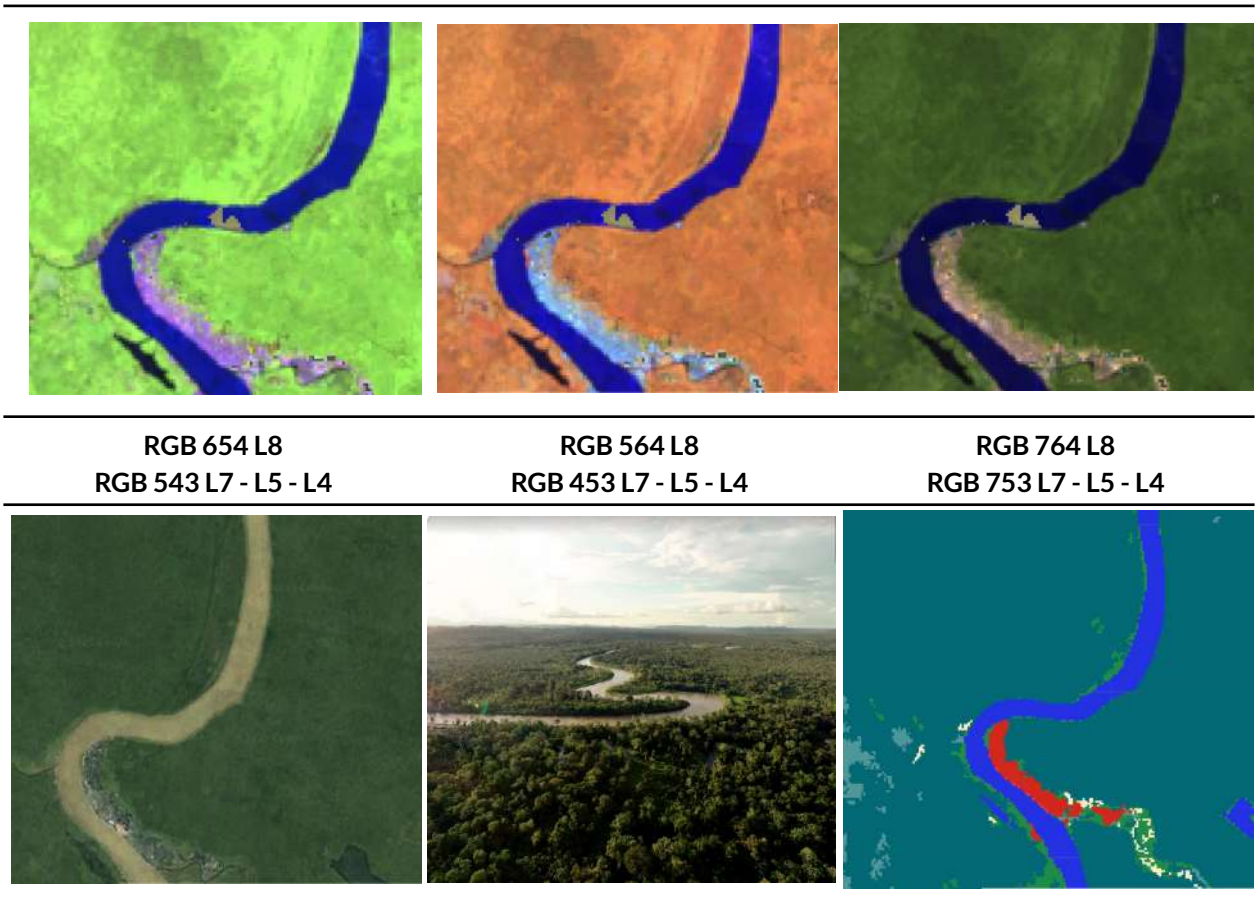
They grow on flat, muddy soils that may be permanently or seasonally flooded due to tidal influence. They are found in estuarine areas, bays, inlets, coastal lagoons, and estuaries, among others, where they receive inputs from continental runoff and the influence of marine or brackish waters. Mangroves are distributed from Jurado, Antioquia, to Tumaco, Nariño.

In the upper part of **Figure 109,** the combinations used for identifying this cover are shown. In false color RGB 654 for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, it is characterized by dark grayish-green tones in areas dominated by arboreal strata with mottled and

smooth textures. For RGB 564 in Landsat 8 and RGB 453 in Landsat 7, Landsat 5, and Landsat 4, the spectral response ranges from red to brown, with greater intensity in vigorous vegetation. Finally, in the RGB 764 combination for Landsat 8 and RGB 753 for Landsat 7, 5, and 4, mangroves appear in opaque dark green tones.

Flooded forests (ID:6)

Flooded forests are forest covers found along riverbanks. They include vegetation in different strata, highlighting the formation of woody or arboreal plants with heights starting from 3 meters. These forests are characterized by being established along temporary or permanent riverbanks. Due to their slightly rugged topography, this formation is also known as gallery forest, although not all gallery forests are necessarily flooded. Similarly, in the Colombian Pacific, flooded formations such as *sajales* and *guandales* can be found, these are coetaneous species that thrive under these edaphic conditions of high floodability.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Rio Atrato, Riosucio - Antioquia, Año: 2018, Escala: 500 m, Coordinates: -77.1030 W, 7.4566 N

Figure 110 Spectral Response of Flooded Forest in the Pacific Region.

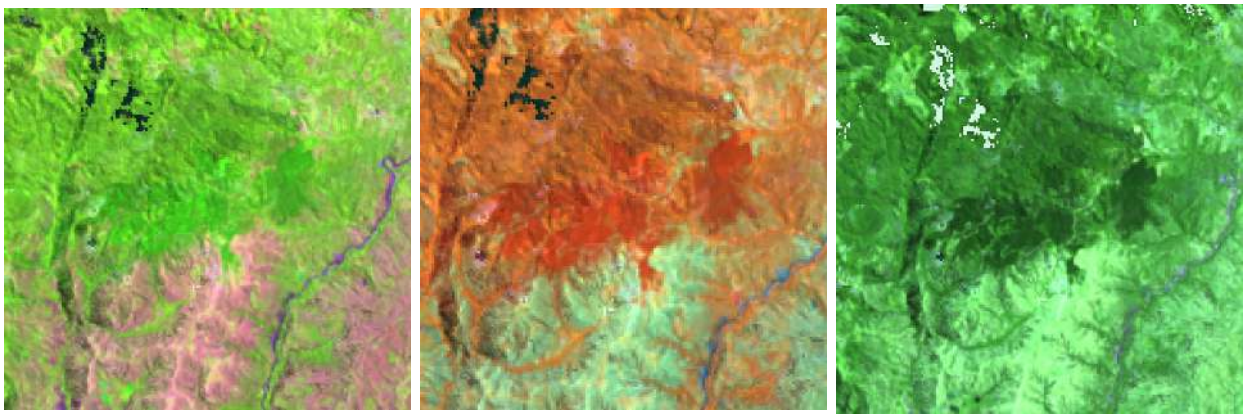
As shown in **Figure 110**, this type of cover, in the false color combination RGB 654 for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, is distinguished by bright light-green tones.

For RGB 564 in Landsat 8 and RGB 453 in Landsat 7, Landsat 5, and Landsat 4, the coloration varies from red to brown with intense orange hues, differentiating itself from the forest by its fine texture compared to the roughness of Class 3. Finally, in the RGB 764 combination for Landsat 8 and RGB 753 for Landsat 7, Landsat 5, and Landsat 4, this class shows dark to light green tones.

Forest Plantation (ID:9)

These covers consist of arboreal vegetation plantations established through direct human intervention for forest management purposes. In this process, forest stands are created through planting and/or seeding during afforestation or reforestation efforts for timber production (commercial plantations). In satellite imagery, this cover displays a regular geometric pattern formed by rows of trees generally of the same age. In the Pacific region, the species with the largest planted area correspond to pine (*Pinus patula*), eucalyptus (*Eucalyptus globulus*), and some native species (MADR, 2022).

For the identification of this class in false color combinations RGB 654 for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, green tones similar to those of forests are observed—dark for mature plantations and bright light greens with yellowish hues in early stages. In RGB 564 for Landsat 8 and RGB 453 for Landsat 7, Landsat 5, and Landsat 4, reddish-orange colors predominate. For the RGB 764 combination in Landsat 8 and RGB 753 in Landsat 7, Landsat 5, and Landsat 4, plantations display dark green tones that can be easily confused with natural forest formations. To distinguish between these classes, it is recommended to observe the distribution pattern, plantations generally have regular or square shapes (**Figure 111**).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

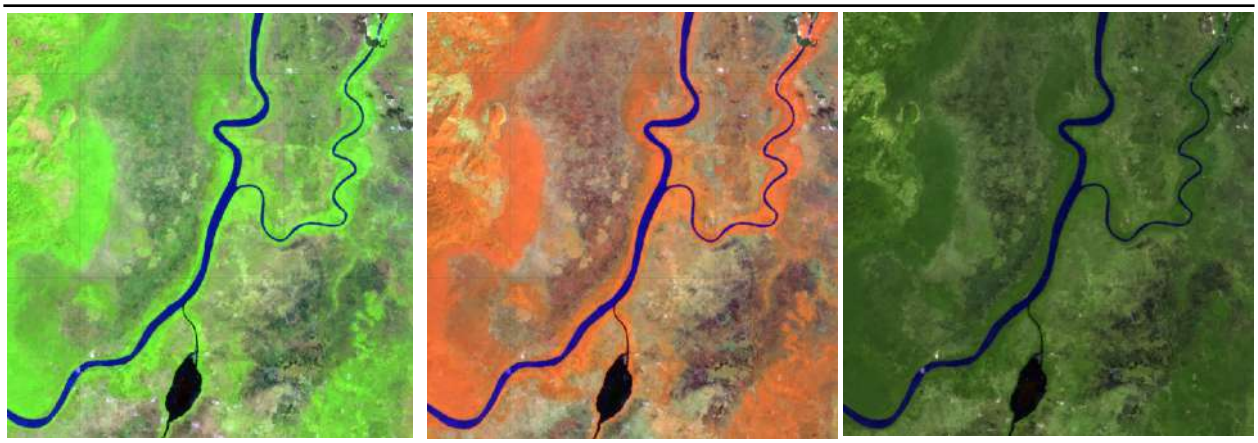
Google Earth	Landscape	MapBiomas

Location: Chigorodó, Antioquia, Year: 2021, Scale: 500 m, Coordinates: -76.65559 W, 3.79894 N.

