Towards sustainable conservation: monitoring moriche palm groves in the Matavén Forest

REDD+ Matavén

METHODOLOGICAL REPORT

This study was conducted as part of the activities of the REDD+ Matavén Project, under the framework of the Verra standard; Climate, Community, and Biodiversity (CCB).

Prepared by: Engineer Miguel Andrés Idrobo

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1 INTRODUCTION

Moriche palm groves, oases of biodiversity in the vast Orinoquía region of Colombia, are wetland ecosystems characterized by the dominance of moriche palms (*Mauritia flexuosa*). These emblematic species not only shape the landscape but also support a rich diversity of life. Interspersed between savannas and forests, these systems are crucial for water conservation, biodiversity, and the local cultures that depend on them.

The objective of this study is to deepen the understanding of these vital systems through temporal monitoring, using primary sources of biodiversity studies. By direct observation and data collection, the study aims to comprehend the internal dynamics of the moriche palm groves, their evolution, and how these factors influence the conservation and sustainable development of the region.

To achieve this goal, cutting-edge technological tools were employed, including the use of the Phantom 4 drone for capturing high-resolution aerial images and specialized software such as Agisoft for photogrammetric processing and QGIS for GIS analysis. These tools have enabled the creation of digital terrain models and the generation of precise data on the spatial configuration of the moriche palm groves.

The methodology adopted for this study involved a careful selection of ten moriche palm groves to be mapped, based on criteria including ecological representativeness and accessibility. The photogrammetric process followed by GIS analysis facilitated the quantification of palms and the estimation of their heights, as well as the generation of key metrics for long-term monitoring, such as moriche palm grove areas, vegetation succession indices, and areas without arboreal vegetation cover.

The results of this study, focused on moriche palm groves M1 to M10, reveal a remarkable diversity among the systems examined, reflecting different states of conservation, degrees of human intervention, and growth dynamics. From expanding palm groves to those in advanced stages of vegetation succession, the study highlights the complexity of these systems and emphasizes the need for adaptive and sustainable management approaches for their conservation.

This study underscores the importance of moriche palm groves in the Matavén Forest and provides valuable insights for future conservation efforts.

2 MATERIALS

In this section, we detail the key tools and technologies employed for monitoring the *morichales* (palm swamp ecosystems). Our methodology relies on a set of specialized equipment and software designed to collect and analyze data with precision and efficiency. Among the resources utilized, the Phantom 4 Pro drone stands out as an advanced tool for conducting photogrammetric flights, allowing us to capture high-resolution aerial images. For processing these images, we used Agisoft Metashape version 1.7.0, a leading photogrammetry software that facilitates the reconstruction of digital models of terrain and vegetation.

Additionally, we implemented GIS tools for the development of cartographic products, enabling a detailed representation of the ecosystem. This includes the creation of points for enumerating *moriche* palms and polygons for the precise quantification of affected areas. SAGA software was employed to perform geostatistical processes, while GeoDa was selected for a specific case where the orthoimage was impacted by cloud brightness and shadows, affecting the digital terrain modeling. This variety of tools equips us to conduct comprehensive monitoring and generate valuable information for the conservation of the *morichales*.

2.1 Phantom 4 Pro

The Phantom 4 Pro drone is an unmanned aerial vehicle (UAV) model manufactured by DJI. It features the following key characteristics (DJI, 2022):

- A 1-inch, 20-megapixel camera sensor, capable of recording 4K video at 60 fps and taking burst photos at 14 fps.
- A maximum flight time of 30 minutes and a transmission range of up to 7 km.
- An infrared sensing system that measures the distance to nearby objects, allowing for safer flight operations.
- A 3-axis gimbal that ensures stable and smooth imagery at all times.
- A maximum speed of 72 km/h in S mode, 58 km/h in A mode, and 50 km/h in P mode.
- A maximum tilt angle of 42º in S mode, 35º in A mode, and 25º in P mode.

2.2 Agisoft Metashape 1.7.0

Agisoft Metashape is a software that performs photogrammetric processing of images to generate 3D spatial data. It allows for very fast processing while providing accurate results. The program is capable of processing thousands of photos and features an intuitive, linear workflow-based project structure, making it easy to master. This enables users to have full control over the accuracy of the results, with a detailed report generated at the end of the processing (Calderón, 2021). Additionally, it can generate vegetation maps, orthophotos, digital elevation models, and other cartographic products. This tool is valuable for various applications, including research, conservation, management, monitoring, and forestry education.

2.3 QGIS 3.28.11

It is an open-source Geographic Information System (GIS) software that allows users to visualize, analyze, and manage geospatial data, such as maps and location data. The software offers a wide range of tools for working with geographic data, including visualization, spatial analysis, data editing, and customization. It is free, compatible with multiple data formats, and widely used in various applications, ranging from cartography to natural resource management and urban planning.

2.4 SAGA

SAGA (*System for Automated Geoscientific Analysis*) is an open-source software used in the field of Geographic Information Systems (GIS) and geospatial analysis. It provides a wide range of tools and algorithms for processing and analyzing geospatial data, particularly in areas related to natural resource management and environmental planning. SAGA is capable of working with both vector and raster data.

2.5 GeoDa

GeoDa (*Geospatial Data Analysis*) is an open-source software specializing in spatial analysis and geographic statistics, facilitating the detection of spatial patterns and relationships in vector-based geographic data. It offers a wide range of tools for evaluating spatial autocorrelation, creating thematic maps, and visualizing geographic data. This helps researchers and professionals better understand the geographic distribution of data and make informed decisions based on spatial information.

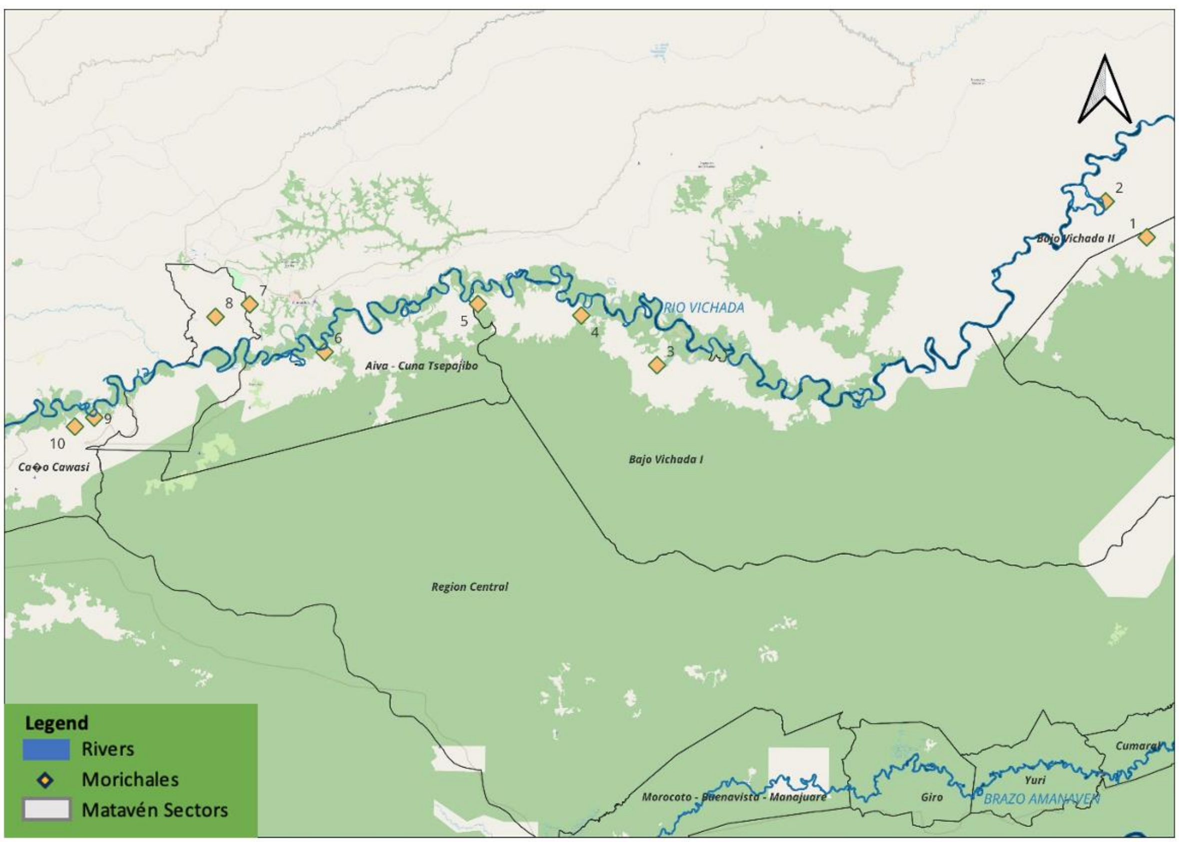
3 METHODOLOGY

Below is an overview of the general procedure used to generate information on the morichales, employing photogrammetry techniques and the generation of cartographic elements through GIS software.

