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Historical Evolution of Land Cover by Remote Sensing: A Case Study

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Abstract: This investigation was performed for the Meandro or Madrevieja de Guarinocito District of Integrated Management, Colombia, and was carried out via remote sensing and Geographic Information System (GIS) tools, which used satellite images, atmospheric corrections, and supervised classification. The results obtained for the twenty-six-year period indicate a gradual decline in forest cover from 1991-2017; grassland cover increased between 1991-2000 and was reduced between 2000-2017. Finally, the presence of the mosaics of grasslands and plantations cover increased considerably. Covers were identified by way of band composition, NDVI, and supervised classification. The patterns of change procedure were then implemented, which revealed that, from 1991-2000, there were no changes to 68.6%, or 1,088.9 hectares, of the area studied, and from 2000-2017, there were no changes in an area totaling 53.8%, or 854.3 hectares. Finally, based on supervised classification and the composition of Landsat band images, seven covers were identified in the District of Integrated Management, and farming systems were recognized as causes of forest cover reduction.

Keywords: remote sensing, land change modeling, multitemporal analysis, supervised classification, normalized vegetation index.

遥感土地覆盖的历史演变：一个案例研究

摘要：这项调查是针对哥伦比亚蜿蜒或瓜里尼科托的老母亲综合管理区进行的，并且是通过遥感和地理信息系统工具进行的，该工具使用了卫星图像，大气校正和监督分类。在这二十六年中获得的结果表明，从 1991 年至 2017 年，森林覆盖率逐渐下降。 1991-2000 年间草地覆盖率增加，而 2000-2017 年间草地覆盖率减少。最终，草原和人工林的马赛克的存在大大增加了。通过乐队组成，归一化植被指数和监督分类来识别封面。然后实施了变更程序的模式，结果显示，从 1991 年至 2000 年，所研究的面积没有变化，为 68.6%或 1,088.9 公顷，而从 2000 年至 2017 年，总面积没有变化，为 53.8% %，即 854.3 公顷。最后，根据监督分类和陆地卫星波段图像的组成，在综合管理区确定了 7 个覆盖层，耕作系统被认为是造成森林覆盖率降低的原因。

关键词：遥感、土地变化建模、多时相分析、监督分类、归一化植被指数。

1. Introduction

The Ramsar Convention is an inter-governmental treaty for conserving and rational using wetlands on both national and international levels. In Colombia, six wetlands have been catalogued internationally, with a total area of 708,684 ha. These internationally-catalogued wetlands include the Ciénaga Grande de Santa Marta, Chingaza, Laguna del Otún, Laguna de la

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Cocha, Delta del Río Baudo, and the Complejo de Humedales de la Estrella Fluvial Inírida [1]. However, the Alexander Von Humboldt Biological Resource Institute and Adaptation Fund map permit the identification of nearly fifty-five wetlands in Colombia, with an approximate total area of 30 million ha, or 20% of the national territory. These include lagoons, peat bogs, hot springs, marshes, mangroves, swamps, and headwaters. Said strategic ecosystems facilitate hydric regulation and reservoirs, as they function as sponges: in the winter, they absorb water, and in summer, they release it [1]. Additionally, they are home to diverse species of flora and fauna, absorb contaminant loads, and enable economic activities, which include: agriculture, fishing, and tourism, among others [2].

However, these bodies of water have been heavily affected by anthropogenic factors, which stem from the environmental goods and services they provide. These have caused the reduction or disappearance of these bodies of water, aquatic ecosystem effects, the presence of vectors, a significant presence of water hyacinth or watercress, overflows, droughts, eutrophication, changes in land use, landscape modification, and flora and fauna diminution, among other things.

Given this situation, the Meandro or Madrevieja de Guarinocito District of Integrated Management was created and declared a natural protected area via INSERENA Agreement 68 of 1988 and Executive Resolution 197 of 1998. That is composed of wetlands including La Rica, La Esperanza, La Charquita, La Caimanera, La Charca de Guarinocito, and el Caño, which connect the Magdalena River to Madrevieja [3], following the information furnished by the Autonomous Regional Corporation of Caldas – Corpocaldas [4]. The Meandro or Madrevieja de Guarinocito District of Integrated Management is located in La Dorada, Caldas, at kilometer 13 of the Honda-La Dorada highway, longitude coordinates: -74 43’ 40.93” and latitude coordinates: 5° 20′ 3.47”. Its area totals 1,589.76 hectares. The wetland and/or Charca de Guarino DIM (District of Integrated Management) area encompasses approximately 80 hectares. The presence of said wetland has been of significant benefit to the area's inhabitants, tourists, and communities, as fishing and tourism are the main activities performed therein. However, its environmental goods and services have been significantly reduced by initiating agriculture-related economic activities and the dumping of wastewater from communities, among other factors [5]. Droughts and floods have been among the manifestations and repercussions of the activities mentioned above.