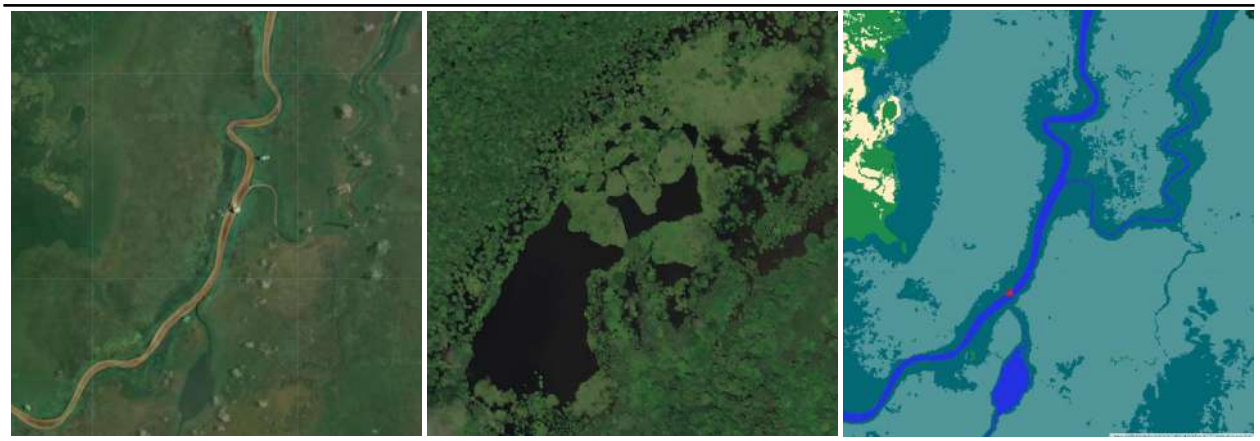
Figure 111 Response of Forest Plantation in the Pacific Region.

Wetland (ID 11)

Areas dominated by natural herbaceous vegetation that may present some arboreal elements to a lesser extent (not exceeding 3 m), as well as areas with dispersed palm communities that in no case exceed 10% of the cover. They are generally found in the floodplains of valleys and alluvial plains, in hydromorphic soils that are permanently oversaturated, and occur on old riverbeds and other formations typically located near bodies of water.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4



Google Earth	Landsat	MapBiomas

Location: Vigia del Fuerte, Antioquia–Chocó border, Year: 2014, Scale: 500 m,
Coordinates: -76.80975 W, 6.52116 N.

Figure 112 Spectral Response of Wetland in the Pacific Region.

The spectral response of this cover is highly variable. As shown in **Figure 112**, along riverbanks, in the false color combination RGB 654 for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, the class displays bright neon green tones, though brown to dark brown hues can also be found. In images with the RGB 564 combination for Landsat 8 and RGB 453 for Landsat 7, Landsat 5, and Landsat 4, it is characterized by orange tones with intense pink and light ochre-green shades in some swampy areas. Finally, in the RGB 764 combination for Landsat 8 and RGB 753 for Landsat 7, Landsat 5, and Landsat 4, vivid green tones are observed. It shows a fine, heterogeneous texture without defined boundary patterns but is generally found near bodies of water or old riverbeds.

Other non forest formation (ID:13)

This corresponds to a natural cover consisting of dense grassland that develops in areas not subject to flooding periods, which may or may not contain dispersed arboreal and/or shrub elements. Within this category, other types of cover are also included, such as areas where shrub vegetation predominates, featuring an irregular canopy structure and the presence of shrubs, palms, vines, and small plants. (IDEAM, 2010)

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Necocli, Antioquia, Year: 2022, Scale: 200 m, Coordinates: -76.87784 W, 8.54221 N.

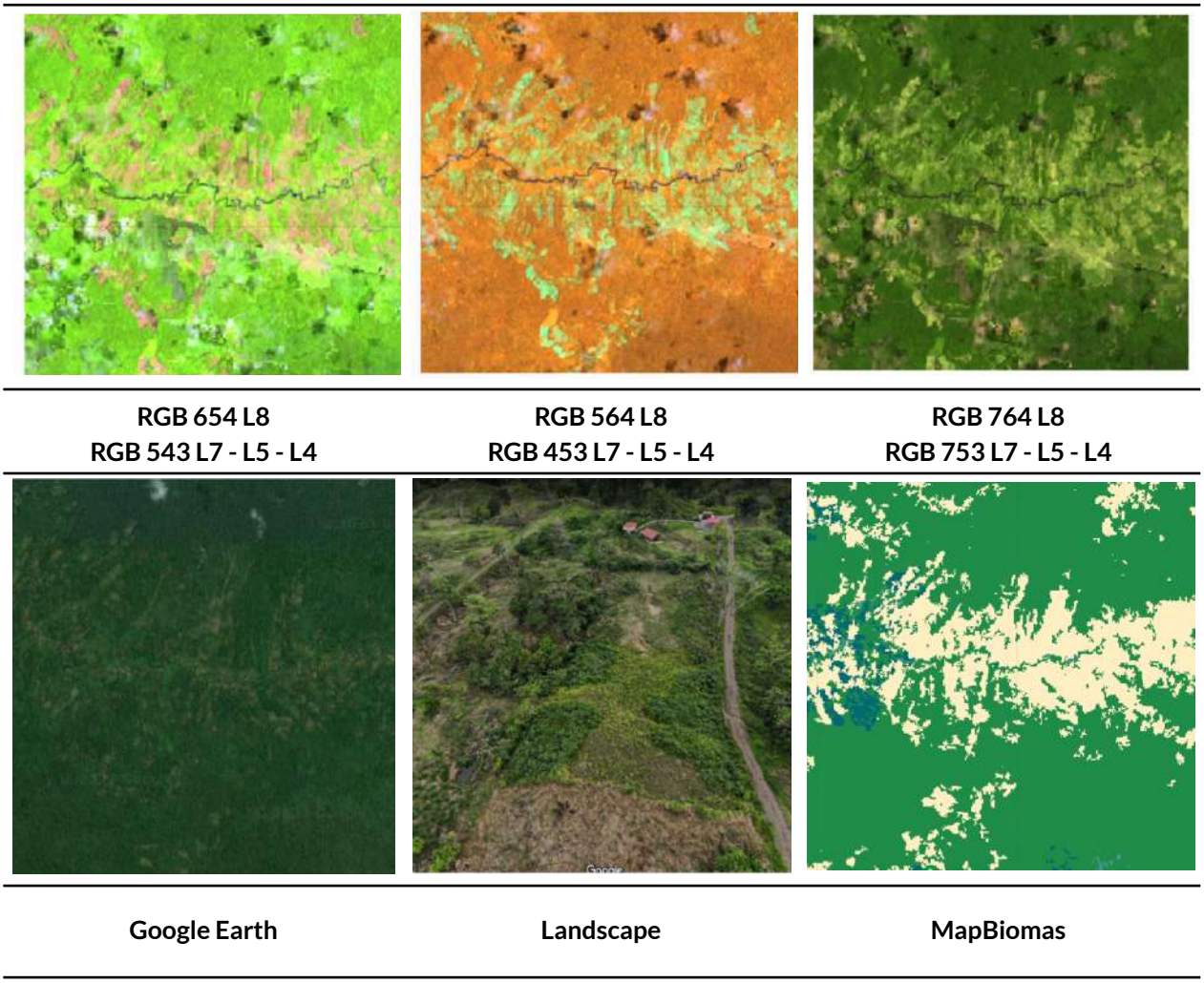
Figure 113 Spectral Response of Other non forest formation in the Pacific Region.

As shown in **Figure 113**, in the false color combination RGB 654 for Landsat 8 and RGB 543 for Landsat 7, 5, and 4, this cover appears in pink to fuchsia tones with an opaque hue. In the RGB 564 combination for Landsat 8 and RGB 453 for Landsat 7, 5, and 4, cyan to pale light-green tones are observed. Finally, in the RGB 764 combination for Landsat 8 and RGB 753 for Landsat 7, Landsat 5, and Landsat 4, this cover displays ochre-yellow tones with olive-green hues. Likewise, this formation shows a fine to medium heterogeneous texture and a pattern associated with areas of low human intervention, rocky outcrops, and hilly reliefs.

Mosaic of agriculture and pasture (ID:21)

In the Pacific region, this cover is represented by temporary and permanent crops, as well as some mosaics of pastures, which display an intricate spatial pattern due to their subdivision into small plots, making their individual representation difficult. Agriculture is mainly associated with the cultivation of plantain, fruit trees, sugarcane, other small-scale family crops, and the vegetative

stages of large-scale crops such as oil palm. Pastures, on the other hand, are used for livestock activities and are not extensive. Clean pastures, weedy pastures, and natural grasslands can be found. As in other regions, this cover presents a wide range of tones due to the different phenological stages and diverse management practices applied across plots, which can therefore cause confusion with other classes. Its main characteristic is the regular or irregular geometric pattern of each plot. (IDEAM, 2018) (Government of Valle del Cauca, 2013).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

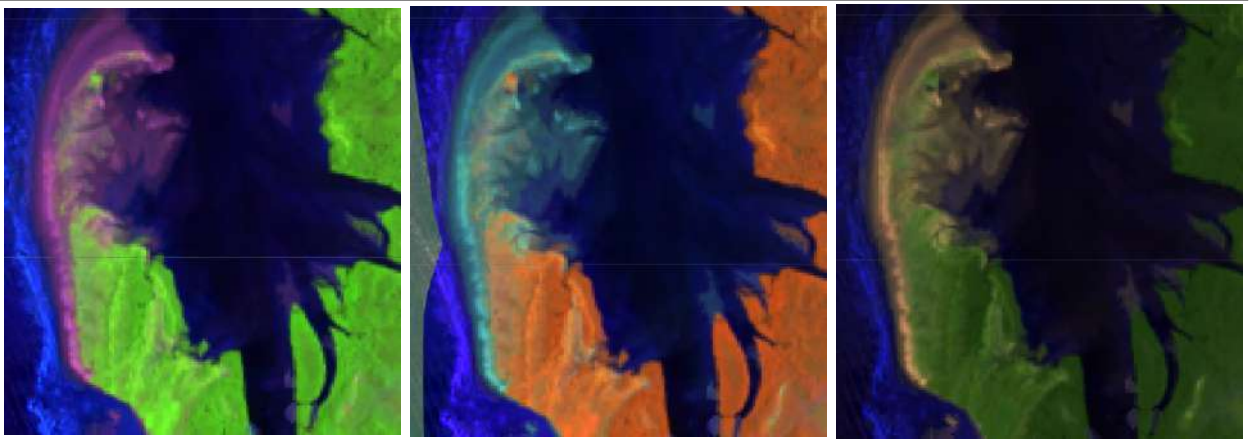
Location: El Charco, Nariño, Year: 2021, Scale: 1000 m, Coordinates: -78.06164 W, 2.33824 N

Figure 114 Spectral Response of Mosaic of Agriculture and Pastures in the Pacific Region.

In **Figure 114**, the false color combination RGB 654 for Landsat 8 and RGB 543 for Landsat 7, 5, and 4 shows pale pink to fuchsia tones with an opaque appearance. In the RGB 564 combination for Landsat 8 and RGB 453 for Landsat 7, 5, and 4, pale light-green tones are observed. Finally, in the RGB 764 combination for Landsat 8 and RGB 753 for Landsat 7, Landsat 5, and Landsat 4, this cover displays ochre-yellow tones with olive-green hues. Likewise, this formation exhibits a fine to medium heterogeneous texture and a pattern associated with areas of high human intervention.

Beach, dune and sand spot (ID:23)

This cover corresponds to the remnants of relict mobile sandbanks and abandoned meanders in scarce proportions. The greatest concentration is found on beaches or coastal areas, where this cover is more evident; in this case, the vegetation is sparse. This cover consists of sandy to rocky surfaces with scattered vegetation not exceeding 20% of the total cover, or in some cases, completely absent.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Orpua, Orpua River, Choco – Choco, Year: 2021, Scale: 200 m,
Coordinates: -77.39234 W, 5.30003 N.