3.1 Selection of the morichales to be mapped

For this study, ten morichales located in the northern region of the Resguardo Selva Matavén were identified. This area is predominantly characterized by the presence of savannas and riparian or gallery forests. The following map illustrates the general location of the morichales under study, providing a visual understanding of the geographic scope of the research.

Map 1 *Location of the morichales in the Resguardo*



In the presented map, orange diamonds indicate the specific locations of the morichales studied. These are distributed across four distinct sectors of the Vichada region: Bajo Vichada 1, Bajo Vichada 2, Aiwa Cuna, and Caño Cawasi.

The methodology for selecting the morichales was established in close collaboration with local communities, including their leaders and the indigenous guard, to incorporate a wide range of distinctive characteristics identified by community members. This approach allowed for the inclusion of morichales ranging from those that are almost untouched, like Morichal 1, to those significantly altered by human activity from nearby communities, specifically Morichales 3, 4, and 9. Additionally, morichales with high susceptibility to savanna fires were included to monitor and compare their responses and adaptability to such events. This approach aims not only to document changes and the resilience of each Morichal but also to identify and understand the possible consequences of these interventions, providing clear evidence of the underlying causes of each observation.

3.2 Photogrammetric Process

The photogrammetric approach adopted in this study proved critical in overcoming the limitations of satellite images in identifying and quantifying the biophysical elements of the morichal due to geographic scale constraints, even when high-resolution satellite images were available. The aerial images captured by drones offered a superior alternative, allowing for scale adjustments that facilitate the detailed identification of each palm and the estimation of its height. This document describes the crucial phases employed in the Agisoft software for creating an orthomosaic and a Digital Surface Model (DSM) from aerial photographs obtained by drones. The orthomosaic georeferencing was based on the automatic geotagging provided by the drone's GPS.

- *Photo alignment:* The images are aligned within the workflow context menu, and the settings are adjusted to their default state. This process results in a 360-degree terrain reconstruction.
- *Dense point cloud creation:* A dense 3D object cloud is generated, incorporating depth data and establishing the coordinate system based on the terrain location (in this case, the 32619 WGS 84 / UTM zone 19 N system).
- *Mesh generation:* A polygonal mesh of the 3D object is created, with quality and polygon scale settings configured in a dialog box.
- *Digital Elevation Model (DEM):* In the final processing stage, a digital elevation model (DEM) is generated, and an orthomosaic of the scene is captured. The point clouds are triangulated and rasterized using Delaunay triangulation as a common strategy (Gallo, Lancheros, Cáceres, Jiménez, & Porras Díaz, 2014).
- *Orthomosaic:* The images are corrected using an elevation model to eliminate terrain-related distortions. Each pixel in the image is projected onto the elevation model to determine an elevation value, which is used to reproject the image. Finally, all corrected images are joined to form a mosaic with the WGS 84 / UTM zone 19 N reference system.

Image 1 *Resolution of an aerial image using a drone*

As shown in Image 1, the moriche palms are clearly distinguishable due to the resolution of the acquired aerial image. This level of detail facilitates the generation of accurate ortho-images, which are essential for quantifying the number of palms present and also allow for estimating the individual height of each palm.

3.2 Digital Terrain Models

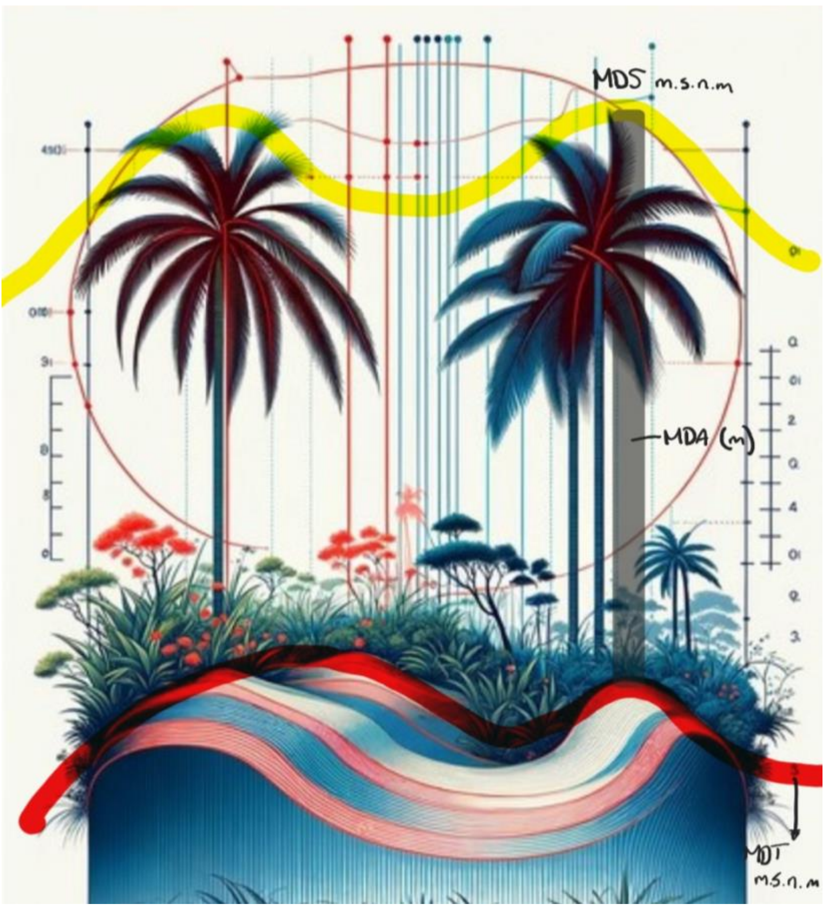
This procedure is of particular importance, as it is through the comparative analysis of digital terrain models that the height of each moriche palm is estimated. This estimation is achieved by calculating the difference between the Digital Terrain Model (DTM) and the Digital Surface Model (DSM), which allows for the generation of an additional layer known as the Digital Height Model (DHM).

- *Digital Surface Model (DSM):* This model represents the elevations of reflective surfaces, including trees, buildings, and other structures protruding from the bare ground, measured from sea level. As a result of the photogrammetric process, a specific DSM is obtained for each flight mission.
- *Digital Elevation Model (DEM):* This model constitutes a grid-based representation that describes the altitude of the bare ground, excluding elevated features, referenced to a specific vertical datum. In this study, points over bare ground areas were identified, and through the use

of SAGA GIS software, an interpolation process using the Ordinary Kriging method was performed to generate a continuous DEM.

- *Digital Height Model (DHM):* Focusing on the objective of estimating the height of moriche palms, this model was calculated by subtracting the DEM, which reflects the elevations of the bare ground, from the DSM, which includes both ground elevations and those of elevated surfaces and features. The result provides an accurate representation of the heights of elements above ground level, such as moriche palms and arboreal vegetation in each study area.

Image 2 *Illustration of terrain models over moriche palm groves*



The yellow line represents the Digital Surface Model (DSM), which reflects the heights of all visible elements in the aerial image, expressed in meters above sea level (m.a.s.l.). In contrast, the red line illustrates the Digital Terrain Model (DTM), which is derived from identifiable ground points in the aerial image. These points, after undergoing an interpolation process, form the DTM, also expressed in m.a.s.l. The final stage involves generating the Digital Height Model (DHM), which is the result of the difference between the DSM and the DTM, calculated using raster map algebra and expressed in meters. This process culminates in the precise estimation of the palm heights, using the DHM as a reference for measurement.

3.3 GIS Process for Data Generation

This section of the document details the methodology implemented for generating crucial data and information for the study and monitoring of moriche palm ecosystems, using Geographic Information Systems (GIS) tools. This process, essential for understanding and effectively monitoring the moriche palm ecosystems, is broken down into three fundamental steps: Identification of Moriche Palms, Estimation of Palm Heights, and Delimitation of Areas Associated with this Ecosystem. Each of these steps plays a critical role in obtaining detailed data and information about each ecosystem, allowing for the extraction of unique characteristics of these systems. The methodology applied for each of these steps is outlined below.

3.3.1 Quantification of Palms

The identification of palms is conducted visually through a detailed inspection of each Moriche Palm Area. Using QGIS software, a point entity is created to digitize the location of each detected moriche palm in the ortho-image. This process ensures the capture of the spatial distribution of moriche palms within the studied ecosystem, thereby facilitating detailed geospatial analysis.

Image 3 *Illustration of point entities over the ortho-image*

The orange points indicate how, using GIS software, we located the palm on the ortho-image.

3.3.2 Estimation of Palm Heights

This process relies on two key elements: the Digital Height Model (DHM) and the digitized points corresponding to each palm. Through a specific geoprocessing operation, the pixel value from the DHM raster associated with the location of each digitized point is extracted. As a result, a new column is added to the point vector layer, reflecting the estimated height for each identified moriche palm. This method ensures precise integration of altimetric data with the spatial distribution of the palms, enabling a detailed assessment of their vertical structure within the metrics to be monitored in this ecosystem (See Image 2).

