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LAND-COVER CHANGE IN THE DEPARTMENT OF VICHADA, COLOMBIA, FROM 1985 TO 2017

CAMBIO DE USO DEL SUELO EN EL DEPARTAMENTO DEL VICHADA, COLOMBIA, DESDE 1985 A 2017

Juan J. Vitar-Mendoza • *juan.vitar@unillanos.edu.co**
Biologist, SUSA investigation group, Department of Biology and Chemistry, Faculty of Basic Science and Engineering, University of the Llanos, Villavicencio, Colombia.

Karen X. Sandoval-Parra • *Karen.sandoval@unillanos.edu.co,*
MSc. Molecular, Cellular and Genetic Biology, SUSA investigation group, Department of Biology and Chemistry, Faculty of Basic Science and Engineering, University of the Llanos, Villavicencio, Colombia.

Martha L. Ortiz-Moreno • *mlortiz@unillanos.edu.co*
Doctor in Ecology and Natural Resources, Department of Biology and Chemistry, Faculty of Basic Science and Engineering, University of the Llanos, Villavicencio, Colombia.

***Corresponding author**

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ABSTRACT

Contextualization: Colombia has experienced multiple land-cover changes derived from socio-economic policies that have reduced the high biodiversity of the country.

Knowledge gap: In the Orinoquía region, the pressure to expand the agricultural frontier is increasing, without considering the importance of its natural resources.

Purpose: This paper aimed to analyze the land-cover variations associated with agricultural practices, in the department of Vichada, with a special interest in vulnerable ecosystems, such as the Bita's river basin, using Geographic Information System [GIS] analysis of historical images taken by a remote sensor from the United States Geological Service [USGS] Earth Explorer portal.

Methodology: Documental review and an analysis of satellite images from 1985 to 2017.

Results and conclusions: The results showed that in Vichada, during a 32-year period, there was a transition from forest to cropland and pastures, in which 60% of the forest cover got lost. Moreover, areas of natural savannas were also replaced with pastures for livestock production. These land-cover changes were associated with government policies that fomented illegal occupation of land, monocultures, and non-native plantation forests. Bita's river basin also lost a significant part of forest cover because of agribusiness development in the municipality of Puerto Carreño (Vichada). These land-cover changes have an impact on the ecological integrity of significant ecosystems and in their functionality in the region, that is why, conservation measures must be implemented.

Keywords: Agribusiness; Agricultural frontier; Biodiversity; Deforestation; Satellite imagery analysis

RESUMEN

Contextualización: Colombia ha experimentado múltiples cambios en la cobertura de los suelos como consecuencia de políticas socioeconómicas, reduciendo, de esta forma, la alta biodiversidad del país.

Vacío de investigación: En la región de la Orinoquía se han intensificado las presiones para ampliar la frontera agrícola, sin considerar la importancia de sus recursos naturales.

Propósito del estudio: Este trabajo tuvo como objetivo analizar el cambio de cobertura asociado a las prácticas agrícolas en el departamento de Vichada, con especial interés en ecosistemas vulnerables, como la cuenca del río Bita, mediante un análisis SIG de imágenes históricas tomadas por sensores remotos del portal Earth Explorer del USGS.

Metodología: Se realizó una revisión documental y un análisis de imágenes satelitales desde 1985 a 2017.

Resultados y conclusiones: Los resultados mostraron que en Vichada, durante un período de 32 años, hubo una transición de bosques a cultivos y pastizales en el que se perdió el 60% de la cobertura forestal. Además, las áreas de sabanas naturales también fueron reemplazadas por pastizales para la producción ganadera. Estos cambios en la cobertura del suelo se asociaron con políticas gubernamentales que fomentaron la ocupación ilegal de tierras, los monocultivos y las plantaciones forestales de especies no nativas. La cuenca del río Bita también perdió una parte significativa de su cubierta forestal, como consecuencia de los agronegocios.

Palabras clave: *Agronegocios; frontera agrícola; Biodiversidad; Deforestación: Análisis de imágenes satelitales*