Figure 115 Spectral Response of Beach, dune and sand spot in the Pacific Region.

Its spectral response in the three band combinations shown in **Figure 115** is very similar, characterized by bright white pixels where vegetation is scarce. In the RGB 654 combination for Landsat 8 and RGB 543 for Landsat 7, Landsat 5, and Landsat 4, some purple and pink tones can be distinguished along the edges, while in the RGB 564 combination for Landsat 8 and RGB 453 for Landsat 7, Landsat 5, and Landsat 4, light blue hues predominate. In the RGB 764 combination for

Landsat 8 and RGB 753 for Landsat 7, Landsat 5, and Landsat 4, ochre-pink colors are observed. This class presents a fine texture and lacks a defined pattern.

Infrastructure (ID:24)

As in the other biogeographic regions (Andean, Pacific, Orinoquia, and Amazon regions), this class encompasses structures and buildings associated with human settlements, such as urban centers (towns), road and railway networks, and related areas. It also includes other artificial zones such as hydrocarbon extraction sites, hydroelectric facilities, military bases, airports, port areas, and non-agricultural green spaces like recreational facilities in urban centers, urban lawns, road medians, and unconventional airstrips in rural areas.

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Quibdo, Choco Year: 2022, Scale: 2 km, Coordinates: -76.655850 W, 5.687135 N.

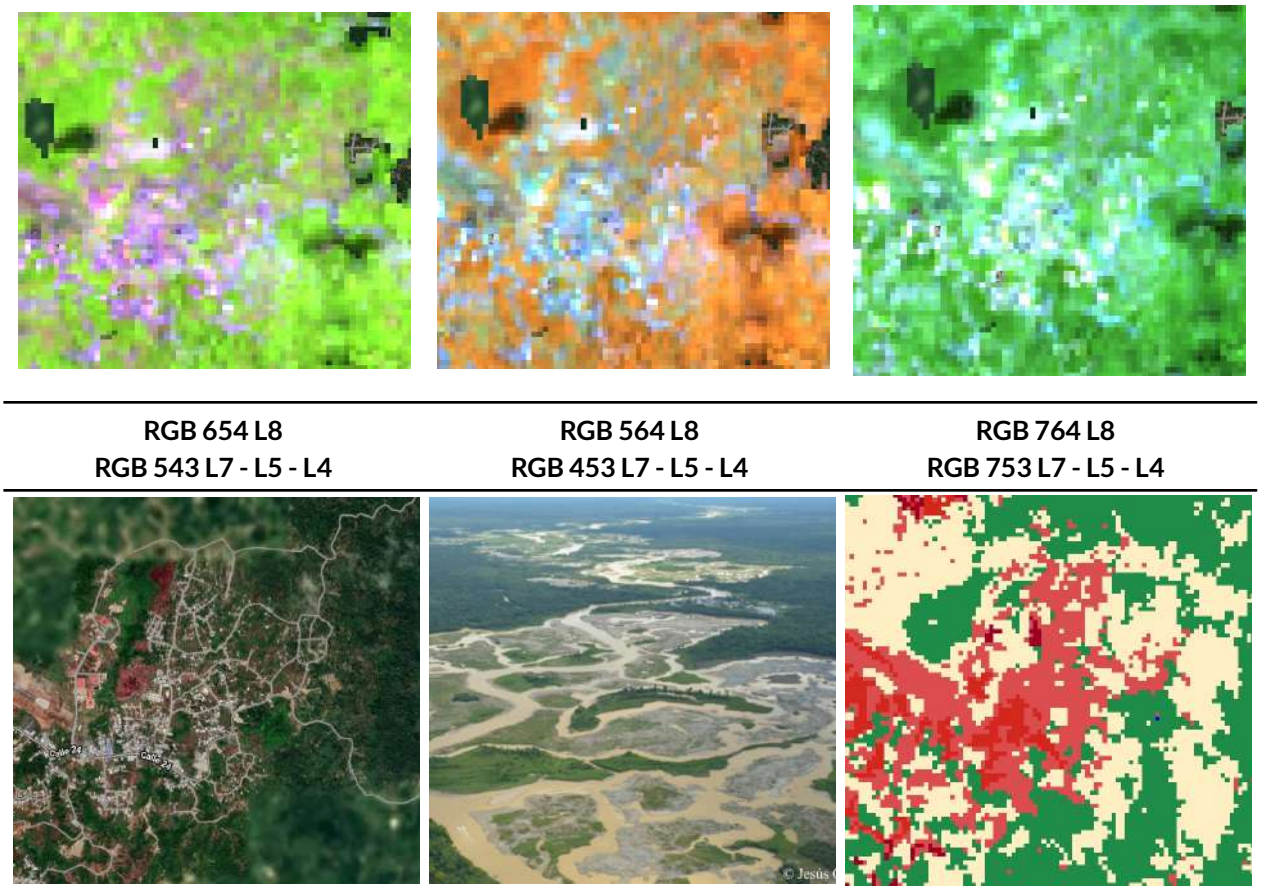
Figure 116 Spectral Response Infrastructure in the Pacific region.

It also includes peripheral areas that are gradually being incorporated into urbanization processes for residential and/or industrial purposes. The covers that make up this class present a spectral response characterized by lavender to lilac tones in the RGB 654 Landsat 8 and 543 Landsat 7,

Landsat 5, and Landsat 4 combinations, while in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4 combinations, they show rosewood to pink hues, and cream to pink tones in the RGB 764 Landsat 8 and RGB 753 Landsat 7, Landsat 5, and Landsat 4 combinations.

Other non-vegetated area (ID:25)

Anthropogenically impacted areas (infrastructure, urban expansion, or mining) not mapped in their respective classes, and soils lacking vegetation or with sparse vegetation cover. Burned areas and fields under preparation or fallow are also included.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

Location: Novita – Choco, Year: 2022, Scale: 500 m, Coordinates: -76.624 W, 5.68766 N

Figure 117 Spectral Response of Other Non-Vegetated Area in the Pacific Region.

For the RGB 654 combination of Landsat 8 and 543 of Landsat 7, Landsat 5, and Landsat 4 shown in **Figure 117**, a spectral response of violet to purple is evident for non-vegetated areas, with slightly rough textures. Meanwhile, images in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, and RGB 764 Landsat 8 and RGB 753 Landsat 7, Landsat 5, and Landsat 4, display blue tones with purple hues and greenish-brown to burnt yellow colors, respectively.

Rocky outcrop (ID:29)

These correspond to areas composed of exposed rock layers, where erosion processes have caused the bedrock to be exposed, with low or no vegetation. They are generally located on steep slopes, associated with mountain glaciers, volcanoes, faults, and geological deformations. (IDEAM, 2010).

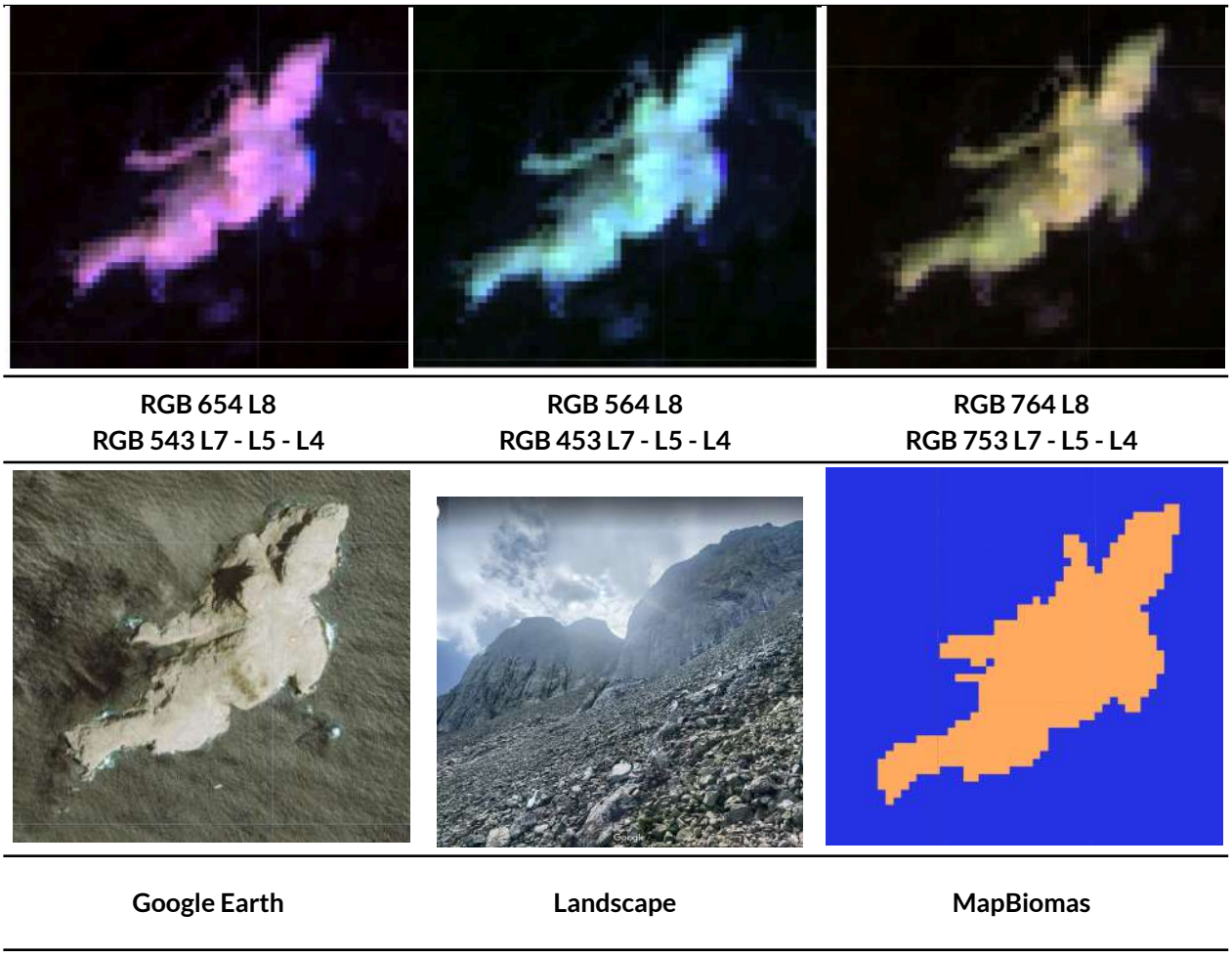
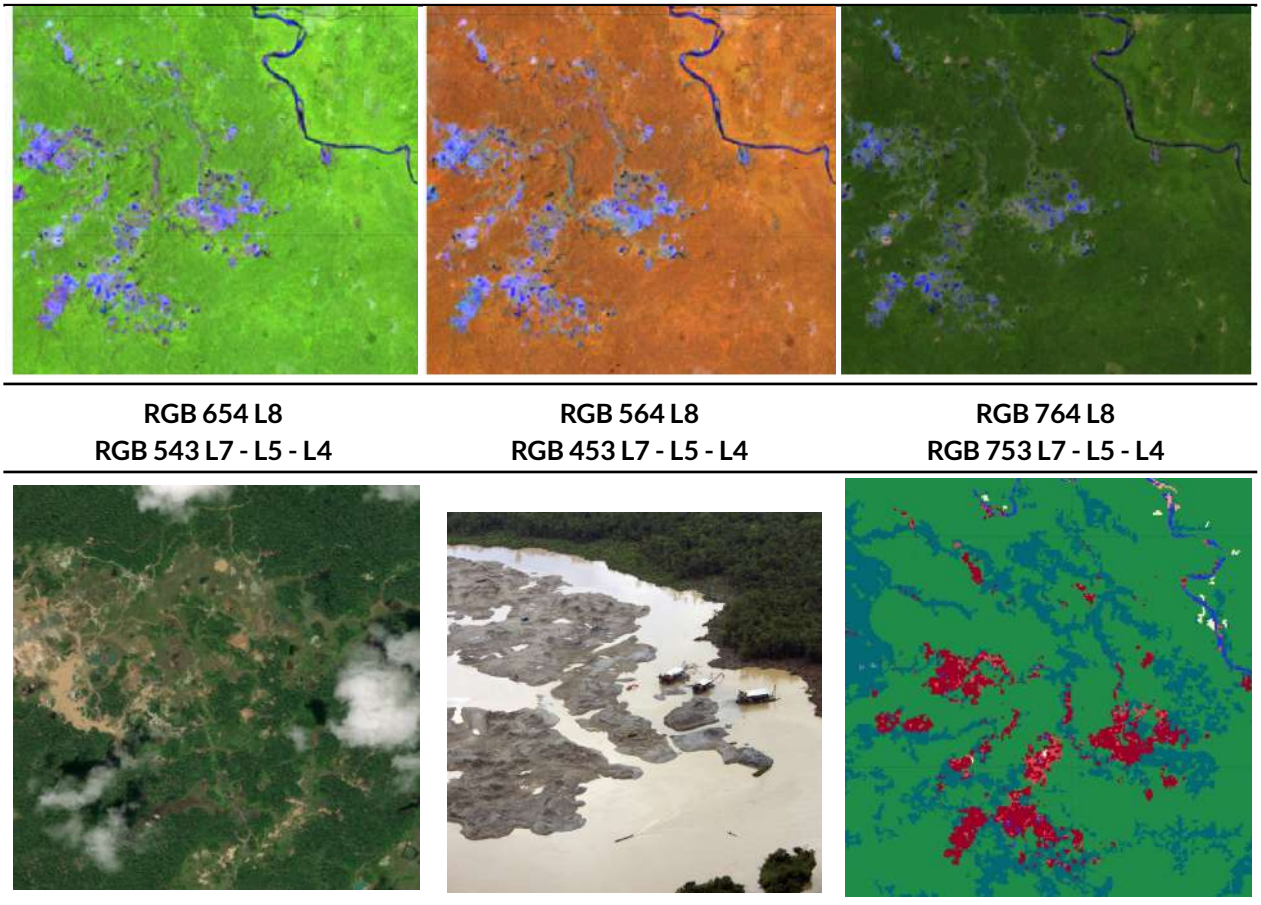