Image 4 *Height in the attribute table of the palms*

Alt_palmas— Objetos Totales: 1829, Filtrados: 1829, Seleccionados: 0

FID	LAYER	Height	Mision
0	Palma	2,353660583496094	3
1	Palma	5,446533203125000	3
2	Palma	5,878479003906250	3
3	Palma	3,136825561523438	3
4	Palma	2,879592895507812	3
5	Palma	7,456527709960938	3
6	Palma	7,621032714843750	3
7	Palma	7,232124328613282	3

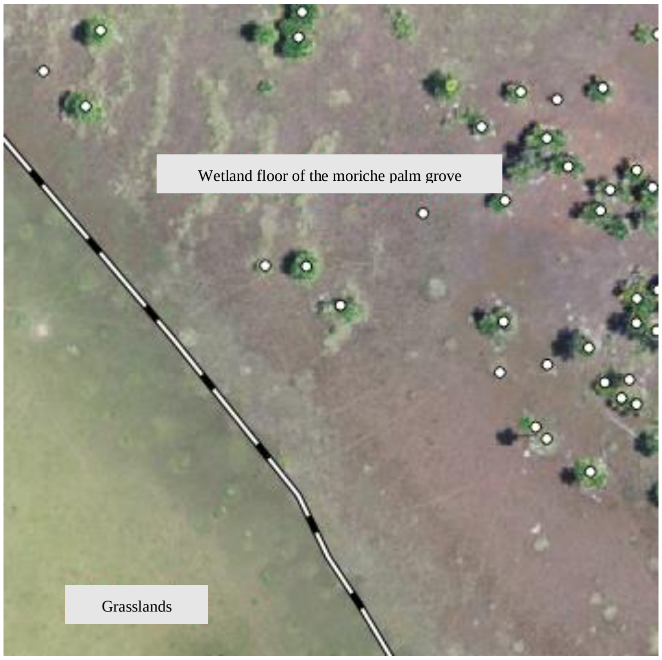
After generating the Digital Height Model (DHM), the corresponding value for each point located on the model is extracted. This step enables the creation of a new field in the database, recording the height of each palm individually. This data becomes an essential metric, providing a quantitative basis for the temporal monitoring of variations in the structure and dynamics of each moriche palm ecosystem.

3.3.3 Area Generation

The generation of areas involves the precise delimitation of distinct zones within the moriche palm ecosystem, based on discernible physical and ecological characteristics. The following are the four main areas identified for long-term monitoring:

- *Moriche Palm Area:* This zone represents the complete geographical delimitation of the moriche palm ecosystem, distinguished by a noticeable transition from the typical grassland of the savannas to wetter soils, with a high-water table and a soft texture. This boundary is identified through the interpretation of drone-captured ortho-images, as shown in Image 5.

Image 5 *Differences between the floor of a grassland and that of a moriche palm ecosystem*



- *Vegetation Succession Area:* Identified through the analysis of aerial images, this area is characterized by a process of vegetation succession in the more extensive moriche palm groves, which promotes the establishment of accompanying plant species and the formation of new riparian forests. The delimitation of this area allows for detailed monitoring of ecological dynamics over time, assessing changes in the expansion, stagnation, or reduction of these successional zones, as illustrated in Image 6.
- *Canopy Area:* This corresponds to the total surface area occupied by the moriche palm canopies within the Moriche Palm Area. This indicator is obtained by reclassifying green pixels with elevations greater than one meter, using the Digital Height Model (DHM). After vectorizing these data, the total area is calculated, excluding the Vegetation Succession Area, to monitor the health and expansion of the moriche palm canopies.

Image 6 *Vegetation succession within a moriche palm grove*

The red line demarcates a vegetation succession area within a moriche palm grove.

- *Area without Arboreal Vegetation Cover:* This area is defined as the Moriche Palm Area excluding the Vegetation Succession Area, focusing on zones that do not exhibit dense forest cover.

Each of these areas has been delineated to facilitate systematic monitoring and evaluation of the state and changes within the moriche palm ecosystem. This approach provides a comprehensive and structured description of the areas designated for monitoring, clarifying the methodology and objectives behind their identification and tracking.

Image 7 *Vegetation succession within a moriche palm grove*

The green polygons highlighted with red squares represent the area known as the foliar region of the moriche palms.

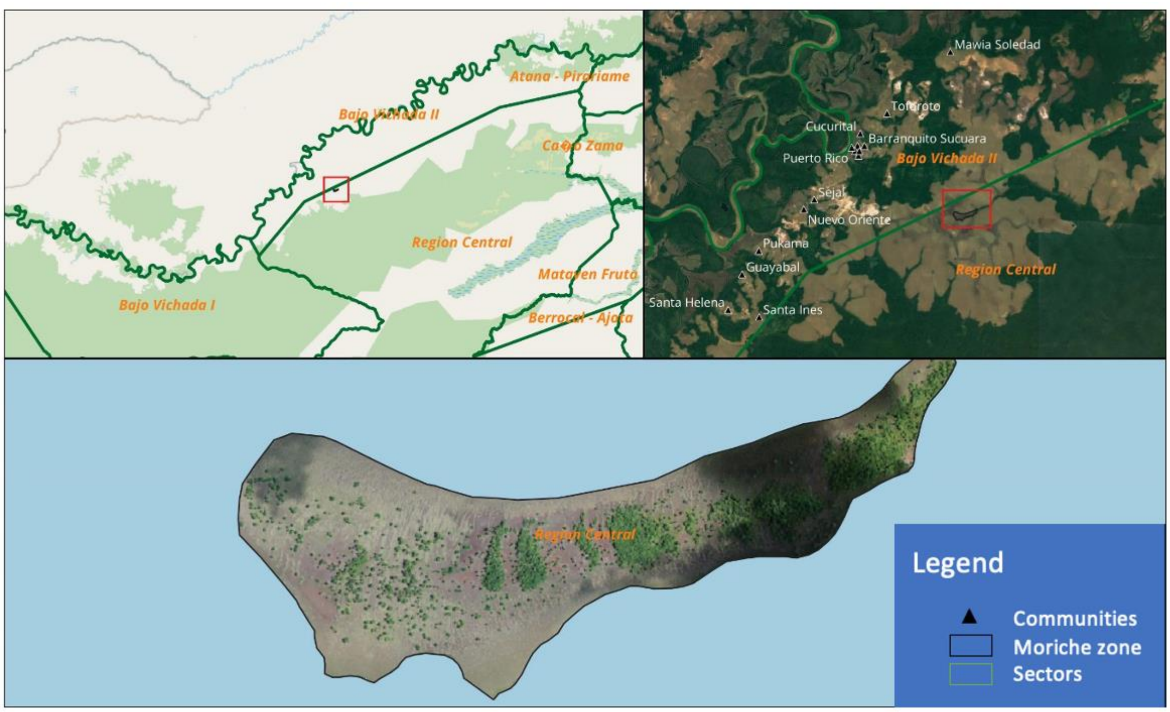
4. RESULTS

This section presents the results and outputs derived from the implementation of the methodology described above, including an individual description of each moriche palm grove studied. The purpose here is to showcase the various geospatial, cartographic, and numerical products obtained, as well as their presentation through statistical charts and maps. Additionally, a detailed evaluation of each moriche palm grove will be provided, highlighting their unique characteristics and current conditions. This approach aims not only to illustrate the key findings of our study and detail the specific metrics that will be used for ongoing monitoring of these systems or landscapes but also to offer a deep understanding of the diversity and particularities of each moriche palm grove within the broader context of conservation and study of these ecosystems. Through this comprehensive exposition, we seek to provide a solid foundation for future research and management strategies aimed at the preservation of these valuable vital systems.