One of the effects in the DIM is specifically appearing in the Charca de Guarino, which has been invaded by aquatic vegetation known as water hyacinth (Eichhornia crassipes) [6]. This vegetation is characterized by its tendency to float and its intertwined stems that shroud large surfaces. It duplicates itself every ten days via sexual reproduction by seed or asexual reproduction by runners and can produce nearly 90 million plants per hectare in a single year. The presence of the water hyacinth on a body of water can become a significant problem if not adequately managed, and its disposal is quite expensive [7], [8] indicates that water hyacinth cover impedes photosynthesis and lowers dissolved oxygen concentrations in the water. That permits the accumulation of venous gases, whether hydrogen sulphide or ammonium, affects fish growth and generates ecosystem deterioration.

Thus, advancement is necessary to evaluate the impact of the above-mentioned anthropogenic effects quantitively. Remote sensing, which uses platforms with remote sensors and satellite images, and Geographic Information Systems (GIS), which permit multitemporal analyses applied to cover changes when detailed information is provided, may be employed. The use of remote sensing tools permits the creation of action instruments to facilitate decision-making regarding land use planning and regulation on local, regional, and national scales [9].

To date, there is very general DIM information available, as created by [10]. However, there are neither qualitative nor quantitative studies for the district mentioned above, or the reason for which it is necessary to quantitively evaluate the impact of anthropogenic action through remote sensing, which uses remote platform sensors and satellite imaging, or GIS, which permit multitemporal analyses applied to cover changes, when detailed information is provided. The use of remote sensing tools permits the creation of action instruments for decision-making in the planning and regulating land use on local, regional, and national scales [9].

Knowledge of DIM cover behavior, over the 26 years, enable actions and territorial planning, such that said the problem might be reduced. This situation highlights the need to utilize technologies that permit their detection, identification, and analysis. Remote sensing and GIS both permit the study of ecological systems on diverse scales and provide pertinent, improved information, as well as projections for ecosystem use and management [11].

Global ecosystemic alterations caused by the need to satisfy the human population's need for food, shelter, infrastructure, etc., have increased excessively. GuhlNannetti [12] mentions that said increase has contributed to the disappearance of numerous species, and the 2007 global ecological footprint has been characterized as unsustainable. Humans have surpassed the limits of nature and affect planetary function. That has resulted in the deterioration of ecosystems' ability to maintain their growth and has caused their unsustainability. Vázquez Roig [13] evaluated risk for coastal Mediterranean wetlands, specifically regarding the presence of chemical contaminants used to satisfy human needs and the effects that these generate on the environment, as they are dumped (via urine) into bodies of water and other ecosystems.

This anthropogenic presence significantly contributes to the demand for water use, and global numbers indicate that 70% of extracted groundwater and surface water is used for agricultural activities, such as plantations and livestock farming, which emit 13.5% of greenhouse gases (methane and nitrous oxide) worldwide. Further, the most degraded land in the world covers 35% of its area, and this land is used for agricultural activities [14]. Remote sensing and GIS permit the study of ecological systems on diverse scales and provide pertinent improved information and a projection for ecosystem use and management [11]. The processing of these images occurs via private or freely available software, including SoPI, Global Mapper, ArcGIS, and QGIS [15]. The use of this software permits one to compose bands, cuts, or mosaics, vegetation indices, graphic outputs, corrections, or remove noise through the use of filters, as needed, and create supervised and unsupervised classifications.

There are two satellite image classification methods: supervised and unsupervised. The supervised classification consists of visual analysis and permits the identification of the object of study and area components via tone, texture, and color [16]. When there is knowledge of the area of study, supervised classification is implemented. Once supervised classification is obtained, covers are classified following the Corine Land Cover methodology, which the European Community Commission developed in response to the need to standardize land cover for all countries. That enabled land comparisons in said countries for the decision-making on both regional and global levels [17]. This methodology is based on satellite imaging. The unit selected totals 1,589.76 hectares, and the images used were taken by Landsat 5 and Landsat 8 satellites.

Land cover is represented in levels, where Level 1 corresponds to artificialized territories, including populated areas, cities, and urban areas. Level 2 includes agricultural areas with farming activities, whether with grasslands, plantations, or others. Level 3 consists of forests or vegetation cover. Level 4 is a wetland area, and Level 5 consists of water surfaces such as rivers, floodable land, etc [18].