Figure 118 Spectral Response of Rocky Outcrop in the Pacific Region.

For the RGB 654 combination of Landsat 8 and 543 of Landsat 7, Landsat 5, and Landsat 4 shown in **Figure 118**, a spectral response of violet is evident for the outcrops, with slightly rough textures. Meanwhile, images in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, and RGB 764 Landsat 8 and RGB 753 Landsat 7, Landsat 5, and Landsat 4, display blue tones with light green hues and greenish-brown to burnt yellow colors, respectively.

Mining (ID:30)

It includes areas where materials are extracted or accumulated from open-pit or riverine mining activities with clear soil exposure. It does not differentiate between industrial, artisanal, riparian, or illegal mining. Areas dedicated to material extraction (sand pits, gravel pits, quarries) and zones for coal, gold, and other mineral exploitation are included; for example, the reference images correspond to gold extraction. (IDEAM et al., 2017).



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Middle Atrato – Choco, Year: 2014, Scale: 1 km, Coordinates: -76.60303 W, 6.05301 N.

Figure 119 Spectral Response of Mining in the Pacific Region.

For the RGB 654 combination of Landsat 8 and 543 of Landsat 7, Landsat 5, and Landsat 4 shown in **Figure 119**, a spectral response of violet to purple is evident, with rough and flat textures and undefined shapes, as this activity is mainly located along riverbanks since most of it is artisanal mining. Meanwhile, images in RGB 564 Landsat 8 and RGB 453 Landsat 7, Landsat 5, and Landsat 4, and RGB 764 Landsat 8 and RGB 753 Landsat 7, Landsat 5, and Landsat 4, display blue tones with purple and greenish-brown to burnt yellow colors, respectively.

Aquaculture (ID:31)

Artificial water bodies intended for the farming of crustaceans, shrimp, and freshwater and saltwater fish. This cover consists of a series of adjacent ponds, characterized by a regular geometric pattern.

RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4

Google Earth	Landscape	MapBiomas

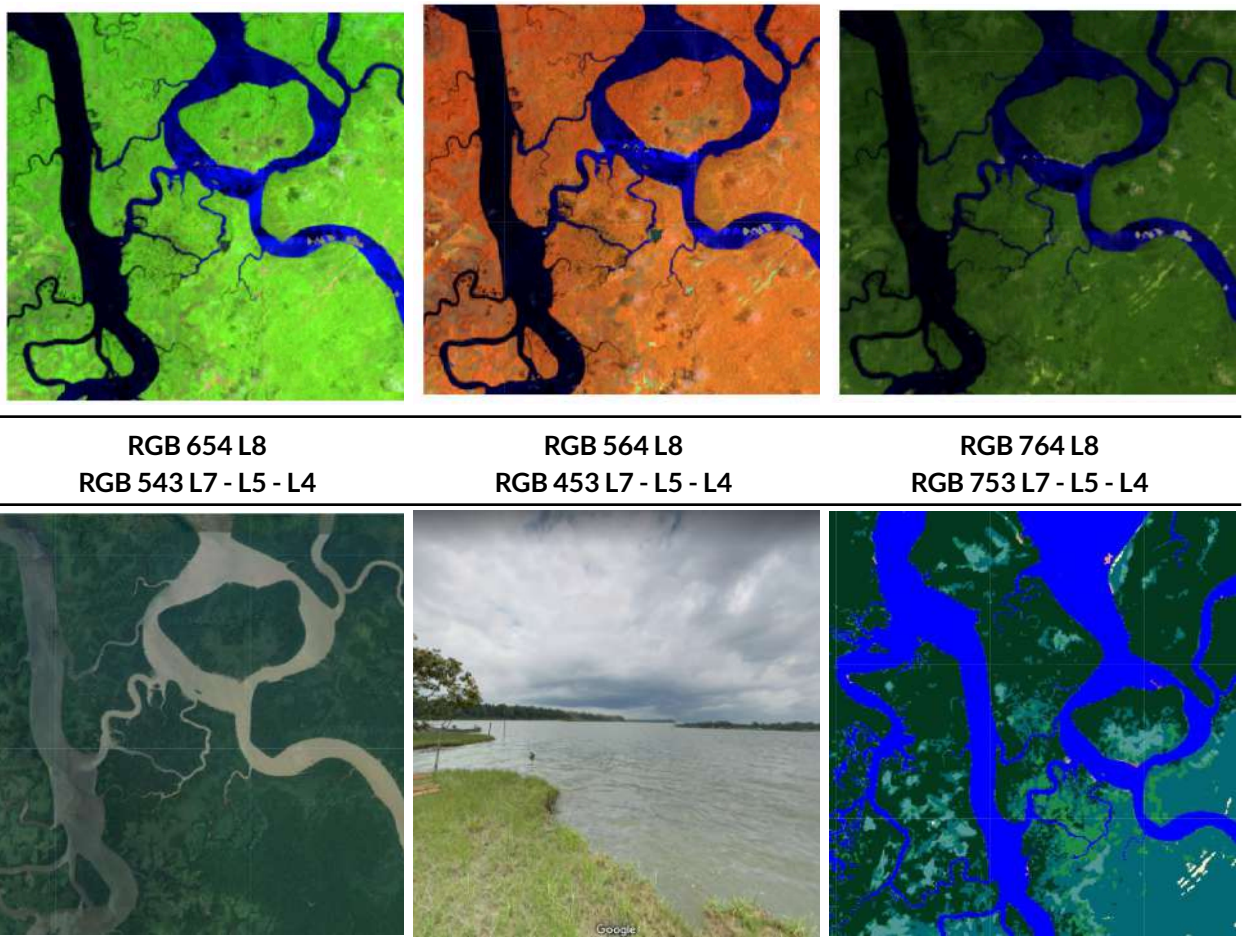
Location: Municipality of Tumaco, Nariño, Year: 2021, Scale: 200 m, Coordinates: -78.6804 W, 1.69697 N.

Figure 120 Spectral Response of Aquaculture in the Pacific Region.

The spectral response of aquaculture ponds is very similar to that of natural water bodies. They appear dark blue due to sediment and organic matter content in the RGB 654 combination of Landsat 8 and 543 of Landsat 7, 5, and 4, as shown in **Figure 120.** In the RGB 564 combination of Landsat 8 and RGB 453 of Landsat 7, 5, and 4, they appear almost black. In true color, this can range from opaque yellow in some clay-rich rivers to dark blue and bluish-black tones. In the RGB 764 combination of Landsat 8 and RGB 753 of Landsat 7, Landsat 5, and Landsat 4, they appear in blue to dark blue tones. This cover is distinguished from other water bodies by its size and defined shapes and is generally located near water bodies or flood-prone areas.

River, lake or ocean (ID:33)

It includes all permanent or seasonal surface water bodies, formed naturally or through human intervention, generally for energy production or water supply. This class encompasses rivers, lakes, lagoons, oceans, reservoirs, swamps, canals, and ponds (IDEAM, 2010), which can be freshwater or saltwater. These formations exhibit meandering patterns in the case of rivers, or undefined shapes with defined perimeters for natural water bodies, and clearly defined shapes for artificial ones.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Santa Bárbara – Nariño, Year: 2021, Scale: 1 km, Coordinates: -78.0597 W, 2.5725 N.