4.1 Presentation of the Moriche Palm Groves

Moriche Palm Grove 1 – M1-Muva

Map 2 Moriche Palm Grove 1

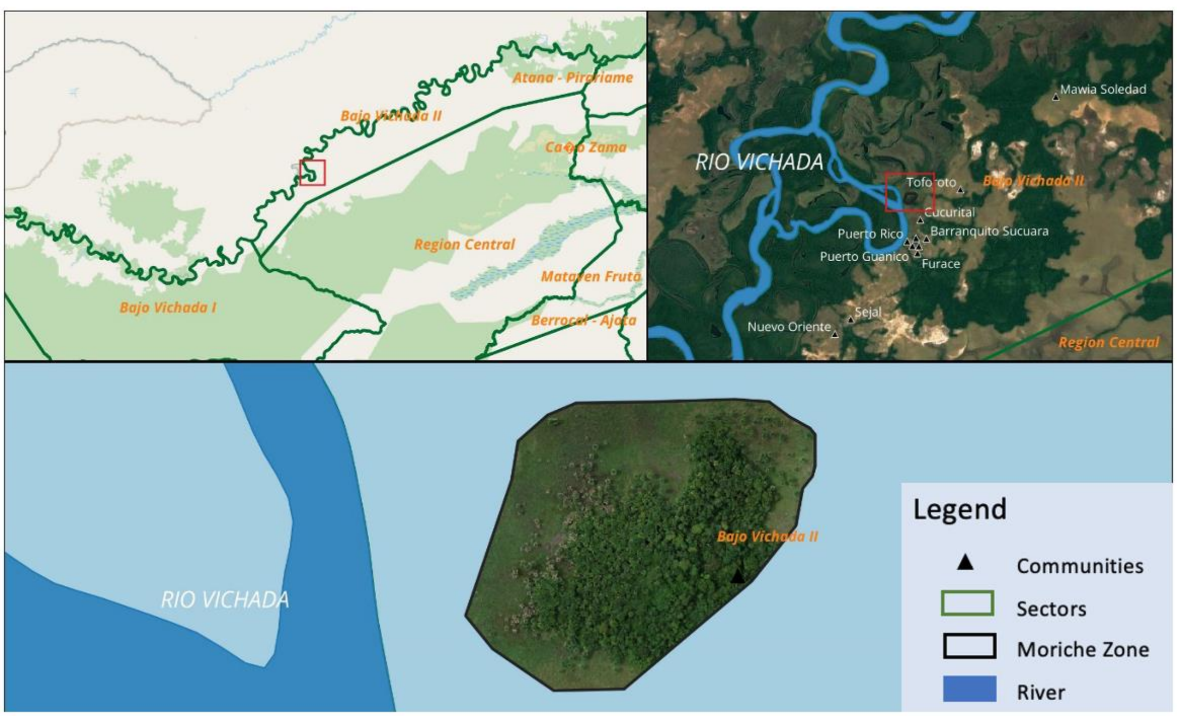


Located in the southern core of the Bajo Vichada 2 sector, near the communities of Cucurital, Puerto Rico, and Barranquito Sucuara, this moriche palm grove is distinctive for marking the final boundary of an expanding riparian forest. This moriche palm grove is in an active growth phase, standing out as one of the least affected by human intervention within the studied region. Notably, no fires have been documented in its vicinity, highlighting its low incidence of anthropogenic disturbances. This context suggests a favorable environment for conservation and an ideal ecosystem for long-term monitoring to observe ecological dynamics over time.

Moriche Palm Grove 2 – M2-La Loma

Situated in the southern heart of the Bajo Vichada 2 sector and near the communities of Toforoto, Cucurital, Puerto Rico, and Barranquito Sucuara, this moriche palm grove defines the edge of a riparian forest nearing the end of its expansion. In this scenario, moriche palms seem to be scarce. This palm grove, in the midst of a maturation phase, may be significantly influenced by human activity due to its proximity to human settlements (ranging from 500 to 2000 meters), suggesting a delicate balance between natural conservation and anthropogenic impact. The location of this moriche palm grove, particularly near a river and the maturing riparian forest adjacent to it, promises to be of great interest for future monitoring, offering a unique opportunity to study the dynamics between human intervention, natural ecological processes, and the evolution into gallery forests.

Map 3 *Moriche Palm Grove 2*



Moriche Palm Grove – M3-La Loma

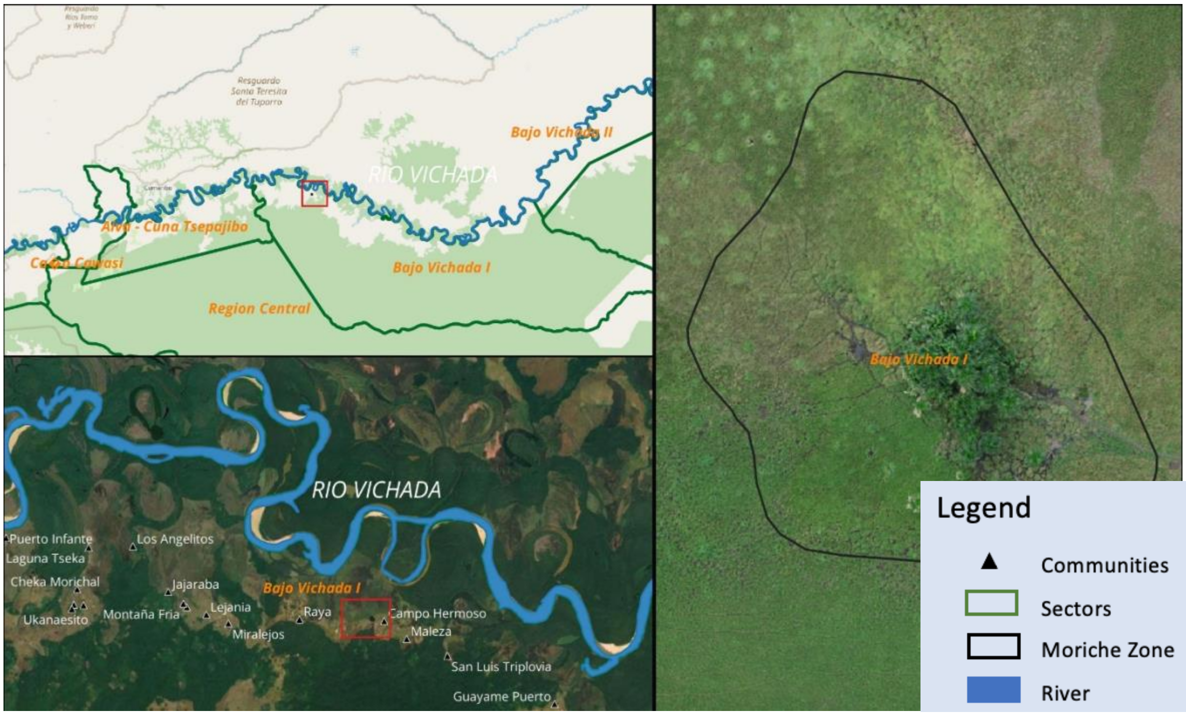
Located in the Bajo Vichada II sector, with the community of Urba Morichal as its nearest neighbor, this ecosystem appears to have found its niche in a lagoon, where particular moisture conditions and the richness of organic matter in the soil have facilitated its emergence and development. The still-limited presence of a vegetation succession area of accompanying species suggests that this is a moriche palm grove in full development. This context provides a unique opportunity to monitor the growth dynamics of a moriche palm grove, offering valuable insights into the environmental and ecological factors driving the formation and expansion of these unique systems.

Map 4 *Moriche Palm Grove 3*

Moriche Palm Grove 4 – M4-Raya

This moriche palm grove, the smallest of those selected for the study, is sustained by a water source emerging from the savanna, located in the Bajo Vichada I sector, bordered by the communities of Raya and Campo Hermoso. Its geographical position, along with high traffic and proximity to other communities, suggests intense human intervention, making it highly susceptible to fires in the surrounding savannas. The uniqueness of this moriche palm grove lies in its small size, raising questions about its potential for persistence or eventual disappearance in the future. Additionally, the absence of accompanying species is notable, setting it apart within the study and underscoring the importance of monitoring its evolution and the surrounding ecological dynamics. This provides valuable insight into the resilience and adaptability of these systems in the face of environmental and anthropogenic pressures.