Considering the above, the present study's investigative question was as follows: How can remote sensing tools permit the evaluation of landscape transformation in the Meandro or Madrevieja de Guarinocito District of Integrated Management via Landsat satellite images between 1991-2000 and 2000-2017. To respond to this question, the objective of the present study focused on evaluating the land cover changes observed in the Meandro or Madrevieja de Guarinocito District of Integrated Management in La Dorada, Caldas, from 1991-2017, to comprehend its landscape transformation using Landsat satellite images.

2. Materials and Methods

2.1. Determination, via Digital Image Processing, of Land Cover Present between 1991 and 2017

Initially, free satellite images were acquired from the United States Geological Service (USGS). The images were subsequently corrected during the preparatory image phase.

Atmospheric correction: a process applied to digital images to eliminate the effects of aerosols and intrinsic radiation, which are added to the sensor and reflected in the image when the sensor interacts with the atmosphere. This process is implemented to improve the images visually [19]. Said corrections were carried out with the ENVI program, version 5.1, and received. MTL files with metadata from each image and tools from the radiometric correction toolbox.

Considering that the images, in this case, did not have radiometric errors, this correction was neither necessary nor implemented. However, radiometric corrections should be considered in image processing. Corrections were made with ArcGIS software.

The processing applied to Landsat satellite images consisted of digital atmospheric correction treatment, or the reduction or elimination of those distortions present in the images, as a product of atmospheric interaction with the sensor. Said interactions occur more frequently in multitemporal analyses, given that, when properties and magnitudes are compared in different properties and magnitudes in temporalities, the effects produced by diffuse radiation in the atmosphere are greater. So it is necessary to correct the radiances registered by the sensor for each band [19].

2.2. Remote Sensing Tool Application for the Quantitative Establishment of Cover Changes in the Study Area

For this phase, the methodology employed by Alzate and Sánchez [20] was used, as the validation of the supervised classification was of interest. Once the images had been submitted for correction, the bands were composed, and the cover present in the area of study, in this case, the DIM, could be better identified. The compositions performed for each image are presented in Table 1.

Table 1 Band composition

No	Image Name	Path	Row	Date	Satellite	Sensor	Scale	RGB[1]

1	LT05_L1TP_008056_08/14/1991_01/26/2017_01_T1	8	56	14/08/1991	Landsat 5	MSS	1:6000	532
2	LT05_L1TP_008056_06/03/2000_12/14/2016_01_T1	8	56	3/06/2000	Landsat 5	MSS	1:8000	532
3	LC08_L1TP_008056_09/06/2017_09/17/2017_01_T1	8	56	6/09/2017	Landsat 8	OLI_TIRS	1:10000	532

[1] Red, green, blue

The procedure employed for band composition in Arcgis® software is described here, as is the NDVI calculation for the obtention of increased cover identification clarity or certainty.

Based on the results obtained in the first phase, the NDVI, and the band compositions, these were sufficient to proceed to supervised classification.

The supervised classification process was implemented with the Arcgis® software, with the images resulting from correction and adapted to the methodology of Alzate and Sánchez [20]. The land covers of interest were assigned a code by the Corine Land Cover methodology. These included: Continuous urban sprawl = 1.1.1, Railroad and associated land networks = 1.2.2, Natural lagoons, lakes, and marshes = 5.1.2, Forests and semi-natural areas = 3, Grasslands = 2.3, Mosaics of grasslands and plantations (MGP) = 3.4.2, and Aquatic vegetation on a body of water = 4.1.3 (Table 2). A shapefile of points was created to select covers, and various points were created for roads, and in ID modified by two, with the covers described previously, and band compositions and NDVI (Normalized Difference Vegetation Index) as support.

The step-by-step method for the supervised classification process is presented herein. A shapefile with the name of each classification, by year, and a cover ID as described in Table 2 were included as necessary. This process was replicated for both 2000 and 2017.

Table 2 Covers

Cover	**CLC [1] Code**
Continuous urban sprawl	1.1.1.
Railroad and associated land networks	1.2.2.
Natural lagoons, lakes, and marshes	5.1.2.
Forests and semi-natural areas	3.
Grasslands	2.3
Mosaic of grasslands and plantations	2.4.2.
Aquatic vegetation on a body of water	4.1.3.

[1] Corine land cover

2.3. Description of the Main Cover Change Patterns and Principal Reasons for the Change

To identify change patterns, Idrisi software and the Land Change Modeler (LCM) tool were used. This application is designed to analyze and predict the impacts of changes in land use and associated biodiversity losses [21]. Information was thus processed, and the magnitude of the changes was identified with this tool.