GRAPHIC SUMMARY
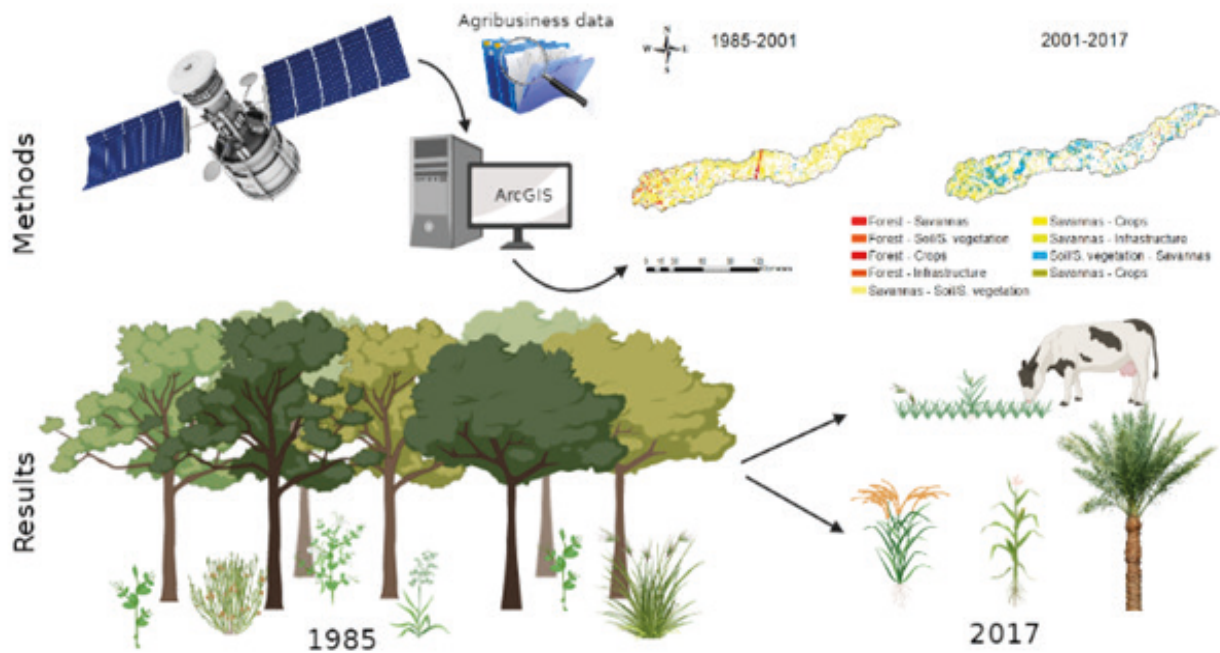
1. INTRODUCTION

Biodiversity is one of the most important components of the planet. It comprises the entire variety of living organisms from all environments and their ecological complexes, including genetic, structural, and functional components (Newbold et al., 2015). In the last decades, biodiversity has been negatively impacted by anthropogenic activities, causing the alteration of ecosystems and the services that they provide (Caviedes and Ibarra, 2017).

Over the last fifty years, the main causes of the damages to ecosystems integrity are variations in land-cover and in land-use (Allan et al., 2015; Jantz et al., 2015; Newbold et al., 2015). Land-use changes have suffered a transition, from natural vegetation to clearings, so land can be used for small-scale agriculture, croplands, livestock production, infrastructure and urban development, mining, and others (Boserup, 2017; Rausch, 2017). The deforestation and forest fragmentation resulting from these transitions have important effects on the landscape, such as the reduction of forest quality, isolated patches, edge effect and connectivity loss. All together lead to disruptions in the functional structure of biological communities (Brodie et al., 2015; Hurd et al., 2016; Thompson et al., 2017).

In Latin America, socio-economic factors and biophysical parameters of landscape represent the main causes of land-use changes (Borras et al., 2012; Rausch, 2017). Two highly used approach to study these changes are: satellite-derived data, and monitoring strategies, such as the Normalized Difference Vegetation Index [NDVI] (Addabbo et al., 2016; Chakraborty et al., 2018). The NDVI allows creating an image that quantifies the photosynthetic capacity of different plant canopies (Chakraborty et al., 2018). In Colombia, this strategy has been used for research, using multitemporal analysis and monitoring river basins (Álvarez & Agredo, 2013; Vargas-Gonzalez, 2013; Grande-Medina, 2015; Mejía-Ramírez, 2016; Monroy & Armenteras, 2017; Barragan-Vera, 2018; Sanabria-Lombana, 2018; Hernández-Calderón & Salamanca-Carvajal, 2019; Salamanca-Córdoba, 2020). An example of using NDVI comes from the work of Muñoz et al., (2009). Their results showed that in Las Minas micro-basin, municipality of Pasto (Department of Nariño), 58.51 ha were deforested between 1989 and 2008 (Muñoz et al., 2009). Another related research comes from Monroy and Armenteras, (2017), that showed the quantification of the land cover changes, and the expansion of mining

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dynamics in the Nechí river from 2009-2014 (Monroy & Armenteras, 2017).

On the other hand, the Orinoquia region of Colombia is considered the future core of agricultural practices, creating a great deal of pressure towards resources exploitation, without contemplating the impact on biodiversity (Caicedo, 2016; Peña-Levano et al., 2018). The National Planning Department [DANE] of Colombia stated, in 2017, that agro-industrial projects and large-scale forestry are the only options to accelerate the region development. So, the development strategy for this region includes the transformation of forest into cropland, pastures for livestock, logging for energy purposes, and the construction of roads. These anthropogenic activities represent the main causes of the loss of forest worldwide (Dudley & Alexander, 2017). Additionally, these processes are associated with social, political, and economical changes that have led to a disorganized growth of urban areas (Caicedo, 2016).

In regions such as the Orinoquía, where the loss of integral ecosystems in favor to agro-industrial expansion is expected, complete knowledge of the biodiversity represents a concern among academics, as it is necessary to develop conservation strategies that reduce the impacts on the ecosystem services, especially when essential ecosystems like river basins are compromised (Williams et al., 2020). Therefore, the aim of this study was to analyse the transformation of land-cover in the department of Vichada, between 1985-2017 period, and the expansion of agribusiness, with special attention to the Bita's river basin, utilizing simple GIS analysis and data from the USGS Earth Explorer portal.