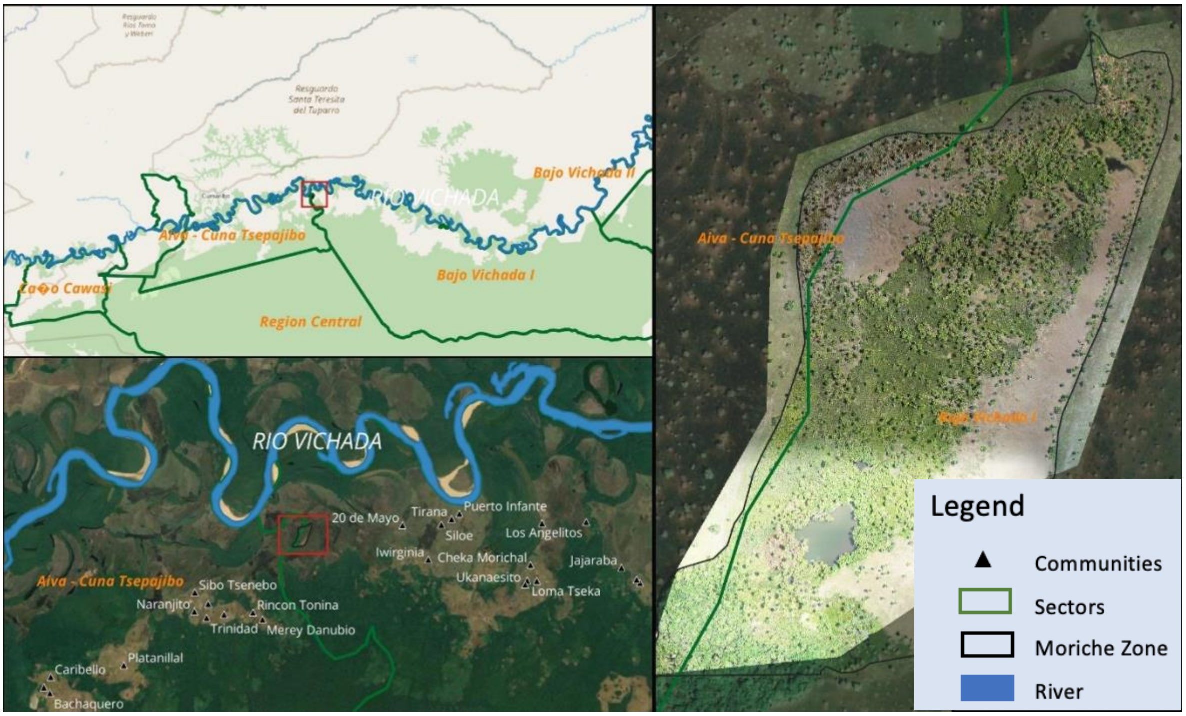
Map 5 *Moriche Palm Grove 4*



Moriche Palm Grove 5 – M5

This moriche palm grove is located at the boundary between two sectors, Bajo Vichada I and Aiva-Cuna Tsepajibo, near the Vichada River, marking an interesting geographical location. Unlike other moriche palm groves, this one does not experience high traffic, and the nearby communities do not seem to frequent it regularly. However, this does not exempt it from potential vulnerability to savanna fires. Detailed observation reveals that the moriche palm grove remains in a favorable state of conservation and is located at the intersection with a riparian forest, a characteristic commonly observed in these systems.

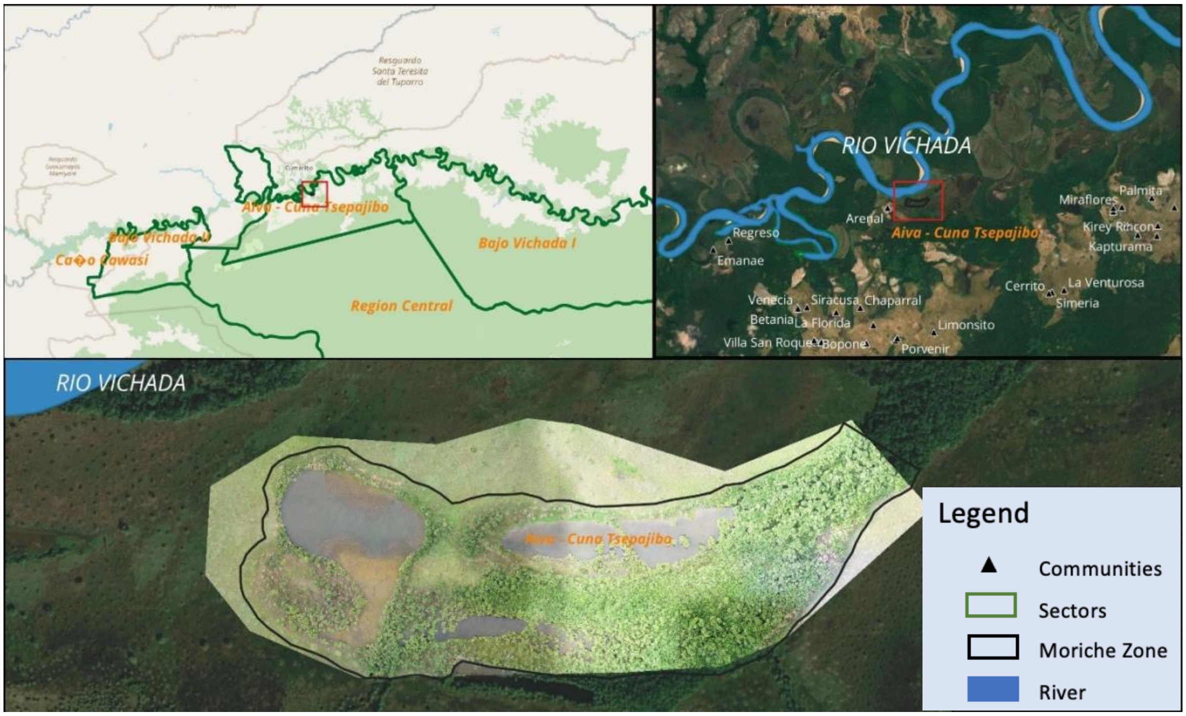
Map 6 *Moriche Palm Grove 5*



Moriche Palm Grove 6 – M6

Located in the central area of the Aiva-Cuna Tsepajibo sector and near the community of Arenal, this moriche palm grove emerges at a strategic point where a gallery forest converges with the lands surrounding a lagoon, and it is notably close to the Vichada River. The terrain configuration and its proximity to water bodies suggest optimal ecological conditions for the development of this ecosystem. The ongoing process of vegetation succession, advancing from the pre-existing forest toward the lagoons, indicates active and continuous ecological transformation. This succession pattern highlights the interaction between different habitats and their reciprocal influence on the configuration and expansion of the moriche palm grove. The location and unique characteristics of this ecosystem make it a valuable subject of study for understanding the dynamics of vegetation succession and the relationships between moriche palm groves, gallery forests, lagoons, and rivers within tropical biodiversity contexts.

Map 7 *Moriche Palm Grove 6*



Moriche Palm Grove 7 – M7 – Cumaribo

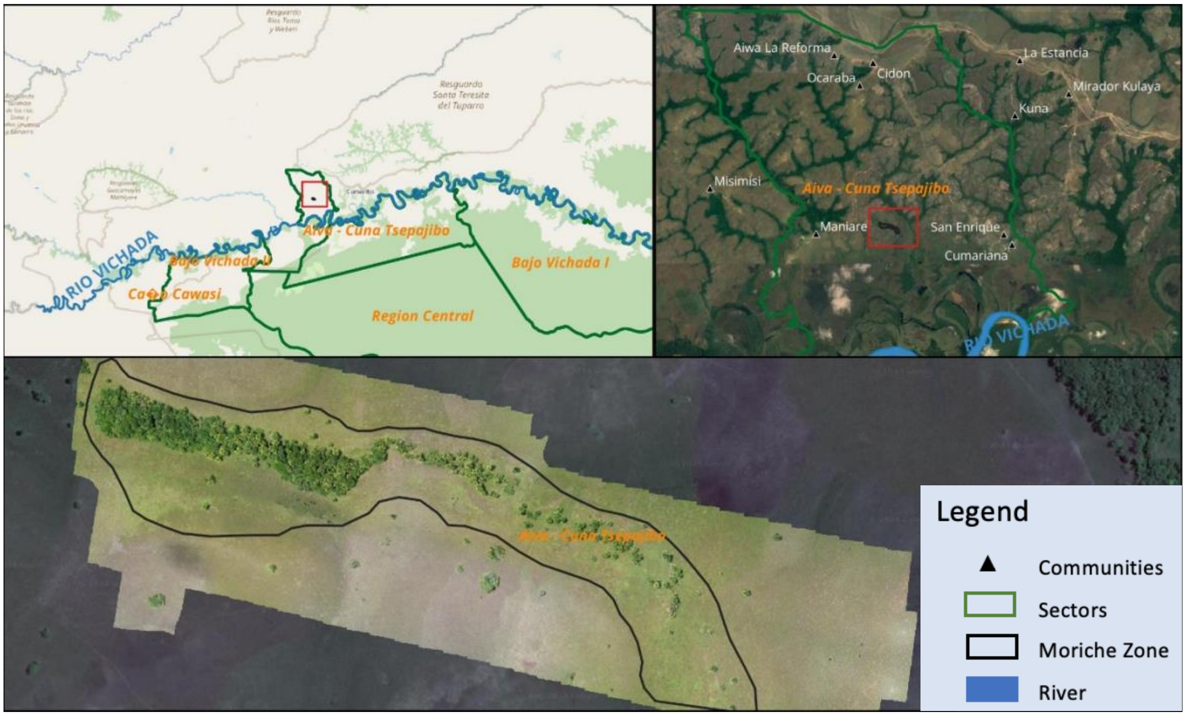
Located on the periphery of the Resguardo, this moriche palm grove, while not strictly within the legal boundaries, is situated near communities belonging to the Resguardo, including Kuna, Mirador Kulaya, San Enrique, and Cumariana. It stands out as the palm grove with the largest palms and the highest index of vegetation succession or associated forest, indicating its advanced state of maturity. As shown on the map, this ecosystem is positioned at the confluence of two gallery forest corridors, demonstrating that it has achieved notable forest connectivity across the savanna. However, a critical aspect is the high degree of intervention by nearby communities, including deforested areas, which raises questions about its resilience and recovery capacity in the face of anthropogenic disturbances. Continuous monitoring of this moriche palm grove will provide valuable insights into human interaction with mature systems and its impact on biodiversity and ecological connectivity.