A land-use projection was performed, by way of a Markov chain model, with the Idrisi land change modeler [22]. This model describes and predicts the analysis of land-use changes and future distributions or use assignments [23]. The Markov chain algorithm was implemented, analyzed images were compared (1991 and 2000), (2000 and 2017), and a transition probability matrix was obtained, which determined the probability that a pixel for one class of land use would change to another class during the analyzed period [24].

3. Results and Discussion

The results of this investigation are framed both conceptually and theoretically by the application of remote sensing tools and geographic information systems.

3.1. Landsat Satellite Image Processing

In this same order of ideas, the need for radiometric correction was evaluated. That consists of restoring lines or lost pixels, converting Digital Level (DL) values to reflectance values, defined as the existing relationship between the reflected energy and incident [25]. However, there was no need for this, as image quality was high and did not require DL conversion.

The same occurred for applying geometric correction, which did not occur given optimal image quality and lack of displacements and geometric distortions (sensor positioning at the time of the take), the influence of relief, and systematic errors associated with the image [26], [27].

Band composition, which would permit the identification and differentiation of the cover types present in the study area, was performed.

3.2. Normalized Difference Vegetation Index (NDVI) Calculation

The NDVI permitted recognition of the state of vegetation in the determined study area. The results show a raster of values that oscillate between 1 and -1, with the positive value representing the best-conserved vegetation or that with the greatest vitality. For the NDVI calculation for 1991 and 2000, Equation 1 was employed. For 2017, Equation 2 was used. The analyzed images for 1991-2000-2017 showed that negative values were associated with the Charca Guarinó body of water. Positive values near zero represent cleared and/or degraded land, which may acquire some vegetation (grasses) until values near 0.3. Beginning at 0.4, forest vegetation was found to be present.

$$NDVI = \frac{Float\ (Band\ 4 - Band\ 3)}{Float\ (Band\ 4 + Band\ 3)} \quad (1)$$

$$NDVI = \frac{Float\ (Band\ 5 - Band\ 4)}{Float\ (Band\ 5 + Band\ 4)} \quad (2)$$

The procedure for the NDVI technique for 2017 is described in this section. It should be clarified that this was performed for 1991 and 2000 with images. The result corresponds to the classification performed on the raster for NDVI obtention and forms part of the process to obtain the same.

The colors simply correspond to a theme that adapts to that and may be used to differentiate vegetation from other covers (Figure 1).

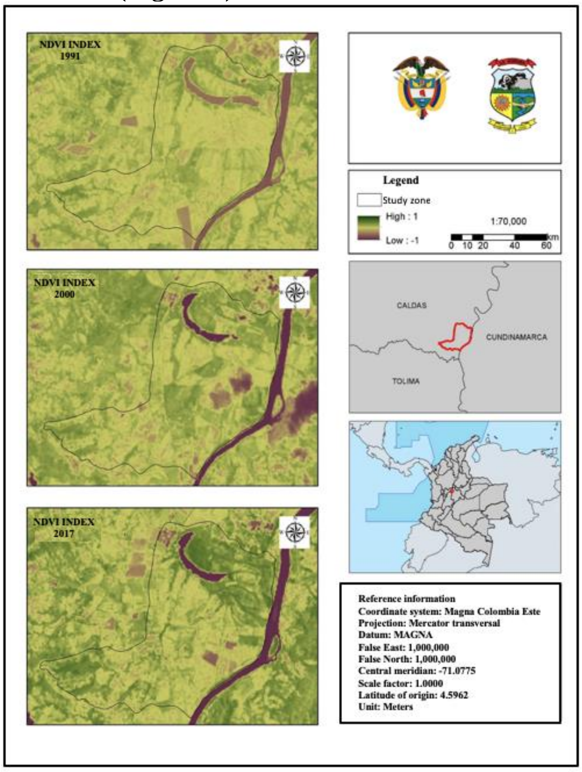

Fig. 1 Normalized Difference Vegetation Index (NDVI) 1991-2000-2017

3.3. Supervised Classification

For supervised classification, the Mahalanobis method, a supervised way to determine the similarity between two random, multidimensional variables [28], was used. Seven types of covers, categorized by the Corine Land Cover methodology, adapted to Colombia, were then identified [29]. The land cover uses included continuous urban sprawl, railroad and associated land networks, natural lagoons, lakes, and marshes, forests, grasslands, mosaics of grasslands and plantations, and aquatic vegetation on a body of water.

The greatest number of points were taken to obtain an error of R^2 minor. Additionally, image quality was considered, as if confusion had occurred between covers, more points would have needed to be considered. Below, Table 3 presents the points considered, following covers, and by year.