2. MATERIALS AND METHODS

STUDY AREAS

Department of Vichada

The Orinoquía region constitutes 30.4 % of the national territory and is located in the southeast of Colombia. This region has 32 % of the country fresh water and 38 % of all micro-basins (Yepes-Mayorga, 2012). Hence, it is one of the most important reservoirs of

biodiversity in the neotropics (Gassón, 2002) with 156 different types of ecosystems and a high number of gramine, amphibians, reptiles and mammals (Yepes-Mayorga, 2012), fishes (Maldonado-Ocampo et al., 2008; Romero et al., 2009), and bird species (Trujillo & Lasso, 2017).

The Altillanura is the subregion of Orinoquía where the economic interest is concentrated, and 57 % of 13.5 million ha are considered suitable for agriculture. The remaining area (43 %) is classified as natural forests, morichales (lotic systems dominated by Mauritia flexuosa), savannas, and semi-natural areas (Trujillo & Lasso, 2017). The department of Vichada is located within the Altillanura, with 10024200 ha and four municipalities: La Primavera, Cumaribo, Puerto Carreño and Santa Rosalía. The potential for agriculture in Vichada is approximately of 4.5 million ha (Gómez, 2015). In Vichada, extensive and continuous savannas shape the landscape, along with gallery forests and morichales (Yepes-Mayorga, 2012). In 1970, El Tuparro National Natural Park was created to protect the ecosystems that regulate the hydrological cycle and control floods (Caviedes & Ibarra, 2017; Duarte, 2016).

Vichada is the second department that has the greatest extension in Colombia (Fig. 1). The total population is 73700 inhabitants of which 56 % live in rural areas, and almost 65 % of them depend on agriculture and livestock production (DANE, 2005). The economy was initially inconspicuous with small scale extractions of rubber and wood. In 1980, an economic model based on illicit crops and extensive livestock farming was implemented (Trillos, 2010). Since then, the expansion of the agricultural frontier has been the purpose of several agrarian laws and policies (Gómez, 2015). In 2002, the project "The rebirth of the high Orinoquía of Colombia" identified productive, agricultural and agroforestry alternatives that did not include native species (MADR, 2004; Viloria, 2009).

Later, the "Action Plan on Biodiversity" policy prepared the department for a new

strategy known as agribusiness (CGR, 2014). First, the Government stimulated the agrarian colonization in Vichada by giving land titles to newcomers. Then, the land passed to foreign and national investors, leaving the local communities evicted from their territories. As a result, large areas were accumulated for agro-industrial projects (CGR, 2014). The main foreign buyers of land in the region were companies from China, Japan, Malaysia, Indonesia, and Brazil (Nieto, 2015). Lastly, in 2014, the "National Council for Economic and Social Policy 3797" was implemented, this policy invested COP 10767 million in 780000 ha of the Altillanura to develop agroindustrial projects and promote land transformation in Vichada (CONPES, 2014; DNP, 2017).