Map 8 *Moriche Palm Grove 7*

Moriche Palm Grove 8 – M8 – Cumariana

This moriche palm grove is distinctive not for being the endpoint of a gallery forest but rather for being an ecosystem in full development, unexpectedly emerging in the heart of the savanna, though surrounded by gallery forests. In its northern, or upper area, a vegetation succession zone is already evident, characterized by the presence of tall tree species, while the southern, or lower area, appears to be the advancing front of the moriche palm grove. A notable feature is its status as a high-traffic area, located near several communities. This interaction with the human environment gives the moriche palm grove a unique dynamic, where the balance between natural expansion and anthropogenic influence shapes its structure and evolution. Observing this ecosystem offers a unique opportunity to study the interactions between growing moriche palm groves and human activity, as well as to understand the vegetation succession processes that contribute to the formation of these landscapes.

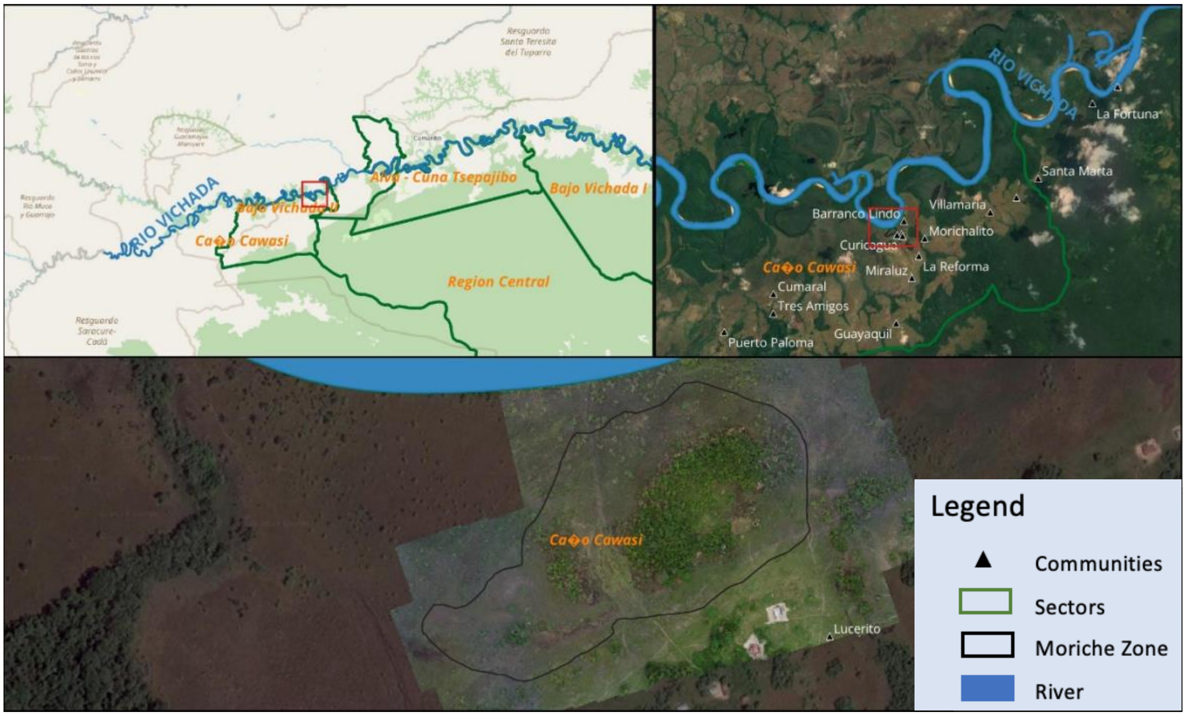
Map 9 *Moriche Palm Grove 8*



Moriche Palm Grove 9 – M9 – Cumariana

This moriche palm grove is characterized by significant human intervention, located in close proximity to at least three communities and serving as a direct corridor to the Vichada River. This proximity makes it particularly interesting, as it offers a unique opportunity to analyze the ecosystem in a mature state and understand how it interacts with the surrounding communities. The evaluation of this moriche palm grove will provide insights into its resilience to anthropogenic influences, offering valuable lessons on the coexistence between moriche palm groves and human settlements.

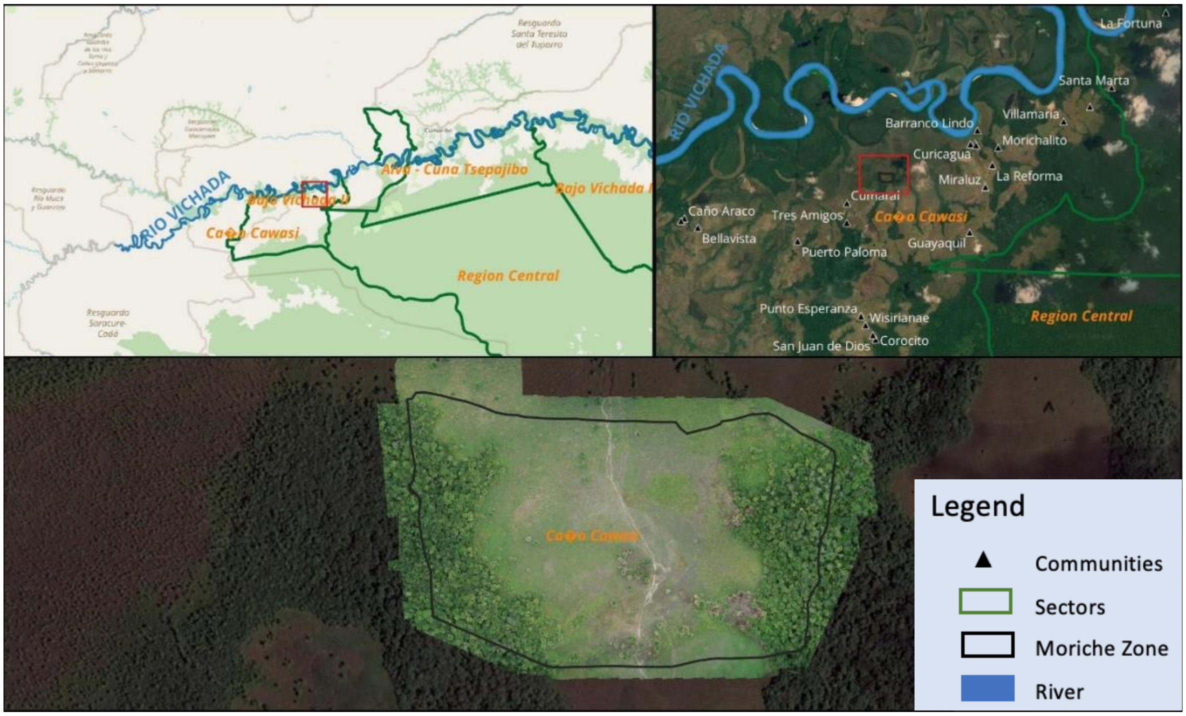
Map 10 *Moriche Palm Grove 9*



Moriche Palm Grove 10 – M10 – Cawasi-Cumaral

This moriche palm grove is situated at the edge of a gallery forest, making it a focal point for studying and analyzing the interaction between both types of ecosystems. The hypothesis that this area was once dominated exclusively by moriche palms, gradually evolving to include a gallery forest, presents a fascinating ecological dynamic. Notably, this moriche palm grove functions as a human transit zone, adding an additional layer of complexity when observing how these interactions unfold. The key interest lies in determining whether the moriche palm ecosystem will eventually be absorbed by the advancing forest or, conversely, manage to sustain its own expansion. This scenario presents a valuable opportunity to understand ecological succession processes and the influence of human activities on the configuration and future of these natural landscapes.

Map 11 *Moriche Palm Grove 10*



4.2 Geospatial Products

The following section presents the various geospatial products resulting from the processes and application of the described methodology. These include both raster and vector products, which together form the cartographic basis of the study. In addition to presenting these products, we will detail the technical characteristics of the corresponding digital files, such as the projection system used, pixel size, and other relevant specifications. These characteristics are essential for understanding the accuracy, scale, and geospatial context in which the data are embedded, thus facilitating a detailed and rigorous analysis of the moriche palm grove ecosystem.