Table 3 Cover points

Cover	Number of points		
	1991	2000	2017
Continuous urban sprawl	12	14	16
Railroad and associated land networks	76	28	128
Natural lagoons, lakes, and marshes	10	29	38
Forests and semi-natural areas	21	3	30
Grasslands	67	49	65
Mosaic of grasslands and plantations	25	38	76
Aquatic vegetation on a body of water	9	19	20
Total	220	180	173

Four supervised classification methods were applied to validate the effectiveness of the supervised classification: minimum distance, Mahalanobis, maximum authenticity, and parallelepiped. Of these, the Mahalanobis method yielded the best result in the Kappa index. The thematic validation was performed with the same images, as these were used for correction and this classification in Table 4.

Table 4 Supervised classification methods

Image	Parallelepiped	Maximum verisimilitude	Minimum distance	Mahalanobis
1991	0.72	0.92	0.95	0.96
2000	0.19	0.97	0.96	0.99
2017	0.12	0.94	0.91	0.98

[1] Corine land cover

3.4. Land Use Cover Analysis

The results for the years analyzed suggest that the anthropogenic pressure exerted in the DIM Madrevieja de Guarinocito has had significant effects on the landscape. For example, the expansion of the agricultural frontier has caused a change in the most predominant landscape cover. That which increased most significantly over time was mosaics of grassland and plantations, with 262.4 ha. In addition, the increase in anthropogenic covers, such as continuous urban sprawl and railroad and associated land networks, grew a great deal, totaling an additional 9.1 ha.

On the other hand, aquatic vegetation on bodies of water in the initial year of analysis (1991) presented the lowest area. Over 26 years, it grew significantly, by 13.2 ha, which indicates that the eutrophication process has increased [30], for which reason the water mirror has decreased by 11.7 ha. Forested areas have been reduced by 121.7 ha.

Table 5 describes, in detail, the area of each cover by year.

Table 5 Land use cover from 1991 – 2000 – 2017 corresponding to DIM Madrevieja de Guarinocito

Cover	Area (ha)		
	1991	2000	2017
Continuous urban sprawl	15.0	18.5	20.2
Railroad and associated land networks	19.8	20.6	23.7
Natural lagoons, lakes, and marshes	50.0	40.9	42.3
Forests and semi-natural areas	431.8	413.8	310.1
Grasslands	437.2	599.6	285.9
Mosaic of grasslands and plantations	622.0	471.1	884.4
Aquatic vegetation on a body of water	8.5	23.8	21.7

Once the graphs had been obtained by area, new cover graphs were created for 1991, 2000, and 2017 (Fig. 2).

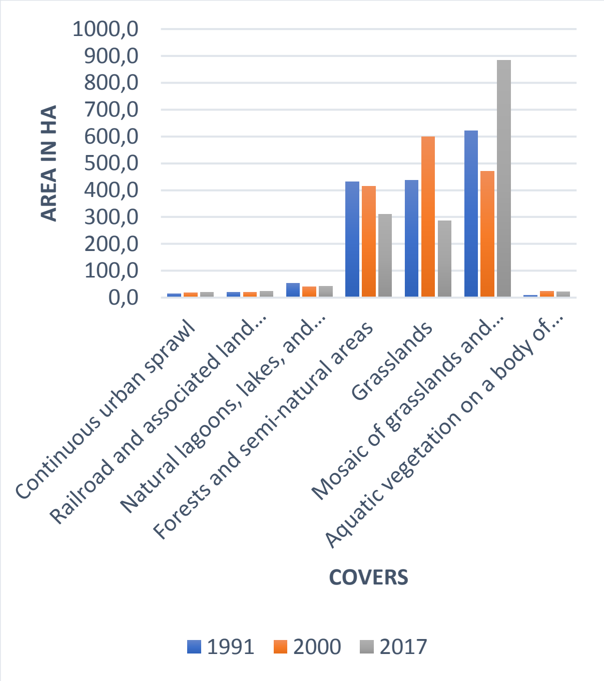

Fig. 2 Cover vs. area (ha) 1991-2000-2017

A graph of the identified covers vs. hectare areas was created for three years, 1991, 2000, and 2017. These graphs lead to the conclusion that predominant DIM covers were forests, grasslands, and mosaics of grasslands and plantations. Forest cover was reduced in 2017, grasslands had the greatest area in 2000, and mosaics of grasslands and plantations increased significantly for 2017.