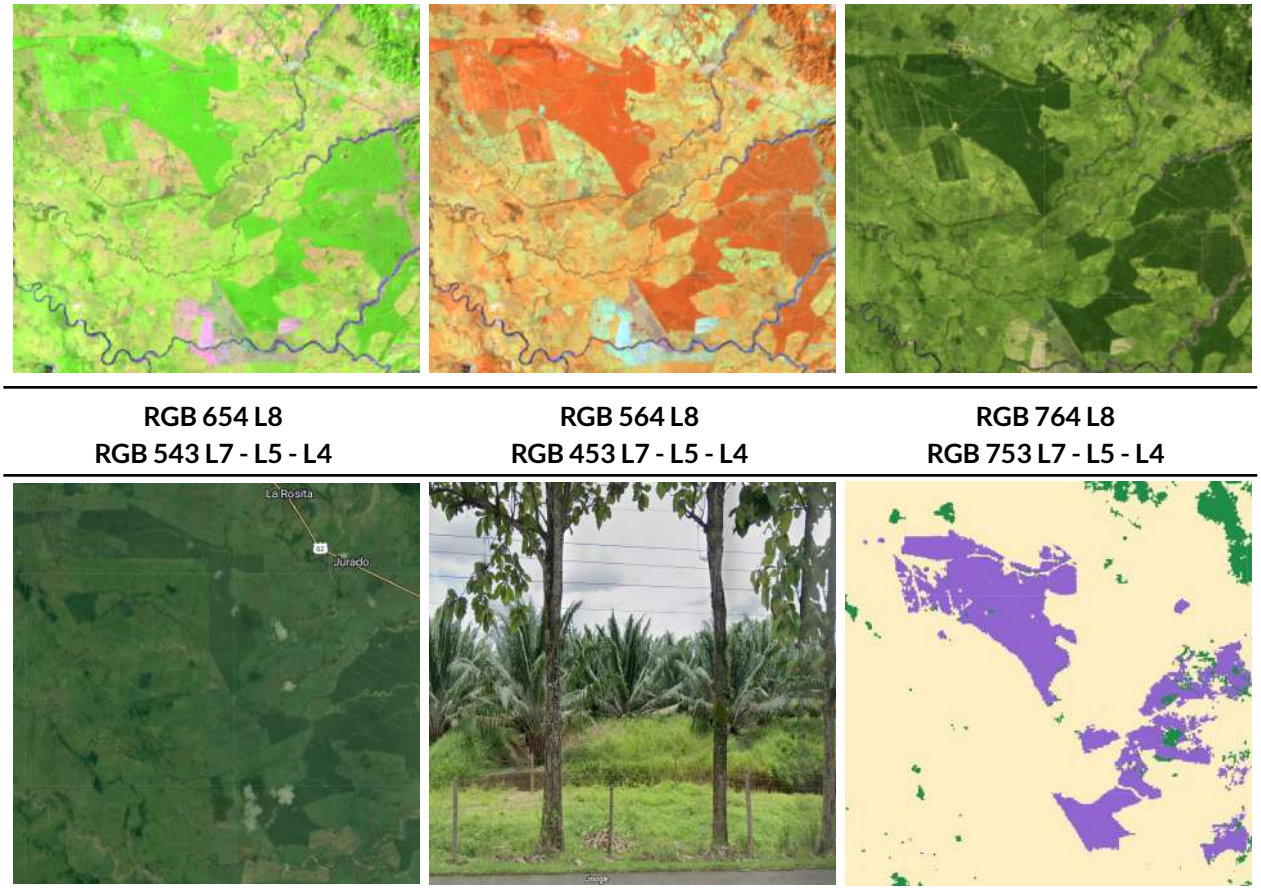
Figure 121 Spectral Response of River, Lake or Ocean in the Pacific Region.

The spectral response of water bodies depends on the suspended particle load; therefore, rivers appear dark blue due to sediment and organic matter content in the RGB 654 combination of Landsat 8 and 543 of Landsat 7, 5, and 4, as shown in **Figure 121**. In the RGB 564 combination of Landsat 8 and RGB 453 of Landsat 7, 5, and 4, they appear almost black. In true color, this can range from opaque yellow in some clay-rich rivers to dark blue and bluish-black tones. In the RGB 764 combination of Landsat 8 and RGB 753 of Landsat 7, Landsat 5, and Landsat 4, they present

blue to dark blue tones. This cover exhibits a very fine, homogeneous texture with a drainage pattern following the various watercourses, sometimes of dendritic type.

Palm oil (ID:35)

This cover is characterized by the presence of extensive plantations with symmetrical and regular palm oil (*Elaeis guineensis*) crops, whether temporary or permanent. They are developed on considerably large plots compared to traditional crops, and production is carried out on an industrial scale. Cultivation thrives on volcanic soils and alluvial or marine clays, in lowland areas (below 500 m a.s.l) with good permeability and drainage (Aguilera, 2002). In the Pacific region, these plantations are mainly concentrated in the south, specifically in the department of Nariño in areas surrounding Tumaco, and to a lesser extent in the north, in the Uraba region of Antioquia.



RGB 654 L8 RGB 543 L7 - L5 - L4	RGB 564 L8 RGB 453 L7 - L5 - L4	RGB 764 L8 RGB 753 L7 - L5 - L4
Google Earth	**Landscape**	**MapBiomas**

Location: Chigorodó – Antioquia, Year: 2021, Scale: 5000 m, Coordinates: -76.6049 W, 7.4906 N.

Figure 122 Spectral Response of Palm oil in the Pacific Region.

This anthropogenic cover is characterized by bright grass green and vivid apple green tones in the RGB 654 combination. In the RGB 564 band combination, it presents bright orange tones, and in the RGB 764 band combination, it shows pine green hues. The texture of this cover is fine and very homogeneous, and it is also characterized by geometric patterns.

4.4.4 Random forest

Random Forest is a non-parametric classification method widely used in artificial intelligence (AI) and machine learning, based on a supervised learning approach (Chen & Ishwaran, 2012; Merino & Chacon, 2017). It is one of the machine learning classifiers integrated into the Google Earth Engine (GEE) geomatics platform.

The algorithm operates by constructing and combining multiple decision trees generated from training data. At each node of a tree, a random subset of predictor variables is selected, and the optimal split that best separates the data is determined (Cutler et al., 2012; Merino & Chacon, 2017). Each tree then casts a "vote" to classify an element, and the final class is assigned by majority vote. In the case of satellite imagery, this means that each pixel is assigned the most frequently voted class. This ensemble learning approach has been shown to achieve high levels of accuracy and robustness, even in scenarios with high variability and noise in the data (Turner & Ghosh, 1996).

For proper configuration, the user must define key parameters such as the number of trees (nTrees), the number of random variables considered at each node (mTry), and the set of input predictor variables. In this study, during the generation of the third collection, the number of trees per region ranged from 50 to 80, with 60 being the most frequent value. The variables used (Item 4.2, Table 6) were derived from annual median mosaics and training data generated from stable pixels within a time window spanning 1985 to 2024.

Table 10 Number of decision trees used by classification regions.

Final classification	
Decision trees used by region	**Number of classification regions**
50	21
60	62
65	8
70	42
75	21
80	1
Total	**155**

4.4.5 Sample collection

The methodological process for land cover classification begins with a clear understanding of the spectral variability of each class defined in Section *4.2*, *Classification Variables (Feature Space)*. This ensures proper guidance for training sample collection, which consists of pixels that remained stable within the same class throughout the time series of the previous collection (1985–2023);

that is, their spectral response corresponds to the same cover type over the entire period. To achieve this, the algorithm identified stable pixels within the selected area. Subsequently, random points were generated from this layer, balanced according to the spatial extent of each class. The number of points assigned per class was defined by the interpreter, and each point's location was used as input to train the Random Forest classifier.

Optionally, the interpreter could exclude classes considered unstable over time, as they may introduce noise into the initial classification. They also had the option of including classes for point allocation in stable pixels or manually modifying the samples to exclude or add locations based on their temporal stability.

This evaluation was carried out by comparing the spectral response of the same pixel across all mosaics in the series that contained data for that pixel. This provided guidance for selecting complementary samples through a multitemporal window, thereby refining the training dataset and enhancing classification accuracy. The process was implemented using the geometry creation tools available in Google Earth Engine, together with the PIAO (Photo Interpretation Assistée par Ordinateur) technique, which consists of the manual interpretation and delineation of features of interest by the analyst—in this case, the land cover in the classification region.

4.4.6 Cross-cutting themes

Given the complexity of identifying and interpreting certain types of coverage, specific working groups were established to map these classes across the general map, developing methodologies adapted to the needs. The cross-cutting themes for Colombia's coverage collection 3 included: Flooded Forest (ID = 6), Wetland (ID = 11), Infrastructure (ID = 24), Mining (ID = 30), Glacier (ID = 34), and Mangrove (ID = 5). The description and interpretation keys for these classes are addressed in previous sections related to the legend. Likewise, the filters mentioned in the methodology were adjusted according to the class of interest in each cross-cutting theme. Finally, the information generated was consolidated into the final map using integration rules.

Additionally, to delve deeper into each of the cross-cutting themes, an appendix is included with this document that allows for a more detailed exploration of each cross-cutting theme.

4.5 Post-classification

After collecting the complementary samples to train the classification algorithm, the methodology allows for an automatic editing of inconsistencies that persist due to residual cloud shadows, missing information from gaps in the mosaics (Landsat), and scattered pixels across the image (known as the salt-and-pepper effect). In this way, a series of filters were applied to achieve a better representation of the mapped classes in the temporal series, which are as follows:

1. Temporal filter.
2. Spatial filter.

---

3. Gap fill.
4. Frequency filter.

The filters were applied in a different order depending on the needs and conditions of each region, according to the interpreters' criteria, as recorded in **Table 10**. Below is a description of the function of each filter used.

4.5.1 Temporal Filter

This filter consists of replacing pixels identified as noise or the salt-and-pepper effect, which represent inconsistencies generated in the classification of land cover due to gradual year-to-year changes and the lack or distortion of information in the mosaics. In this context, three filters are used within the temporal filter, including those for the intermediate year, the first year, and the last year. These are described in detail below.

4.5.1.1 Intermediate year

The filter is executed by taking into account the first and last pixels of the temporal series, changing the classification of the pixels located in the intermediate years to match those classified at the extremes of the temporal series (1986–2024). In the lower part of **Figure 123**, it can be seen that, for the 3-year rule, a pixel is classified as forest (in green) in years t1 and t3, while in t2 it transitions to the agriculture and/or pasture mosaic class (in beige), which is an unlikely ecosystem behavior. After applying the filter, it stabilizes abrupt changes in the classification by changing the intermediate pixel to match the classification of its initial and final counterparts. Similarly, this method is applied for 4- and 5-year temporal series, as explained in **Figure 123**. It is important to note that for the first and last years of the analyzed period, in this case 1985 and 2024, the intermediate-year rule is not applied because there are no years to compare.