Table 1 *Raster Products*

Product	Quantity	Spatial Resolution
Ortho-images	10	3 a 5 cm / Pixel
MDS	10	10 cm / Pixel
MDT	10	10 cm / Pixel
MDA	10	10 cm / Pixel

Table 2 Vector Products

Product	Cartographic Entity
Morichal Area	Polygon
Vegetation Succession Area	Polygon
Canopy Area	Polygon
Palms	Point
Area without Arboreal Vegetation Cover	Polygon

4.3 Metrics and Comparison Between Moriche Palm Groves

The following table provides a comprehensive analysis of various ecological and demographic metrics related to ten specific moriche palm groves, identified from M1 to M10. It details key aspects such as Moriche Palm Grove Area, Vegetation Succession Area, Canopy Area, and Area without Arboreal Vegetation Cover, along with figures on the Number of Palms present in each ecosystem. Additionally, critical indicators such as the Palm Canopy Area Index, the Vegetation Succession Index, and the Palm Density Indicator (Number of Palms per Hectare) are included, offering deep insight into the structure, biodiversity, and conservation or intervention status of these systems. This dataset not only illustrates the inherent diversity of each moriche palm grove but also highlights the dynamics of vegetation succession and the interaction between moriche palms and other vegetative components. Each metric is subsequently described in terms of Areas and Indices.

Table 3 Ecosystem characteristics and moriche palm indices: a comparative analysis

Metrics/ID of Moriche Palm Groves	*M1*	*M2*	*M3*	*M4*	*M5*	*M6*	*M7*	*M8*	*M9*	*M10*
Moriche Palm Grove Area (ha)	29,1	10,4	7,3	0,4	18,1	15,7	8,4	7,3	6,4	13,4
Vegetation Succession Area (ha)	4	5	1	0	1	6	5	1	1	4
Canopy Area (ha)	3,5	0,7	1,7	0,0	4,2	1,4	0,2	0,4	0,3	0,9
Area without Arboreal Vegetation Cover (ha)	25,4	5,0	6,8	0,4	16,8	9,5	3,5	6,3	5,1	9,8
Number of Palms	1040	154	1830	67	2880	937	227	199	115	385
Palm Canopy Area Index	0,2	0,5	0,3	0,1	0,3	0,5	0,6	0,2	0,3	0,3
Vegetation Succession Index	0,13	0,44	0,07	0,00	0,07	0,39	0,27	0,14	0,20	0,27
Palm Density Indicator (palms/ha)	36	15	251	149	159	60	27	27	18	29

Source: Own elaboration

Moriche Palm Grove Area: The extent of the studied moriche palm groves shows notable variability, with the smallest area recorded in M4 (0.4 ha) and the largest in M5 (18.1 ha) and M1 (29 ha). This diversity in size suggests that the moriche palm groves are at different stages of development and face varying degrees of disturbance. This hypothesis is supported by the analyzed indicators, which reflect differences in the ecological structure and composition of each moriche palm grove.

Vegetation Succession Area: The highest values observed in M1, M2, M6, M7, and M10 (greater than 4 ha) indicate active vegetation succession processes, which could be contributing to the formation of new riparian forests. This dynamic is crucial for the biological diversification and ecological resilience of the moriche palm groves. In contrast, the absence or lower presence of vegetation succession in other moriche palm groves may indicate environmental disturbances or, alternatively, early stages of development.

Canopy Area: With values ranging from 0.0 ha in M4 to 4.2 ha in M5, this metric is essential for evaluating the overall health and density of moriche palm canopies. These data provide a better understanding of the ecosystem structure and the living conditions of associated species.

Area without Arboreal Vegetation Cover: This metric reveals the proportion of the moriche palm grove without dense forest cover, varying significantly across the studied sites. The observed differences suggest variability in habitat composition and structure, which have direct implications for biodiversity and resource availability within the moriche palm groves.

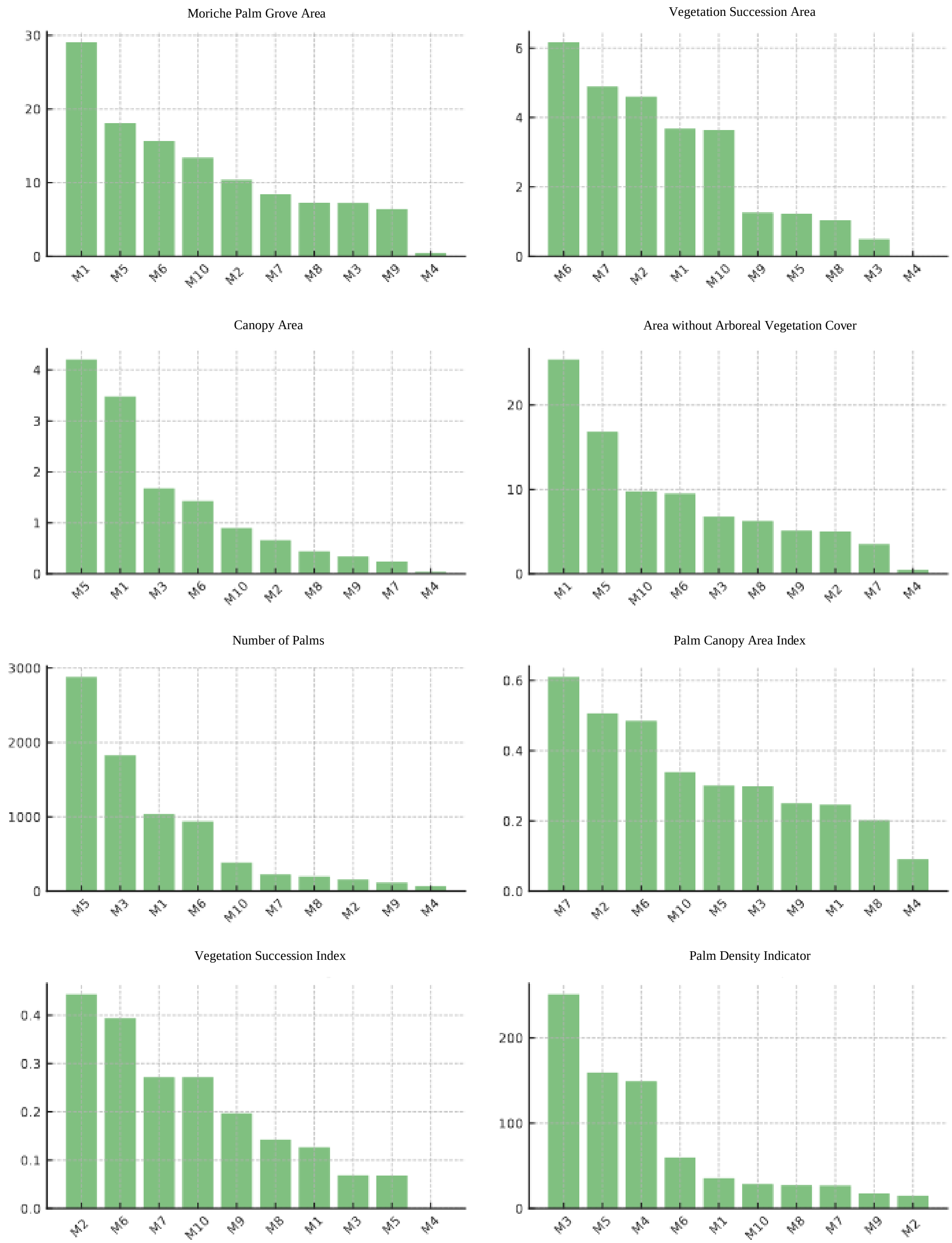
Analysis of Indices and Indicators

Palm Canopy Area Index: Variability in this index suggests differences in canopy cover among the moriche palm groves. A higher index indicates greater canopy coverage, serving as a key indicator of palm health.

Vegetation Succession Index: This index allows for the evaluation of the degree of vegetation succession and the potential formation of riparian forests, providing a basis for comparisons between different moriche palm groves.

Palm Density Indicator (Palms/Ha): The density of palms per hectare varies considerably, highlighting significant differences in palm distribution and abundance within the moriche palm groves. This metric is fundamental for understanding the specific ecological dynamics of the moriche palm ecosystems.

Image 8 *Graphical Indicator of Area and Index Variations*



4.4 Analysis of Moriche Palm Heights

Table 4 provides a comprehensive analysis of the heights of moriche palms distributed across ten moriche palm groves selected for the study. This table summarizes key statistical data, including the mean, median, variance, standard deviation, coefficient of variation, and the minimum and maximum recorded heights. The table offers a detailed comparison that reflects not only the diversity in the vertical structure of the moriche palm groves but also the intrinsic variability within each studied location. By presenting these indicators, the table provides a solid quantitative basis for understanding the growth dynamics and ecological characteristics of moriche palms, which are essential for further analysis of the ecosystem conditions and processes influencing these unique systems. This methodological approach enables a rigorous and comparative evaluation of palm heights, offering valuable findings for future research, conservation strategies, and long-term monitoring.