For greater detail regarding covers and their areas, see Fig. 3, 4, and 5:

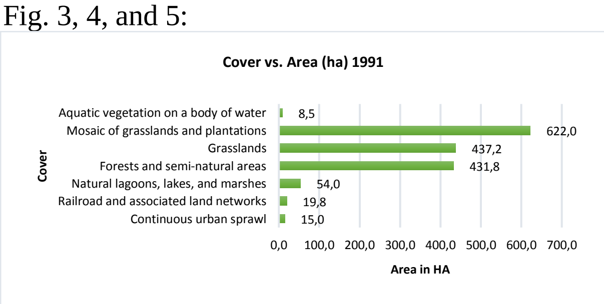

Fig. 3 Cover vs. area (ha) 1991

In 1991, the most widespread covers were: mosaics of grasslands and plantations, with 622 ha, followed by grasslands, 437.2 ha, and forests, with 431.8 ha. The cover with the smallest area corresponded to aquatic vegetation on bodies of water, or water hyacinth, with a scant 8.5 hectares.

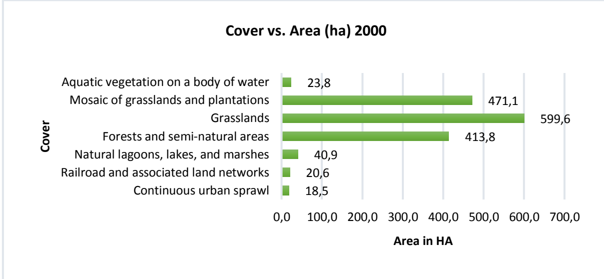

Fig. 4 Cover vs. area (ha) 2000

In 2000, there were three (3) sizeable covers: grasslands, with 599.6 hectares, followed by mosaics of grasslands and plantations, with 477.1 ha, and forests, with 413.8 hectares. It should be noted that there was a significant increase in aquatic vegetation on bodies of water compared to the 1991 numbers. Compared to the 1991 cover as a reference, there was a large increase in grassland cover, cattle farming and agricultural activity, DIM, and a reduction in forest cover.

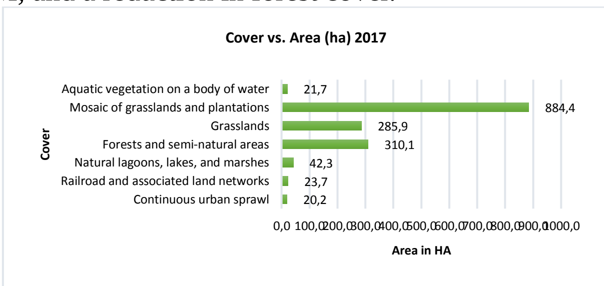

Fig. 5 Cover vs. area (ha) 2017

Figure 6 leads to the conclusion that mosaics of grasslands and plantation coverage represent the greatest area, with 884.4 hectares, followed by forest cover, with 310.1, and grasslands, with 285.9 hectares. Coverage of mosaics of grasslands and plantations doubled from those identified in 2000, and forest cover was reduced by 103.7 hectares.

3.5. Patterns of Change

Over the 26 years analyzed, five patterns of change were identified in the landscape. Between 1991-2000, the predominant pattern in the matrix was that of conversion of mosaics of grasslands and plantations to grasslands, while between 2000-2017, the main pattern was the change of forests into mosaics of grasslands and plantations. Forest areas were replaced by mosaics of grasslands and plantations and grasslands by 5.9% and 12.2%, respectively. Note that, among the patterns of change, that of mosaics of grasslands and plantations to forests presented 5.8% and 1.8%, respectively. These occurred as a cause of anthropogenic landscape restoration processes. The net landscape transformation for the first year was 31.4%, and for the last year, 46.2%, as shown in Table 6.

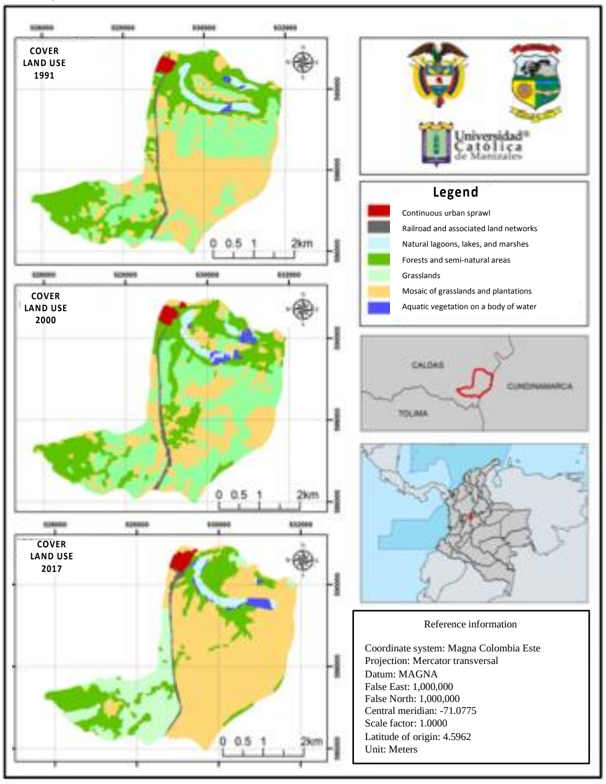

Fig. 6 Land use cover 1991-2000-2017

Table 6 Patterns of change for analyzed years 1991 – 2000 and 2000 – 2017 corresponding to DIM Madrevieja of Guarinocito