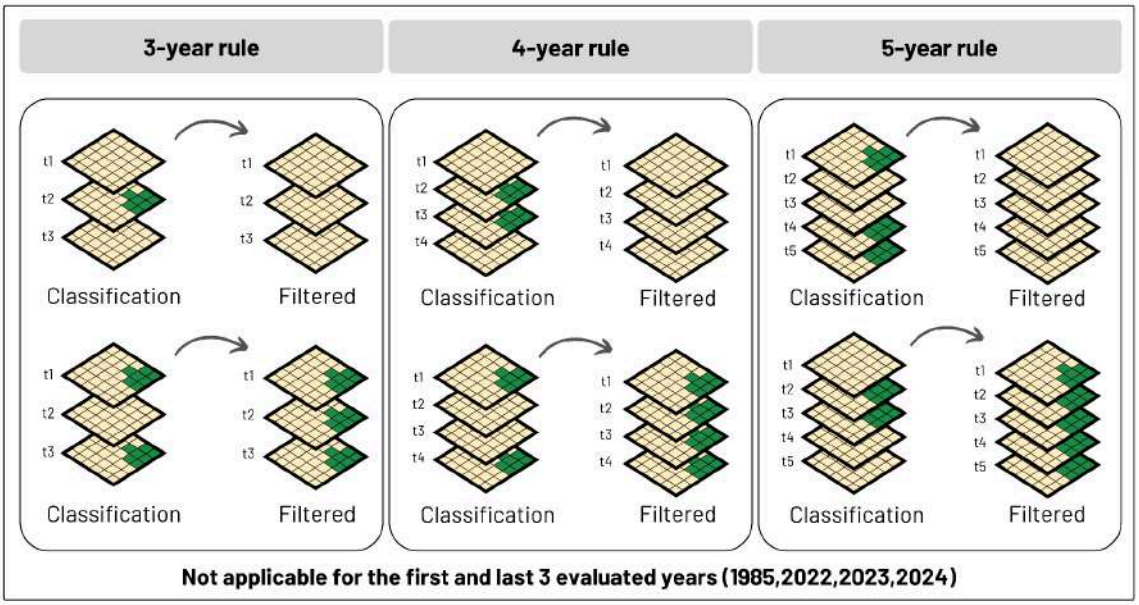


Figure 123 Temporal Filter

4.4.1.2 First and Last Year

The first-year rule corrects inconsistencies in the time series caused by missing information for the year 1985. The example illustrates a transition from mosaic areas of agriculture and/or pasture to forest in subsequent years — a phenomenon that is unlikely in the evaluated regions (**Figure 124)**.

The last-year rule corrects misclassified pixels at the end of the time series (2024) due to abrupt changes, such as those mentioned above. In **Figure 124**, it can be observed how the filter acts on a pixel classified as forest (in green) at the end of the series, which, after applying the filter, is reclassified as a mosaic of agriculture and/or pasture, thereby homogenizing the time series.

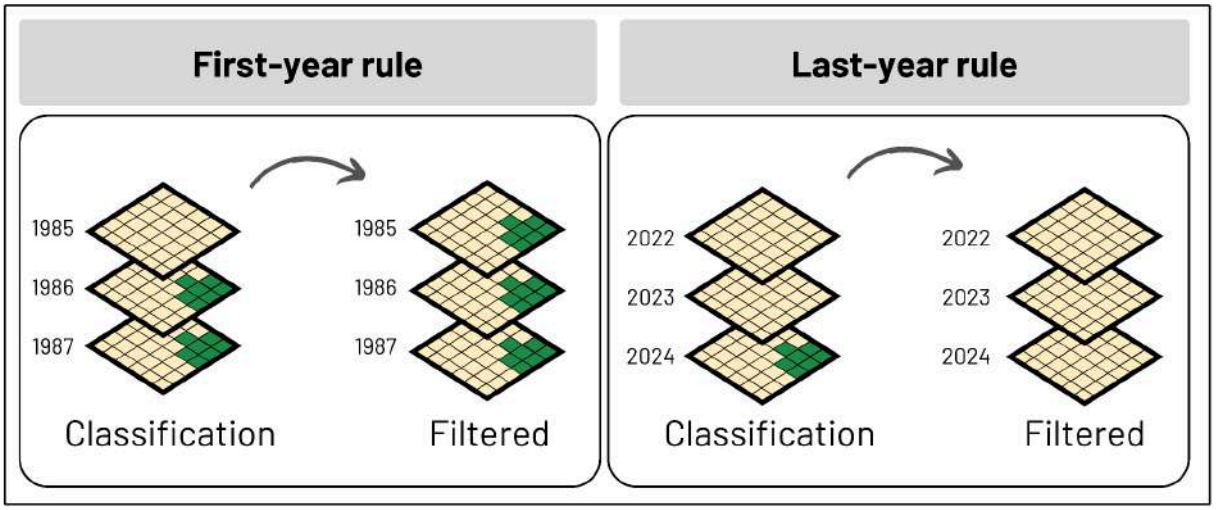


Figure 124 Temporal Filter – First and Last Year Rule

In the filter, it is possible to configure and add the classes that are necessary for correction. Therefore, it should be considered that, although any class may be subject to this filter, the interpreter evaluates which classes are suitable for its application, since some classes may indeed experience abrupt changes over very short periods, such as the transition from forest to mosaic of agriculture and/or pasture. To conclude, the main objective of this set of filters is to obtain a stable time series, without inconsistent jumps that could affect statistical reports or the classification itself. Likewise, just as classes can be excluded from any of the three temporal filters, specific years can also be excluded. This mainly occurs in intermediate years, when the series remains stable for certain periods but not for others.

4.5.2 Spatial filter

The spatial filter is a function executed for image enhancement, which improves the brightness and contrast of images through the correction of isolated pixels that show a difference with groups of neighboring pixels (salt-and-pepper effect). This prevents the mapping of errors such as shadows or remnants of other land covers, and also allows the reduction or intensification of specific details of the mosaic. For the filter application, a minimum area of 0.5 hectares, equivalent

to 5 pixels, is considered. These pixels must be connected to each other to be classified as a representative pixel group, which eliminates local or isolated differences by unifying the land cover classes within the mosaic.

As shown in **Figure 125**, in the input image, three isolated pixels are classified as water. After applying the spatial filter, these pixels—having a value difference from the surrounding pixel groups—are replaced by the predominant class in their vicinity. As a result, in the output image, these pixels are reclassified as mosaic of agriculture and/or pasture.

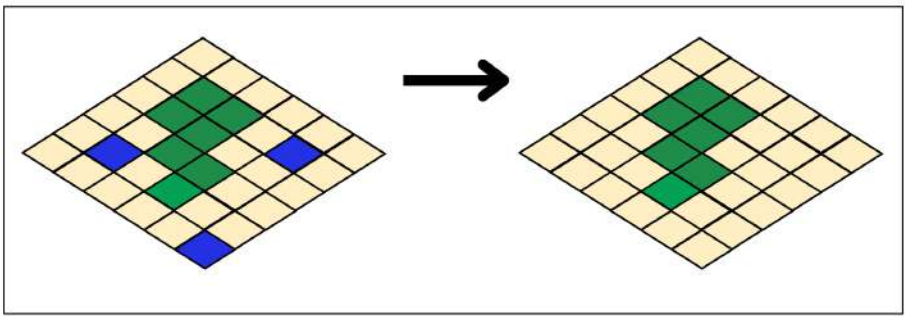


Figure 125 Spatial filter

4.5.3 Gap Fill (Void Filling)

The purpose of the *Gap Fill* filter is to fill empty spaces within mosaics caused by the lack of information in the defined temporal window. This filter is particularly useful due to the absence of high-quality images for certain years and/or specific regions. As mentioned in Chapter 4.1 *Landsat Mosaics*, there are cases where several consecutive years lack available imagery or display voids resulting from cloud exclusion during image processing.To address this issue, the implemented algorithm identifies areas with missing information in the mosaics and, based on the temporal series, fills these gaps using data from the previous year until valid information becomes available, as illustrated in **Figure 126**.

It is important to emphasize that, before applying this filter, the temporal series from previous years must be carefully verified, since the algorithm could fill voids with incorrect data, potentially representing classes different from those intended to be mapped in the study area.

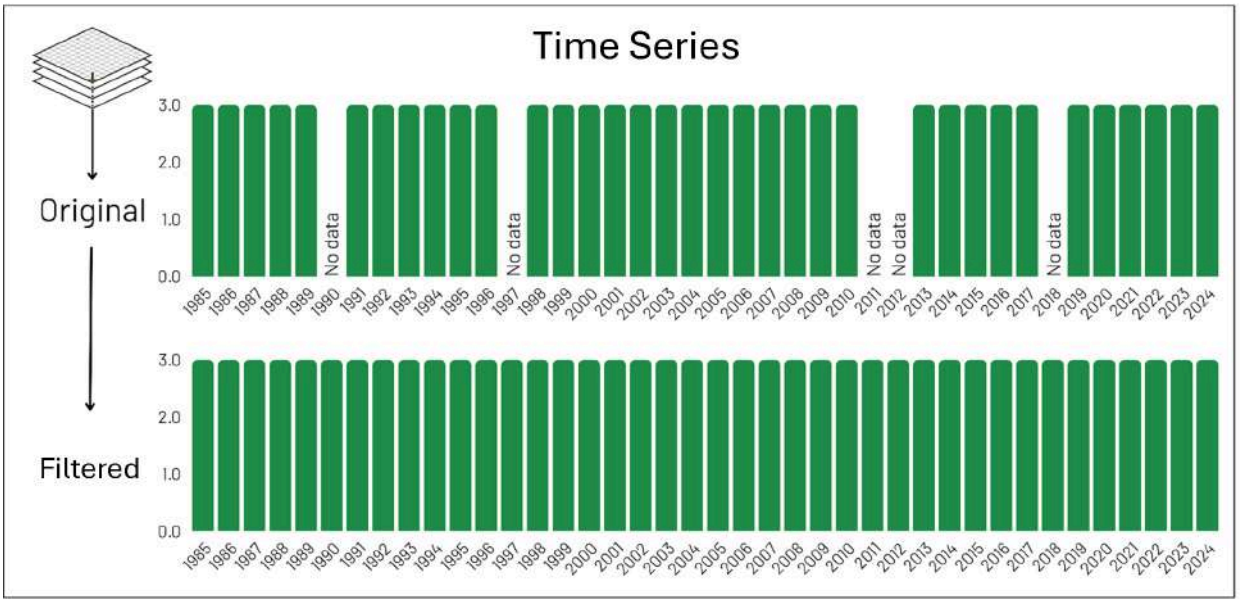


Figure 126. Gap Fill Filter (Void Filling).

The figure above illustrates the pixel-by-pixel process used to fill cells without data. In the example shown, no information is available for 1990; therefore, the value is filled using data from the immediately preceding year, 1989. Following this logic, data for the years 1997, 2011, 2012, and 2018 are filled using information from their respective previous years.

Although this filter helps to partially stabilize data gaps, it has the limitation of not capturing changes that occurred during the years in which the filter was applied. These changes will only be reflected in the following year once new valid data are available. Consequently, this can affect the mapping of land cover change or deforestation in areas where data were filled. This effect was most evident during the 1992–1995 period, when the Landsat data archive contained no available imagery.

4.5.4 Frequency filter

The filter analyzes the sequence of classified images for each pixel and determines which land cover class appears most frequently during the intermediate years, excluding the first and last years of the series. This exclusion prevents isolated changes from altering the interpretation of the overall trend. If the most frequent class exceeds a minimum value defined by the interpreter (threshold), the pixel is assigned to that class. The filter allows the configuration and addition of any necessary classes for correction; therefore, it is important to consider that, although any class can be subjected to this filter, the interpreter evaluates which classes are suitable for its application. **Figure 127** illustrates the result of applying the frequency filter.