The "Master Plan for the Orinoquía", in 2016, continued the 3797 policy, again, involving the private sector and international cooperation, without considering the local communities. Moreover, in recent years, the Colombia's government peace agreement and other political and economic drivers, have brought a significant increase to agro-industrial crops and forest plantations in Vichada (Oficina del Alto Comisionado para la Paz Colombia, 2016).
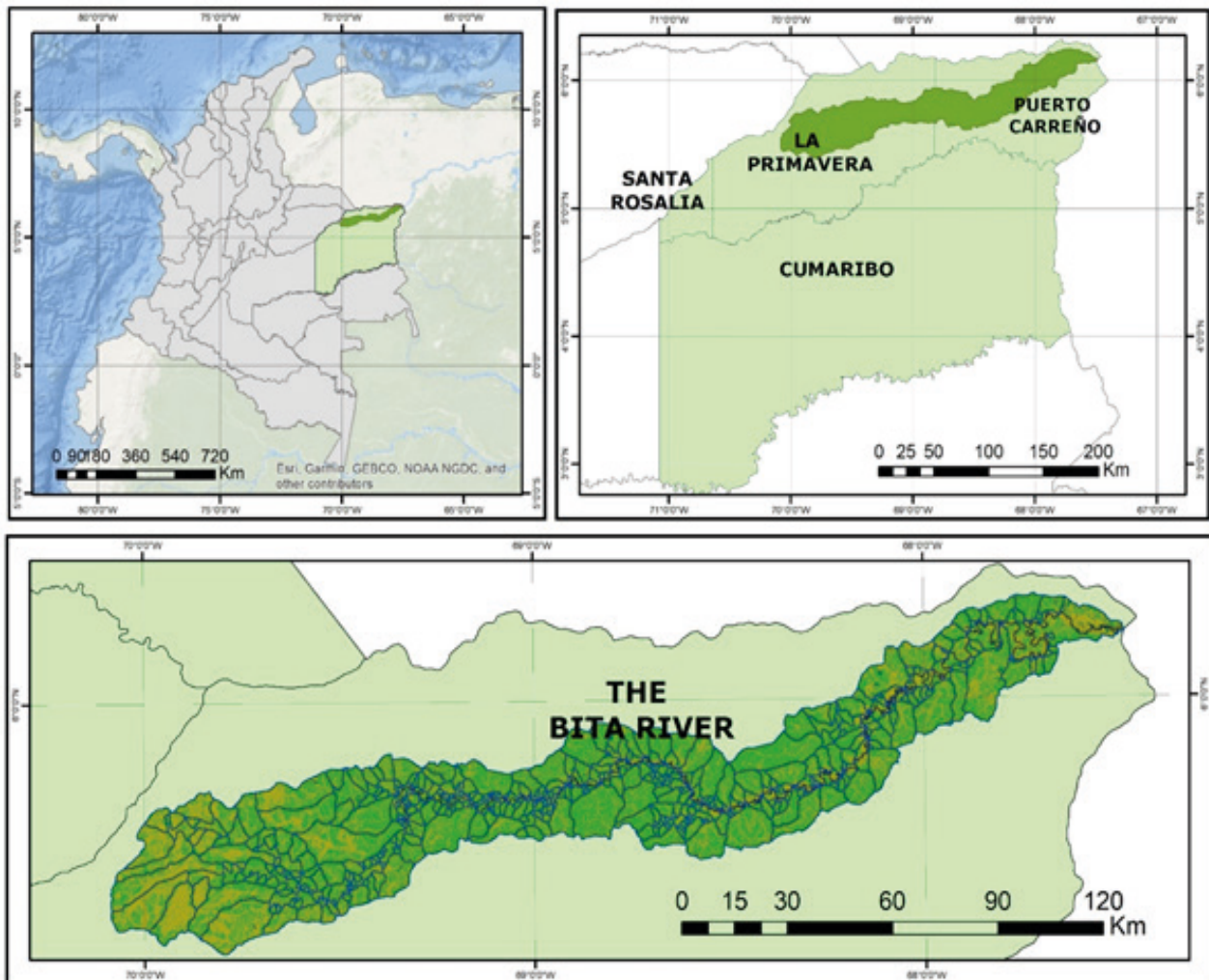
Figure 1. Location of the Vichada department and the Bita's river basin within Colombia.

Source: authors.

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Bita river Basin

The Bita river is located in Vichada, within the municipalities of La Primavera and Puerto Carreño (Fig. 1). It has a linear extension of 700 Km, an area of 812312 ha, an altitudinal gradient of 50-300 masl, an average temperature of 27-28°C, and a monomodal precipitation regime (Peñuela & Rodríguez, 2014; Romero et al., 2017). Gallery forests are alternated with savannas, floodplain savannas, and rocky outcrops from the Guiana Shield. There are numerous high-value ecosystems with unique biodiversity in the basin, that include at least 16 wetlands, mainly estuaries, madreviejas (a type of permanent freshwater lagoon), zurales (a lentic and temporary water system), and morichales (Lasso et al., 2014; Romero et al., 2017).

Currently, the ecosystems in the basin have a high degree of conservation. Almost 95 % of the areas are natural ecosystems, 2.5 % are agricultural or forestry territories, and 3 % are semi-urban areas (Trujillo & Lasso, 2017; Suárez et al., 2021). However, the Bita river basin is currently threatened by mining, logging, deforestation, livestock production and agricultural mega-projects in the region. These economic, social, and political interests alarmed to the scientific community. As a result, in 2018, the basin became a Ramsar's wetland, for its international importance (DNP, 2018).

Despite its importance, until today there is only one research about the biodiversity in the area. Hence, there is not enough information for the formulation of efficient conservation plans (Trujillo & Lasso, 2017). The mentioned study was carried out in 2016, in two sections of the Bita basin (municipalities of La Primavera and Puerto Carreño) (Trujillo & Lasso, 2017). It found 424 plant species, two species of freshwater sponges, 34 species of coprophagous beetles, 26 families of aquatic macroinvertebrates, 11 species of crustaceans, 254 species of fish, 38 species of reptiles, 18 species of amphibians, 201 species of birds and 63 species of mammals. It was concluded that the Bita river basin is important for the maintenance of migratory birds and acts as a biological corridor between the Altillanura and the Guiana Shield (Trujillo & Lasso, 2017).

Since large scale agricultural activities in Vichada have become lucrative in the past decades, due to government incentives (Vargas et al., 2015) and, according to Castiblanco et al., (2013), these industries will expand even more, there is a need to evaluate the territory in order to determinate the land-cover use and recognize the deterioration of natural areas, so resource exploitation and conservation policies can be formulated. Additionally, the impact in biodiversity have been poorly investigated in the area due to the armed conflicts that have occurred over the last 50 years in Colombia (Hoffmann et al., 2018; Romero et al., 2017). The diagram in Fig. 2 shows the overall methodology used in this study.