Patterns of change	1991-2000		2000-2017	
	Area (ha)	%	Area (ha)	%
Forests to the mosaic of grasslands and plantations	57.2	3.6	143.5	9.0
Forests to grasslands	36.8	2.3	51.2	3.2
Mosaic of grasslands and plantations to forests	91.5	5.8	28.8	1.8
Mosaic of grasslands and plantations to grasslands	220.9	13.9	96.1	6.1
Grasslands to the mosaic of grasslands and plantations	93.0	5.9	414.4	26.1
No change	1088.9	68.6	854.3	53.8
Total	1588.2	100.0	1588.2	100.0

3.6. Eichhornia Crassipes Losses, Gains, and Persistence

Note that it is possible to identify this species following cover verification in the countryside, history, local knowledge, and interpretation of images of floating vegetation (Figure 7). The disproportionate increase in water hyacinth, whose scientific name is *Eichhornia crassipes*, is a situation that has led to eutrophication processes of the Charca de Guarinó and has reduced the water mirror in the landscape, as shown in Table 7.

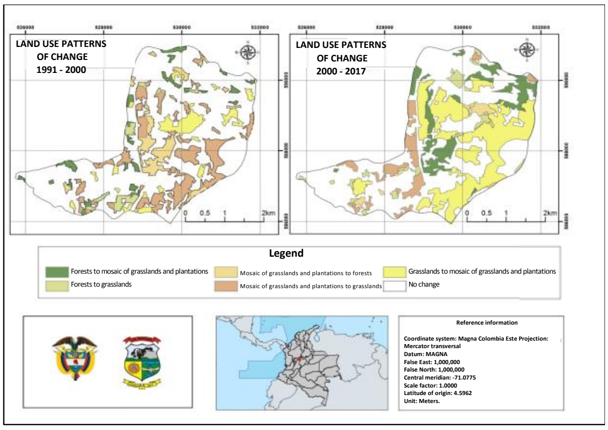

Fig. 7 Land use patterns of change 1991-2000-2017

Table 7 Eichhornia crassipes and water body losses, gains, and persistence 1991 – 2000 and 2000 – 2017 corresponding to the DIM Madrevieja of Guarinocito

Status	*Eichhornia crassipes* (area in ha)		Body of water (area in ha)	
	1997-2000	2000-2017	1997-2000	2000-2017
Losses	5.1	17.2	26.3	14.0
Persistence	3.0	5.8	27.5	27.0
Gains	19.8	15.2	13.5	15.3

The information contained in Table 7 is represented in graph form, where the significant amount of water hyacinth on the pond between 1991-2000 (Figure 8) is demonstrated. Its occupation and increase were so significant that it covered 19.8 hectares of the body of water, which is inversely proportional to the body of water, as its gains were only 13.5 hectares.

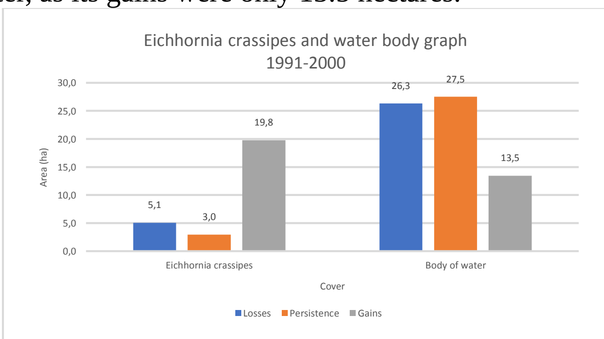

Fig. 8 Eichhornia crassipes and water body graph 1991-2000

Below, the presence of *Eichhornia crassipes* vs. the water body 2000-2017 (Figure 9) is represented to identify whether there were changes, gains, or losses in these two covers.

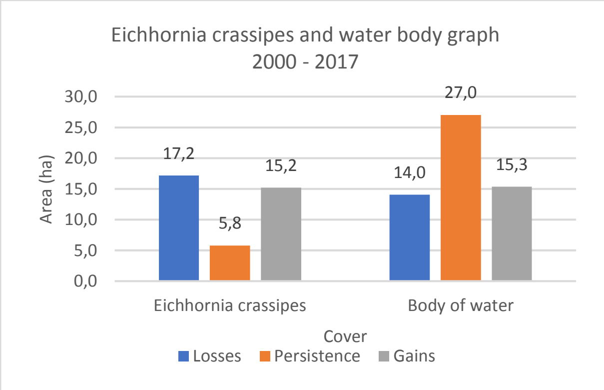

Fig. 9 Eichhornia crassipes and water body graph 2000-2017

Between 2000-2017, there were gains in these covers, directly proportional to their areas. Eichhornia crassipes presented gains of 15.2 hectares, and the body of water gained 15.3 hectares.