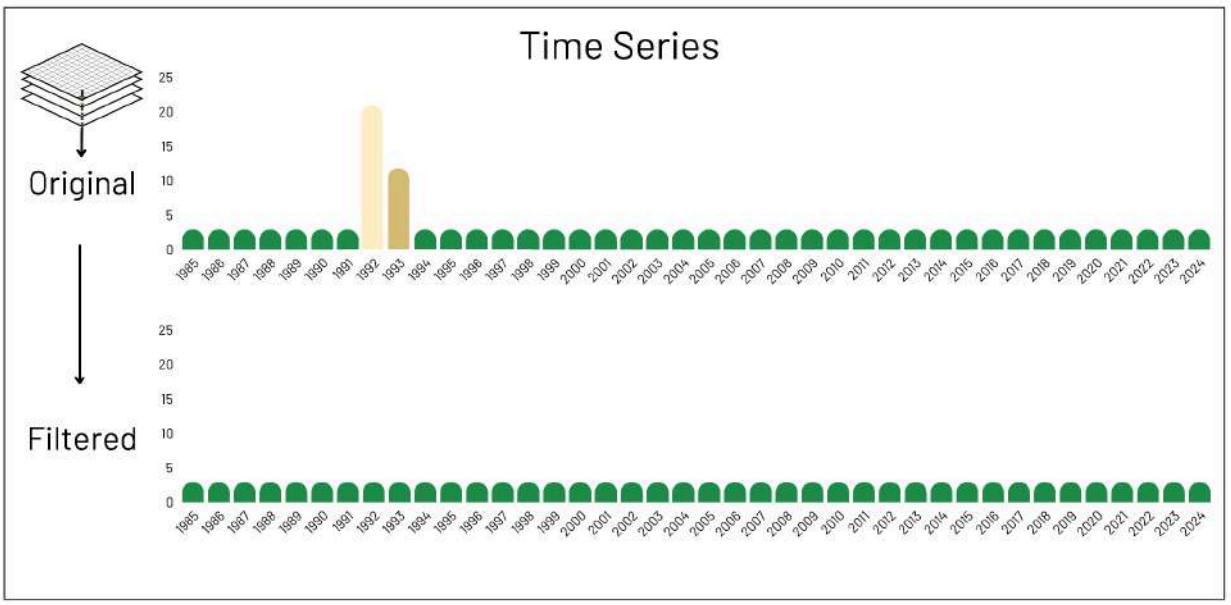


Figure 127. Frequency filter

4.5.5 Filter Application Order

In each of the classification regions, a series of filters were applied to achieve the final classification. The order of filter application was determined by each interpreter and is shown in **Table 11**, where FT corresponds to Temporal Filter, GP to Gap Fill, SF to Spatial Filter, and FF to Frequency Filter.

Table 11. Hierarchical Application of Post-Classification Filters

Region	Classification region	1	2	3	4	5	6	7	8	9	10
Andean	30101	GP	FT	FF	SF	FF	FF				
	30102	SF	FT	GP	FF	SF					
	30103	SF	GP	FT	FF	SF					
	30104	SF	GP	FT	FF	SF					
	30105	GP	FF	FF	FT	SF	FT	SF			
	30106	FT	FF	GP	SF						
	30107	GP	FT	FF	SF						
	30108	SF	GP	FT	FF	FF	SF				
	30302	SF	FT	GP	FF	FF	FF	SF			
	30303	SF	GP	FT	FF	SF					
	30304	GP	FF	FT	FF	SF	FF	FF			
	30305	FF	GP	FT	FF	FF	FF	SF			
	30306	GP	FT	FF	FF	SF					
	30308	SF	FT	GP	FF	FF	SF				

Region	Classification region	1	2	3	4	5	6	7	8	9	10
	30309	SF	FT	GP	FF	FF	FF	SF			
	30310	SF	GP	FT	FF	SF					
	30311	SF	GP	FT	FF	FF	FF	SF			
	30312	GP	FT	FF	FF	FF	FF	SF			
	30313	SF	FT	GP	FF	FT	SF				
	30314	SF	GP	FT	FF	SF					
	30316	SF	GP	FF	FT	SF					
	30317	SF	FT	GP	FF	FF	SF				
	30318	FT	GP	FF	FF	SF					
	30319	GP	FT	SF	FF	FT	SF				
	30320	GP	FT	FF	FF	SF					
	30401	FT	GP	FF	SF						
	30402	SF	GP	FT	FF	FF	FF	SF			
	30403	SF	FT	GP	FF	FF	SF				
	30404	GP	SF	FT	FF	FT	SF				
	30405	GP	FT	FF	SF						
	30406	SF	GP	FT	FF	SF					
	30407	SF	GP	FT	FF	SF					
	30408	GP	FF	FT	FF	SF					
	30409	SF	GP	FT	FF						
	30410	SF	GP	FT	FF	SF					
	30411	GP	FT	FF	FF	SF	FF	SF			
	30412	SF	FT	GP	FF	FT	FF	SF			
	30413	SF	GP	FT	FF	SF					
	30414	SF	GP	FT	FF	FF	SF				
	30415	SF	FT	GP	FF	FF	FF	SF			
	30416	FF	GP	FT	FF	FT	SF				
	30417	SF	FT	GP	FF	SF					
	30418	SF	FT	GP	FF	SF					
	30419	GP	FT	FF	FF	SF					
	30420	GP	SF	FF	SF						
	30421	GP	FT	SF	FF	FF	FF				
	30422	GP	FT	FT	SF						
	30423	GP	FT	SF	FT						
	30424	GP	FT	SF							
	30425	GP	FT	FF	SF						
	30426	GP	FT	FF	SF						
	30427	GP	SF	FF	FT	FT	SF				

Region	Classification region	1	2	3	4	5	6	7	8	9	10
	30428	GP	FT	FF	SF	FT	FF	FT	FT	SF	
	30429	GP	FT	FF	SF						
	30430	GP	FT	SF							
	30458	GP	FF	FT	SF						
	30459	GP	FT	SF							
	30460	GP	FT	FT	SF						
	30461	GP	FT	SF							
	30464	GP	FT	FF	SF	FT	SF				
	30465	GP	FT	SF							
	30466	GP	FT	FF	SF						
Amazon	30201	GP	FF	SF	FT	FF	SF	FF			
	30202	GP	SF	FT	FF	SF	FF	FF	SF		
	30203	GP	SF	FT	FF	SF					
	30204	SF	FT	FT	FF	FF	GP	FF	SF	FF	
	30205	SF	GP	FF	FT	FF	SF	FF			
	30206	GP	FF	SF	FT	FT					
	30207	GP	FF	SF	FT						
	30208	GP	FF	FF	FF	SF	FT	FT	FT	FT	
	30209	GP	FT	SF							
	30210	GP	FT	FT	FF	FF	SF	FF	FF		
	30211	SF	FT	GP	FT	FF	FT	SF	FF		
	30212	SF	GP	FT	FT	FF	SF				
	30213	SF	GP	FT	FT	SF					
	30214	SF	GP	FT	FT						
	30215	SF	GP	FT	FT	SF	FF	FF	SF	FF	
	30216	FT	GP	FT	FT	SF	FF				
	30217	SF	FT	GP	FT	SF	FF				
	30218	SF	FT	GP	FT	FF	SF	FF	FF	FF	
	30219	SF	GP	FT	FT	FF	FF	SF			
	30220	SF	GP	FT	FT	FF	SF	FF			
	30221	SF	FT	FT	GP	FF	FF	SF			
	30222	GP	FT	SF							
	30223	GP	FT	FF	SF	FF	FF				
	30224	GP	FT	FF	FF	SF					
	30225	SF	SF	FT	FT	GP	FF	FF	FF		
	30226	GP	FT	FT	FF	FF	FF	SF	FF	FF	
	30227	GP	FT	FT	FF	FF	FT	SF			
	30228	GP	FT	FF	FF	FF	SF				

Region	Classification region	1	2	3	4	5	6	7	8	9	10
	30229	GP	FT	FF	FF	SF	FF				
	30230	GP	FT	FF	FF	FT	FT	SF			
	30231	SF	SF	FT	FT	GP	FT	FF	FF		
	30232	SF	SF	GP	FT	FT	FF	FF	FT	FF	FF
	30233	GP	FF	FF	FF	FF	GP	FT	SF		
	30234	GP	FT	FF	FT	FF	FF	SF			G
	30235	GP	FT	FT	SF	FF	FF	FF	SF	FF	
	30236	SF	GP	FT	FT	SF	FF				
	30237	GP	FT	FF	FF	FF	FT	FF	SF		
	30431	GP	FT	FF	SF						
	30432	GP	FT	FF	SF						
	30433	GP	FT	SF	SF						
	30434	GP	SF	FT	FF						
	30435	FT	SF	GP	FT	FF	SF				
	30436	FT	GP	FF	FT	SF					
	30437	GP	FT	FT	SF						
	30438	GP	FT	FF	FT	FT	SF				
	30439	GP	FT	FF	SF						
	30440	GP	FT	FF	SF						
	30441	GP	FT	FF	FT	SF					
	30442	GP	FT	FT	SF						
	30443	GP	FT	FF	FT	SF					
	30444	GP	FT	FF	FF	SF					
Caribbean	30445	GP	FT	FT	SF						
	30446	GP	FF	FF	SF						
	30447	GP	FT	FF	FF	FT	SF				
	30448	GP	FT	FF	SF						
	30449	GP	FT	FF	SF						
	30450	GP	FT	FF	FT	SF					
	30451	GP	FT	FF	SF						
	30452	GP	FT	SF	SF						
	30453	GP	FT	FF	SF						
	30454	GP	FT	FT	SF						
	30455	FT	GP	FF	FF	SF					
	30456	FT	FF	GP	FT	FT	SF				
	30457	FT	GP	FT	SF	FF	FT	SF			
	30462	FT	GP	FT	FF	SF					
Orinoquia	30469	GP	FT	FF	SF						

Region	Classification region	1	2	3	4	5	6	7	8	9	10
	30470	FT	GP	FF	SF						
	30471	GP	FT	FF	SF						
	30472	GP	FT	FF	FF	FF	SF	FF			
	30473	GP	SF	FT	FF	FF	FF				
	30474	GP	FT	SF	FF	FT	FF				
	30475	GP	FT	FF	SF						
	30476	GP	FT	FF	FT	SF					
	30477	GP	FT	SF							
	30478	GP	FF	SF	FT	FT					
	30479	GP	FF	FF	FF	FT	SF				
	30480	GP	SF	FF	FT	SF					
	30481	GP	FF	FT	SF	SF					
	30482	SF	FT	FT	GP	FF	FF	FF	FF		
	30483	GP	SF	FT	FF	FF	FT	FF	FF	FF	
Pacific	30484	GP	FF	FF	SF	FT	FT				
	30485	SF	FT	GP	FT	FF	FF				
	30486	SF	FT	FF	FT	GP	FF	SF			
	30487	GP	FF	SF	FT	SF	FT				
	30488	GP	FF	FF	FT	FT	SF				
	30489	GP	FF	SF	FT	FT	FF				
	30490	GP	FF	FT	FF	SF					
	30491	GP	FF	SF	FT	SF					
	30492	GP	FT	FF	SF	FT	SF				
	30493	GP	FT	FT	FF	FF	FF	SF			
	30494	SF	FT	FT	FF	GP	FF	SF			
	30495	GP	FF	SF	FT	SF					
	30496	GP	FF	SF	FF	FT	FF	FT			

4.6. Integration

Based on the annual classifications by region, generated through the general methodology, and on the cross-cutting themes, an integration process was carried out to obtain a collection of 40 annual maps. This procedure included the definition of a set of rules and hierarchical priorities among classes, aimed at resolving overlaps and assignment conflicts. These rules establish, for example, the prioritization of permanent land covers, such as water bodies or forests, over secondary or temporary-use covers, thereby ensuring thematic coherence and temporal consistency of the data. The result was a unified set of land cover maps corresponding to Collection 3.0 of Colombia, as detailed in **Table 12**.