DOCUMENTAL ANALYSIS OF AGRIBUSINESS IN VICHADA

Several documents, regarding the development of agribusiness and the expansion of the agricultural frontier in Vichada during the period 1985-2017, were consulted as reference and comparison. Legal and administrative documents (Table 1), academic literature and press, were included as well.

SATELLITE IMAGE PRE-PROCESSING

In this study was used images acquired from the US Geological Survey Center for Earth Resources Observation and Science (USGS) (https://glovis.usgs.gov/). The dataset comprised cloud-free (<5 %)) satellite images of the dry season (October to February), taken in the following years: 1985 and 1998, collected from the Landsat 5 satellite (TM) with a resolution of 30 m (USGS, 1985; USGS, 1998); 2001, 2005, 2009 and 2013, collected from Landsat 7 (ETM) with a resolution of 30m (USGS, 2001; USGS, 2005; USGS, 2009; USGS, 2013); and 2017, collected from Sentinel2 with a resolution of 10m (USGS, 2017). The spatial resolution of these images made possible to identify and map agricultural fields, deforested areas, vegetated zones, and inhabited places within the landscape that were transformed during the 32 years, a methodology used in different studies that also cover large periods of time (Mendoza et al., 2011; Keshtkar et al., 2017; Ávalos et al., 2018; Souza-Filho et al., 2018). All images were georeferenced using a polynomial geometric model (order 3).
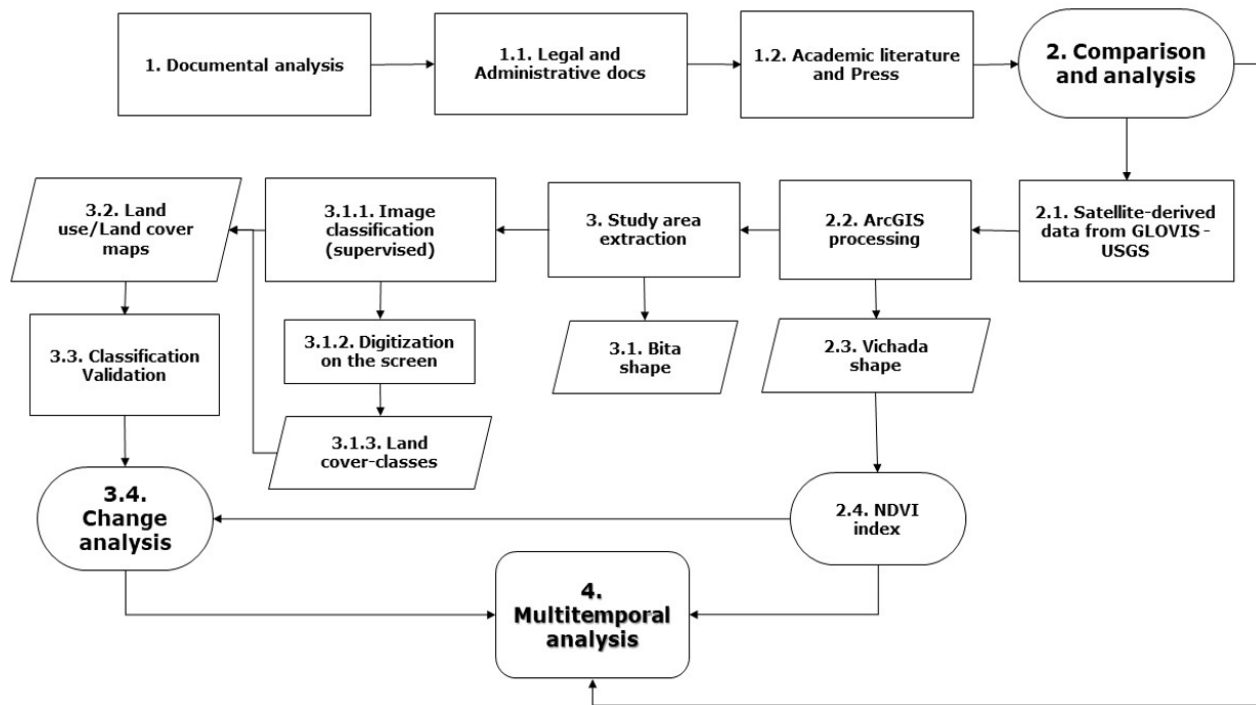
Figure 2. Schematic representation of the methodology used in the present study.

Source: Authors.

DEFINITION OF THE DIFFERENT LAND-COVER CLASSES

The satellite images were classified into seven land-cover classes (Table 2), using a pixel-based, supervised classification method, the Maximum Likelihood Classification (MLC) algorithm. MLC is one of the most widely used methods due to its quickness, user-friendly and a clear interpretation of the results (Bolstad & Lillesand, 1991; Ávalos et al., 2018). MLC can obtain a spectral image of each land-cover class through variance and covariance statistics of the set of training sites identified in the image, and then calculates the probability of belonging to each class according to the spectral signature (Fig. 3), with accurate results (Bolstad & Lillesand, 1991; Ávalos et al., 2018). Subsequently, a more detailed review was done digitizing the screen, especially on the land-cover near the water round.