Table 4 *Height Statistics (in meters) of Moriche Palms*

Moriche Palm ID/ Statistics	1	2	3	4	5	6	7	8	9	10
Mean	8,1	4,1	5,3	7,1	5,3	5,2	13	6,3	5,4	7,9
Median	8,2	4,3	5,2	7	5,1	5,2	13,5	6,3	5	7,8
Variance	18,0	1,26	5,8	5,7	5,4	3,6	25,1	4,3	5,4	9,4
Standard Deviation	4,2	1,1	2,4	2,4	2,3	1,8	5	2,	2,3	3
Coefficient of Variation	51,8	27,6	45,6	33,9	43,8	36,2	38,6	32,7	42,8	38,7
Minimum Value	1	0,7	1,0	2,6	1	1	1,1	1	1	1,5
Maximum Value	20,8	6,7	14,3	11,7	16,6	13,3	23,9	14,4	10,4	18,9

Source: Own elaboration

After examining Table 4, we delve into a detailed analysis of the heights of moriche palms in the ten moriche palm groves studied. This section of the document focuses on exploring the complexities and variations observed in the metrics presented earlier. By diving into this analysis, we will reveal the height trends and perspectives that characterize each moriche palm grove, highlighting significant differences in their growth conditions, population structures, and ecological dynamics. This analysis will be combined with the metrics and indicators from Table 3 and Image 8. This approach will allow us to better understand the factors contributing to the diversity of these systems, while also providing a solid foundation for decision-making in conservation and monitoring.

Moriche Palm Grove 1 stands out for its significant variability in palm height, reflected in a coefficient of variation of 51.8%, the highest among those studied. With an area of 29 hectares, this moriche palm grove is not only the largest but also presents a notable area of vegetation succession, indicating an ecosystem expanding both in terms of area and the number of palms. However, the low proportion of palms per hectare suggests potential for further growth in the height of existing palms.

Moriche Palm Grove 2 stands out for its remarkable homogeneity and stability, recording the lowest average height in the sample at 4.1 meters, as well as the lowest coefficient of variation at 27.6%. This moriche palm grove, already in an advanced stage of maturity, is characterized by its high vegetation succession index and the lowest count of palms per hectare, suggesting an almost complete transition into a gallery forest. This evolution is a dynamic that future observations could verify, marking it as a key area for long-term monitoring and the study of ecological succession processes in these systems.

Moriche Palm Grove 3 is characterized by a moderate average height of 5.3 meters, accompanied by notable variability. This, combined with one of the smallest observed vegetation succession areas, contrasts with its high palm density. This phenomenon suggests that soil conditions are optimal for the flourishing and proliferation of new palms, indicating a vibrant and expanding ecosystem. Despite this apparent vitality, the moriche palm grove has not yet reached the ecological threshold necessary to trigger a vegetation succession process that culminates in the formation of a gallery forest. This suggests that it is in a dynamic growth and transformation phase, which promises to be a focal point for monitoring the transition towards a forested environment.

Moriche Palm Grove 4 stands out for its small size and lack of vegetation succession, along with a high proportion of palms per hectare, which could indicate intense human intervention and stagnant growth.

Moriche Palm Grove 5 is similar to Moriche Palm Grove 3 in terms of average height, extent, and growth characteristics, with the largest number of palms and a significant proportion per hectare, reflecting dynamic and comparable growth conditions.

Moriche Palm Grove 6 presents a balance between average height and variability, notable for its extensive vegetation succession area, suggesting an advanced state of maturity despite a lower palm density per hectare.

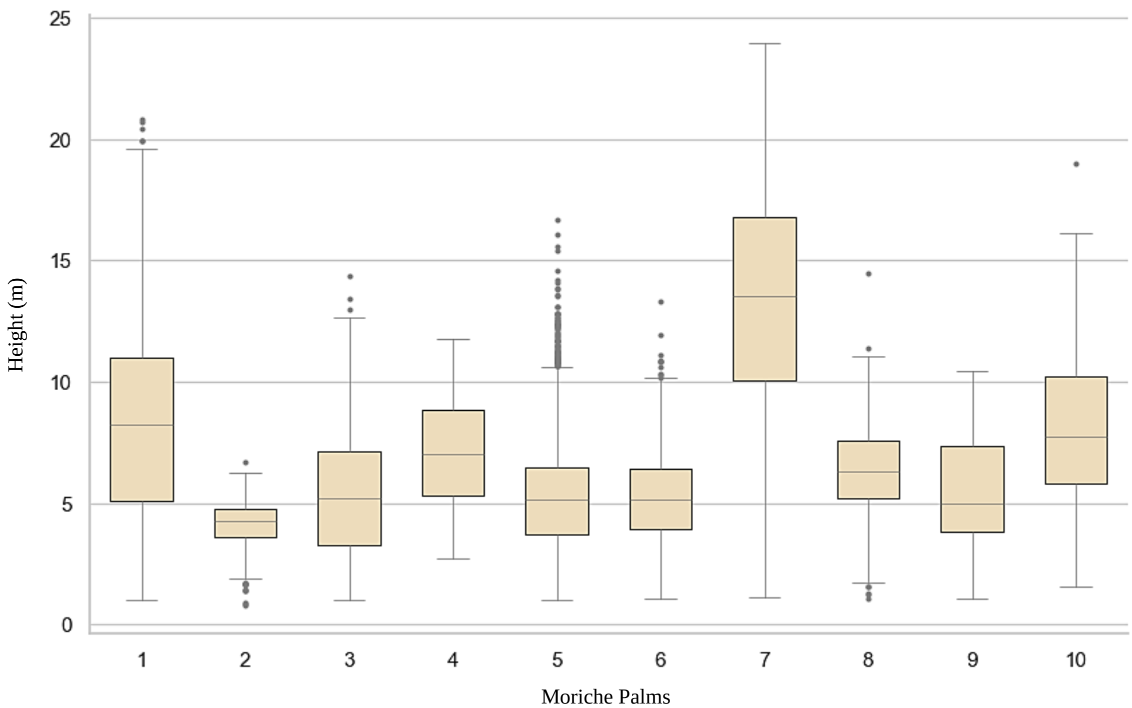
Moriche Palm Grove 7 stands out for its optimal growth conditions, recording the highest average height (13 meters) and the greatest variability. This moriche palm grove, with tall palms and a significant vegetation succession index, indicates an advanced degree of ecosystem maturity.

Moriche Palm Grove 8 is emerging as a growing ecosystem, marked by significant accessibility and considerable human intervention, inferred from its strategic geographical location. Observations indicate that the palms present do not reach considerable heights and exhibit limited variability, as seen in other evaluated metrics, which also record low values. This configuration suggests that the moriche palm grove is in an active development and expansion phase, not only in terms of moriche palms but also in terms of accompanying plant species. Such dynamics underscore the importance of continuously monitoring this moriche palm grove to better understand the growth patterns and interactions among the various life forms inhabiting it, as well as the effects of human activity on its evolution.

Moriche Palm Grove 9 stands out for how accessibility and human intervention have shaped its ecological structure, reflected in low indicators across most evaluated metrics, with the notable exception of its vegetation succession index. This peculiarity suggests a dynamic of vegetation succession, possibly due to the anthropogenic reduction of the water tables. Despite this, in terms of palm height, this moriche palm grove does not feature particularly tall specimens, and it also shows limited variability in this aspect. This configuration suggests that, although the ecosystem is in a process of adaptation and change, the diversity in palm height remains relatively homogeneous.

Moriche Palm Grove 10 is notable for having one of the highest average palm heights, and although it shares conditions of human intervention with other moriche palm groves, it stands out for its higher degree of vegetation succession, suggesting a particular ecological complexity.

__Image 9__ Graphical indicator of the variations in moriche palm heights



5. CONCLUSIONS

Importance of High-Resolution Imagery: High-resolution imagery is essential for the study and monitoring of moriche palm ecosystems, allowing for precise identification of biophysical characteristics and the generation of detailed metrics due to its scale and spatial resolution. This methodological approach enables the accurate observation of changes over time, facilitating a deep understanding of ecological dynamics and the assessment of the impact of human interventions and natural phenomena.

Richness of Moriche Palm Groves in the Resguardo Selva Matavén: The Resguardo Selva Matavén hosts a remarkable diversity of moriche palm groves, each exhibiting varied forms, states, and stages of development. From palm groves in full growth to those in advanced stages of vegetation succession, these systems reflect the rich biodiversity and ecological complexity of the region. Noteworthy examples include palm groves with high palm densities, those located at the confluence of gallery forests, and others in fire-prone areas, demonstrating the wide range of environmental and ecological conditions present for monitoring.

Palm Heights as an Ecosystem Indicator: The variability in palm height within the moriche palm groves provides valuable insights into the ecosystem's status. Significant differences in height and palm variability can reflect different levels of ecological maturity, human intervention, and the resilience capacity of the palm grove. These data are crucial for understanding the overall health of the ecosystem, its stability, and potential threats to its conservation.

Interaction Between Moriche Palm Groves and Communities: The 10 studied moriche palm groves exhibit a variety of interactions with surrounding communities, ranging from high human intervention to relative preservation. The proximity of these palm groves to human settlements influences their ecological dynamics, highlighting both the challenges and opportunities for harmonious coexistence between the palm groves and local populations. The sustainable management of these natural resources is essential to ensuring their preservation and the well-being of the communities that depend on them.