Table 12. Integration Hierarchies

Collection 3	ID	Layer	Prevalence ID Colombia
Glacier	34	Cross-cutting	1
Rocky outcrop	29	General	2
Hypersaline tidal flat	32	General	3
Mining	30	Cross-cutting	4
Banana	74	General	5
Solar panel farm	75	General	6
Infrastructure	24	Cross-cutting	7
Forest Plantation	9	General	8
Other natural non vegetated area	68	General	9
Beach, dune and sand spot	23	General	10
River, lake or ocean	33	General	11
Palm oil	35	General	12
Aquaculture	31	General	13
Mosaic of agriculture and pasture	21	General	14
Other non Vegetated Areas	25	General	15
Flooded Andinean Herbaceous and Shrubby Vegetation	82	General	16
Wetland	11	Cross-cutting	17
Andinean Herbaceous and Shrubby Vegetation	81	General	19
Other non forest formation	13	General	20
Grassland	12	General	21
Mangrove	5	Cross-cutting	22
Flooded forests	6	Cross-cutting	23
Forest	3	General	25
Wooded sand vegetation	49	General	26
Herbaceous sand vegetation	50	General	27

Note: The prevalence presented in the following table corresponds to the general hierarchy; however, depending on the specific characteristics of each region, some classes had their prevalence order adjusted.

The ID column represents the identifier of each class within the map; the Prevalence column indicates the order or hierarchy of each class in the map. In the case of Collection 3.0 of Colombia, it was defined that class 34 (“Glacier”) and class 30 (“Mining”) must be placed above all others during the integration process, to avoid overlap with other classes and thus prevent information

loss. Similarly, two exceptions were established in which the priority order of the floodable classes (5, 6, 11) takes precedence over the classes “Mosaic of agriculture and pasture (21)” and “Other non Vegetated Areas (25)”. In the second case, the Flooded forests (6) is prioritized above the herbaceous Grassland (12) and other Other non forest formation (13). Finally, the Layer column indicates whether the class originates from the general map or the cross-cutting map. It is worth noting that cross-cutting methodologies were used throughout the project to map the themes of Infrastructure, glaciers, mining, mangue, flooded forests, and wetlands. (See further details in the ATBDs of each theme.)

Figure 128. Integration of the Multitemporal Classification – Colombia Collection 3.0

5. Statistics and Platform

Based on the annual land cover classification maps and the integrated land use and land cover dataset generated for the 40-year series (1985–2024), annual and zonal statistical data are

produced for the different mapped classes. The following layers are used as spatial reference units for statistical calculations:

- Departmental Protected Area
- National Protected Area
- Biomes
- Tropical Dry Forest
- Glacier Complex
- Community Councils
- Level 1 Hydrographic Basin
- Level 2 Hydrographic Basin
- Level 3 Hydrographic Basin
- Department
- Glaciers
- CAR (Regional Environmental Authority) Limits
- Municipality and ETI
- Country
- Páramos
- RAMSAR Sites
- Regions
- Forest Reserves (Law 2)
- Indigenous Reserve
- Peasant Reserve Zones

It is important to note that the analytical regions have a different definition from the classification regions shown in **Figure 28**, In addition, they include specific areas of interest, such as inter-Andean valleys, as presented in **Table 13.**

Table 13. Areas of analysis regions

Region	Area WGS84 UTM Web Mercator (km2)*	Area SRC_FGA sinusoidal(km2)**	National Single Origin 12 (km2)***	Percentage
Amazon	460.399,09	458.756,58	456.894,60	39,69%
Andean	297.810,96	294.358,77	293.157,28	25,67%
Caribbean	118.813,37	115.107,53	114.566,37	10,24%
Insular Caribbean	82,67	78,94	79,63	0,01%
Caribbean Buffer	3.147,96	3.027,98	3.018,37	0,27%
Pacific	67.532,50	66.794,48	66.787,60	5,82%
Pacific Buffer	3.288,61	3.254,53	3.257,10	0,28%
Insular Pacific	14,96	14,88	14,92	0,00%
Orinoquia	173.756,96	172.003,79	171.324,55	14,98%

Inter-Andean Valleys	35.276,72	34.831,93	34.663,11	3,04%
National total (without buffer)	1.153.687,24	1.141.946,90	1.137.488,07	100,00%
National total (with buffer)	1.160.123,82	1.148.229,42	1.143.763,53	100,00%

Note: From left to right, areas were calculated using: Google Earth Engine with the *ee.Image.pixelArea* function under the WGS84 UTM Web Mercator projection; sinusoidal projection; and national origin projection. Surface values may differ from those obtained using other projections. The data include a buffer area generated for mapping dynamic land cover along coastal boundaries.

6.Validation process

Accuracy analysis is a method for evaluating the quality of maps. It is carried out by an institution external to the authors or interpreters of the classification and provides information on the overall accuracy of the map, as well as omission and commission errors for each classified category. In this case, the accuracy analysis was performed by sampling the maps; the population (i.e., the total number of pixels) was divided into two domains: Colombia inside and outside the RAISG boundary.

For each domain, a one-stage stratified proportional random sampling was performed. Stratification was defined by dividing the domain into six slope levels. Within each stratum, a simple random sampling of primary sampling units (pixels) was performed. The results of the accuracy analysis showed that the maps were generally accurate. Overall, the accuracy analysis provided evidence that the maps were of good quality. This information is useful for map users, as it allows them to trust the accuracy of the data.

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

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

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 areas outside RAISG, the maximum proportion of 0.25 was used); and z is the standardized normal distribution factor corresponding to the adjusted confidence level 1 − g, calculated using the Bonferroni correction, where g = k − 1 and 1 − α is the desired confidence level; k is the number of land use and land cover classes. (Cochran, 1977).

Three independent interpreters classified each sample annually from 1985 to 2024. In this study, the class with the most votes in each observation was considered. Visual inspections were carried out using a tool called Temporal Visual Inspection (TVI). The TVI tool was developed by the Image Processing and Geoprocessing Laboratory (Lapig) at the Federal University of Goias (UFG). For each year evaluated, the interpreter had access to two Landsat images (SWIR-NIR-RED composition). Auxiliary information, such as coordinates and region, was also provided.

Interpreters also had the ability to view high spatial resolution images from Google Earth Pro software.

7. Application

The application of MapBiomas Colombia data can encompass several areas, primarily associated with land cover monitoring at both spatial and temporal scales. These applications can be approached from multiple perspectives, including environmental, social, and political dimensions. The temporal series generated by MapBiomas, based on medium-resolution satellite imagery, enables the understanding of dynamics such as land cover transitions, land use change, forest loss and gain, urban expansion, mining and water dynamics, natural hazards, territorial planning, and the management of protected areas, among others.

Likewise, since these data cover a 40-year period (1985–2024), they have the potential to complement studies on environmental impact assessment, greenhouse gas emissions, climate change, glacier retreat, and deforestation across different regions of Colombia. They can also support analyses of public policies and planning instruments developed during this period, such as the implementation of local and regional land-use plans, the designation of protected areas, the construction of reservoirs and hydroelectric plants, spatial dynamics associated with conflict and peace agreements, agricultural frontier expansion, and disaster and risk management, among other processes that can be evidenced through land cover monitoring using medium-resolution imagery.

8.Practical considerations and challenges

The generation of multitemporal geospatial information on LULC provides insight into the state of the country's forests and strategic ecosystems, serving as a basis for establishing mechanisms for land-use planning and biodiversity conservation. In this regard, the production of the MapBiomas Colombia Collection 3.0, covering the entire national territory for the period 1985–2024, aims to contribute to knowledge generation through the application of these data in research, as well as to consolidate a monitoring tool that enables the visualization of dynamics and changes in different land-cover types.

The methodology implemented in the project, standardized by the MapBiomas Initiative across the Amazon region, has demonstrated several advantages that position it as a replicable methodology. The automation of processes through the use of machine learning has improved mapping efficiency, the reliability of results, and processing speed. The Google Earth Engine (GEE) platform is particularly suitable for processing large volumes of data, and the application of post-classification filters has helped mitigate the effects of low-quality or limited satellite image availability, mainly affecting the early years of the time series. Additionally, the mapping of specific land-cover types across all regions has provided greater thematic detail in land-use and land-cover maps. During the implementation of this methodology, a multidisciplinary team collaborated, which contributed to consolidating a more comprehensive approach.

Based on the challenges encountered in the previous collection, several adjustments and improvements were made to the legend and methodology. First, for the current collection, classification regions were redefined due to the simultaneous presence of certain classes in some areas that caused confusion during classification, given their similar spectral responses. The stable samples used to train the algorithm were obtained from the MapBiomas Colombia Collection 2.0. There was also an improvement in the optimization of the scripts used for both the general map and the different cross-cutting themes. Two cover types were added for high-altitude areas: High Andean Herbaceous and Shrubby Vegetation (ID 81) and Flooded Andean Herbaceous and Shrubby Vegetation (ID 82). In the lowland areas of the Caribbean, the mapping of cover types associated with banana cultivation (ID 74) was included, and across Colombia, a new class corresponding to Solar Panel Farms (ID 75) was added.

At the methodological level, the satellite mosaics corresponding to Collection 3.0 were fully parameterized for the entire national territory using the World Reference System (WRS), the standard employed by the Landsat mission for systematic image organization. It was decided to discontinue the national map sheet system (1:500.000 scale) for the Amazon region in order to homogenize spatial transitions in the border areas between the Amazon region (RAISG) and the rest of the national territory. This methodological decision made it possible to mitigate abrupt discontinuities in land-cover spectral reflectance and to optimize the number of images required for mapping the Colombian Amazon.

A topographic correction module was implemented for mosaic processing, integrating geomorphological and illumination variables such as terrain slope, solar incidence angle, and solar azimuth. The main objective of this correction was to minimize omission and overestimation errors in land-cover classification, a problem particularly relevant in steep-slope areas such as the mountainous regions of the Andes, where topography-induced reflectance variability affected the accuracy of previous collections.

Finally, qualitative improvements were made to the mosaics, prioritizing in this version the accuracy in detecting anthropogenic-use areas that transition with natural cover. While previous collections prioritized complete coverage of all classes, the current strategy involved a relative reduction in overall mosaic quality, offset by a significant improvement in the delineation and characterization of these transitional areas. For future collections, the objective is to further refine the methodology, incorporating a more detailed classification legend, improving mapping accuracy, and integrating new technologies and remote-sensing tools to produce higher-quality outputs.

9. Appendix

Appendix 1 - Glacier
Appendix 2 - Mining
Appendix 3 - Infrastructure
Appendix 4 - Wetlands
Appendix 5 - Mangrove

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