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Table 1. Administrative and legal documents consulted for the purposes of the present study.

Type and source of document	Revised documents	References
Administrative Ramsar-Convention on Wetlands	2	Ramsar, 2015 Ramsar, 2016
Administrative Office of the High Commissioner for Peace Colombia	1	Oficina del Alto Comisionado para la Paz Colombia, 2016
Administrative Office of Ministry of Justice and Law	1	Minjusticia, 2014
Administrative Office of Ministry of Agriculture and Rural Development	2	MADR, 2004 MADR, 2011
Administrative Office of Comptroller General of the Republic	2	CGR, 2012 CGR, 2014

| Type and source of document	Revised documents	References
Administrative Colombian Federation of cattle ranchers	1	Fedegan, 2021
Administrative Office of National Department of Planning	2	DNP, 2017 DNP, 2018
Administrative National Administrative Department of Statistics	3	DANE, 1985 DANE, 1993 DANE, 2005
Administrative National Council for Economic and Social Policy	7	CONPES 3192, 2002 CONPES 3218, 2003 CONPES 3467, 2007 CONPES 3558, 2008 CONPES 3669, 2010 CONPES 3797, 2014 CONPES 3827, 2015
Administrative CIAT- Corporation for the Sustainable Development of La Macarena Special Management Area	1	CIAT and CORMACARENA, 2017
Administrative Orinoquía Regional Autonomous Corporation	1	CORPORINOQUIA, 2009 CORPORINOQUIA, 2013a CORPORINOQUIA, 2013b
Legal Presidency of the Republic	2	Decree 2858, 1981 Decree 1729, 2002
Legal Congress of the republic	5	Law 135, 1961 Law 30, 1988 Law 160, 1994 Law 1337, 2010 Law 1776, 2016
Legal Office of Ministry of Agriculture	1	Decree 1541, 1978
Legal Office of Ministry of Environment and Sustainable Development	6	Decree 3100, 2003; Decree 1640, 2012; Decree 1235, 2018; Resolution 157, 2004; Resolution 196, 2006 Resolution 1128, 2006
Legal Orinoquía Regional Autonomous Corporation	3	Resolution 200.41-09-1592, 2009 Resolution 200.41-11-1130, 2011 Resolution 500.41-13-1571, 2013

Source: *authors.*

The land-cover classes were adapted from the book: Leyenda nacional de coberturas de la tierra. Metodología CORINE Land Cover adaptada para Colombia Escala 1:100000 (IDEAM, 2010). The classes were chosen because the spatial resolution for all the images allowed their identification. The details of the seven land-cover classes are described in Table 2. The satellite-image matrices were easily classified using visual interpretation, considering the seven predefined classes, then using used manual vectorization via ArcGIS 10.6 software. This methodology ensured that the lines of polygons, without land-use changes, remained unaffected. The visual interpretation is a reliable method for studying small (Bita river) and large areas (Vichada) (Munsi et al., 2010; Zuo et al., 2014).

Table 2. Descriptions of seven land-cover classes identify for this study adapted from the Leyenda nacional de coberturas de la tierra. Metodología CORINE Land Cover adapted for Colombia, scale 1:100.000.

Land-cover class	Description
Forest	Natural land constituted mainly by arboreal elements of native species.
Gallery forest	All land constituted by arboreal vegetation that forms as corridors along rivers or wetlands.
Cropland	Land dedicated to permanent crops, transitory, grazing land, and heterogeneous agricultural land.
Savannas	Areas constituted by a vegetal community dominated by herbaceous elements.
Soil / Scattered vegetation	Areas where the ground surface consists of layers of exposed rocks and/or a slight development of vegetation such as pastures for livestock farming.
Water	Natural streams of freshwater flowing continuously and water surface reservoirs, open or closed, which may or may not be connected with a river.
Infrastructure	Cities, towns, areas covered by roads, highways, bridges, and airports.

Source: Authors.