The area of research occupies 1,574,597.01 hectares, of which the forest, in 1991, covered 431.8 ha. In 2000, its area was reduced to 413.8 ha, and in 2017, it showed a significant reduction, totaling 310.1 ha. In those 21 years, forest cover was reduced by 121.7 ha. The covers that presented significant gains in said 21 years were mosaics of grasslands and plantations and aquatic vegetation (Table 2). That reflects the significant reduction of a cover as relevant as forest for the DIM function. The farming activities which dominate in the said sector were trigging factors for this change. To clarify, there are existing zoning and special conditions for the DIM, as listed in the Basic Land Use Management Plan, which is geared toward DIM conservation and preservation. The municipal administration has spearheaded a strategy to conserve the municipality's areas of environmental interest, following Decree no. 007 (January 19, 2018). The exemption of property tax is governed for environmental conservation areas [31].

The supervised classification validation was performed using four methods: maximum verisimilitude, parallelepiped, minimum distance, and Mahalanobis. The highest Kappa index was given by the Mahalanobis method, which for 1991 was 0.96, for 2000 was 0.99, and for 2017, it was 0.98. These results are similar to those of Alzate and Sánchez [20], for whom the Mahalanobis method also yielded the highest Kappa index.

The NDVI technique was quite useful for the differentiation of body of water cover from aquatic vegetation cover. However, there was confusion between forest, grassland, mosaics of grasslands and plantations, and aquatic vegetation covers in certain cases. Comparing these results to those of another investigation [32], it was demonstrated that NDVI, in certain cases, presents confusion between forest and grassland covers, as seen here.

4. Conclusions

Based upon the supervised classification and the band composition of Landsat images, it was possible to identify seven covers in the DIM, including continuous urban sprawl, forests, and semi-natural areas, railroad and associated land networks, natural lagoons, lakes, and marshes, grasslands, mosaics of grasslands and plantations, and aquatic vegetation on bodies of water. These covers are from the Corine Land Cover methodology.

The covers analyzed presented changes—both gains and losses. There was clear landscape modification, which resulted from anthropogenic pressure on the DIM that directly affected the landscape. That is a clear example of cover expansion, including continuous urban sprawl, which increased 5.2 hectares over 26 years, railroad and associated land networks, which gained 3.9 hectares, and mosaics of grasslands and plantation cover, which increased by 262.4 hectares and affected the landscape, as natural cover and/or those of environmental interest for DIM conservation were reduced. These included natural lagoons, lakes, and marshes, reduced by 11.7 ha, and forests and semi-natural areas, which finally occupied less than 121.7 hectares.

The presence of Eichhornia crassipes, or water hyacinth, is significant in wetlands. Satellite images were quite useful, as it was possible to identify the gains, losses, and persistence in aquatic vegetation cover, specifically that of Eichhornia crassipes, considering that the area for its identification was quite small. Another aspect of note regarding aquatic vegetation cover and bodies of water, in Table 4, is that, from 2000-2017, its gains were similar to its area—Eichhornia crassipes gained 15.2 hectares, and water body cover gained 15.3 hectares.

Five patterns of change were revealed during the 26 years. Between 1991-2000, significant cover changes occurred, from mosaics of grasslands and plantations to grasslands, and between 2000-2017, the pattern of change was from forests to mosaics of grasslands and plantations. The total landscape transformation between 1991-2000 was 31.4%, and for 2000-2017, it was 46.2%. Generally, this situation corresponds to the current DIM panorama. Agriculture has taken precedence in the area, a fact that directly affects the ecosystems present there and the ability to conserve said ecosystems.

Regarding NDVI with Landsat images, this permitted the clear identification of that vegetation that remained and that which did not. Notably, for certain covers, confusion occurred, and it was necessary to complement or support these determinations via combinations to be more certain. It was possible to identify the presence of forests—although they have been modified, they have been conserved, and interventions must occur to reduce the decrease or transformation of said cover. The wetland's 100-meter protective forest belt, or Charca de Guarino, is highlighted for this purpose, as established in the La Dorada Basic Land-use Plan. The present study demonstrated that the NDVI technique might be utilized to identify vegetation cover in areas of ecological interest in the DIM.

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