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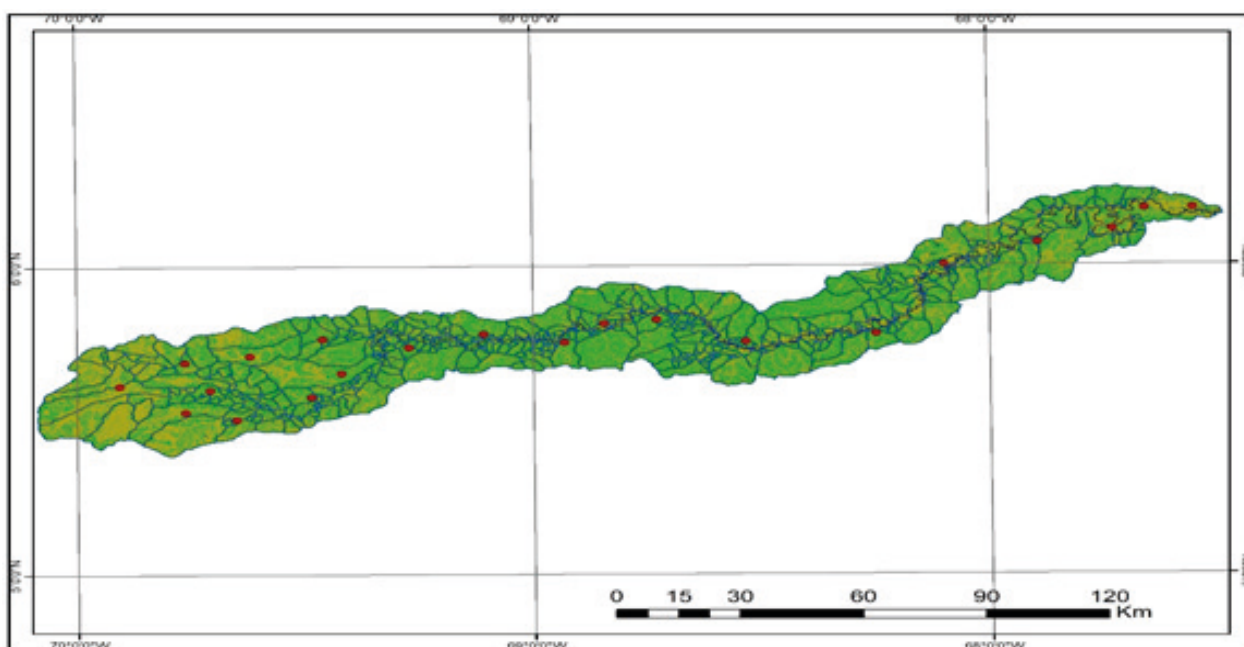
Figure 3. Location to the control fields within the Rio Bita basin.

Source: Authors.

NDVI INDEX

The NDVI index is one of the most used vegetation indices and it provides the best results regarding variations in vegetation canopies (Khan et al., 2014; Addabbo et al., 2016; Beisel et al., 2018; Sun et al., 2018). The values of the index were generated using ArcGIS by combining near-infrared bands and visible bands according to the satellite from which the images were obtained. The used formula was:

$$NDVI = \frac{(NIR-R)}{(NIR+R)} \quad \text{(Formula 1)}$$

Where NIR = Near Infrared Channel; R = Red Channel

The NDVI index of 10000 pixels belonging to the same land-cover class were averaged to obtain one single value. This was done for each land-cover class. Layer stack images from 1985, 1998, 2001, 2005, 2009, 2013, and 2017, were created and evaluated to detect the land-use change.

MULTI-TEMPORAL ANALYSIS OF LAND-COVER CHANGE

Land-cover maps were designed in the methodological framework of a multi-temporal analysis to evaluate the land-cover changes in a 32-year period. ArcGIS and satellite images of the Bita river basin of the years 1985, 2001 and 2017 were used. The different bands from the satellite imagery were combined in the traditional RGB (Red, Green, and Blue) channels (Fröhlich et al., 2013; Sheng et al., 2020). The combination 742 was used for the images obtained from Landsat 5 and 7; and 843 for those obtained from Sentinel-2; those band composites correspond to false colour and false IR colour respectively (Nawar et al., 2014; Príncipe & Willems, 2018; Modica et al., 2019). This combination is suitable for studies involving natural vegetation and cropland (Addabo et al., 2016; Chakraborty et al., 2018). Based on the obtained images, polygons for each land cover class were created and the area in hectares was calculated using ArcGIS tools in the two evaluated periods: 1985 to 2001, and 2001 to 2017. Deforestation rates were not estimated in this study.

Based on the land-cover maps obtained, two processes were carried out: a majority filtering procedure (6x6 pixels) and a method of generalization of polygons of less than one hectare, thus, reducing image noise and isolated polygons. After these, the final land-cover maps were obtained, one for the period 1985-2001 and one for 2001-2017

(Fig. 6-Annex). Polygons for each land-cover class were created and their area calculated in hectares using MLC. To standardize and confirm the land-cover areas of the Bita river basin, a visual inspection using secondary information and historical data from the IGAC web portal (https://geoportal.igac.gov.co/) and geoviewers was performed for the same analyzed periods. To obtain percentages of each land-cover class in the evaluated year (1985, 2001 and 2017), the total area of the Bita river basin, 812310 ha, was considered; each land-cover class area (in ha) was multiplied by 100% and then divided by 812310 ha.

To validate the obtained results, the classified land-cover maps were compared against control fields through a cross-tabulation matrix. The kappa index (which indicates the degree of similarity between control fields and the maps), the general accuracy (which shows the percentage of pixels correctly classified), the user's accuracy (that provides the percentage of each land-cover class that corresponds with the field information) and the producer's accuracy (that establishes the percentage of each land-cover change properly classified in the image) were evaluated (Ávalos et al., 2018; Wu et al., 2018).

3. RESULTS AND DISCUSSION

Land change is the result of a complex interaction between multiple factors, such as economy, demography and environment, at different spatial-temporal scales. Since land-cover change can be a rapid process, understanding its relationship with driving factors is vital to evaluate the effect of land transitions in ecosystems (Santacruz-Delgado, 2019). In the particular case of the department of Vichada, these processes are related to the socioeconomic status of the Altillanura region, an isolated region with high levels of poverty, institutional absence, and grave human rights violations (OXFAM, 2013).

DOCUMENTAL ANALYSIS OF AGRIBUSINESS IN VICHADA

Three main processes acted as driving factors of land change in Vichada: first, a large number of land transactions; second,

the arrival of investors and multinationals and third, the current agro-industrial dynamics (CONPES, 2014). As a result, the land was occupied by foreign and national investors, who accumulated large areas of land without the proper regulation of any local or regional authorities and taking advantage of the abolition of the Law 160 (Agrarian Reform) that limited the area that could be purchased, in favor of the Law 1776 of 2016 that created the ZIDRES (Areas of Interest for Rural, Economic and Social Development), which supported only great agro-industrial projects (Aide et al., 2013; Etter et al., 2008; Ortega, 2016).

Considering those facts, this paper presents the first regional land-cover change description of the department of Vichada and the Bita's river basin. The constructed maps represent a 32-year period with intense land-use transformations.

The information regarding agribusiness in the department, during the 1985-2001 period, was non-existent, mainly because agricultural development was incipient. Oppositely, the period between 2001-2017 was characterized by agrarian and resource management policies (described in the introduction) that resulted in agricultural megaprojects occupying more than 50% of the territory in Vichada (Table 3). That included oil palm and other crops such as cashew nuts, which are perennial plants that require a wide range of time to reach productive size and be industrialized. Moreover, Colombia has recently ended a 50 years armed conflict, by signing the Peace Agreement with the militia group FARC in 2016. That agreement included policies that stimulated the economy of Vichada, having as a result a significant increase of agro-industrial crops and forest plantations (Oficina del Alto Comisionado para la Paz Colombia, 2016).

Some of the biggest agribusiness in Vichada are (CGR, 2014; Gómez, 2015; Gómez & Soto, 2012):

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Table 3. Area and percentages of agribusiness found from 1985 until 2001, and from 2001 until 2017 in the Vichada department.

Agribusiness	1985-2001		2001-2017	
	ha	%	ha	%
Cereals	NIA	NIA	96384	11.86%
Rubber	NIA	NIA	25000	3.08%
Oil palm	NIA	NIA	21205	2.61%
Illicit crops	9200	1.13%	2264	0.28%
Forest plantations	8000	0.98%	69762	8.59%
Other crops	3816	0.47%	38000	4.70%
Extensive livestock production	107000	13.23%	180000	22.25%

NIA: No Information Available.

Sources: *CGR (2014); Gómez & Soto (2012); Fedegan (2021); Gómez (2015); Viloria (2009).*

• *Cargill-Colombia Agro*: started operations in Vichada in 2010, is the country's largest grain farm with over 60000 ha of wheat, soybean, rice, sorghum, and corn crops.

• *Riopaila-Castilla*: started operations in 2010 with 10000 ha of oil palm, 5000 ha of timber, 20000 ha of grains, and 5000 ha of technified extensive livestock production.

• *Forest First*: started operations in 2006 with 20000 ha of different tree species. This initiative could represent a threat to ecosystem stability considering that non-native arboreal species were introduced.

• *Indupalma*: started operations in 2012 with 25000 ha for rubber extraction.

Lastly, there is an extensive livestock production, which represents about 45% of Vichada's economic activity and occupies almost a quarter of the territory (CORPORINOQUIA, 2013a; Fedegan, 2021; Viloria, 2009).

VICHADA'S NDVI PROFILES AND THE INCIDENCE OF AGRIBUSINESS

The profiles obtained in this study with the NDVI index, showed variations of the different land-cover classes during the evaluated time. The NDVI index (Fig. 4) indicates a drastic reduction of the forest cover during the 1985-2001 period, with a short stabilization period from 2001-2009, and then a continuous reduction until 2017. These changes are compatible with the periods of colonization and early exploitation in the territory, together with the implementation of several agrarian policies (CGR, 2014).

The index also showed that savannas and croplands remained without major variation until 2009, when they began to increase notably (Fig. 4). The savanna class includes both natural species and improved pastures introduced for livestock production. Initially, in Vichada, livestock farming was performed under the extensive system with traditional practices, which can produce a series of negative effects on the biophysical characteristics of ecosystems, such as biodiversity lost, soil compaction and erosion (Viloria, 2009). Moreover, these activities were intensified with government policies, creating monocultures of African pastures, which coincides with the increase of savannas according to the NDVI index (Table 3).

The review of agribusiness in Vichada showed a significant number of hectares dedicated to forest plantations (Table 3). These plantations of non-native species can alter natural ecosystems (Chakraborty et al., 2018). Although the NDVI values could be confusing about the forest plantations, and even some crops, with the natural forest cover, the forest plantation and crops can be easily distinguished in the maps by detailed observation since the plot edges are visible (Fig. 5).

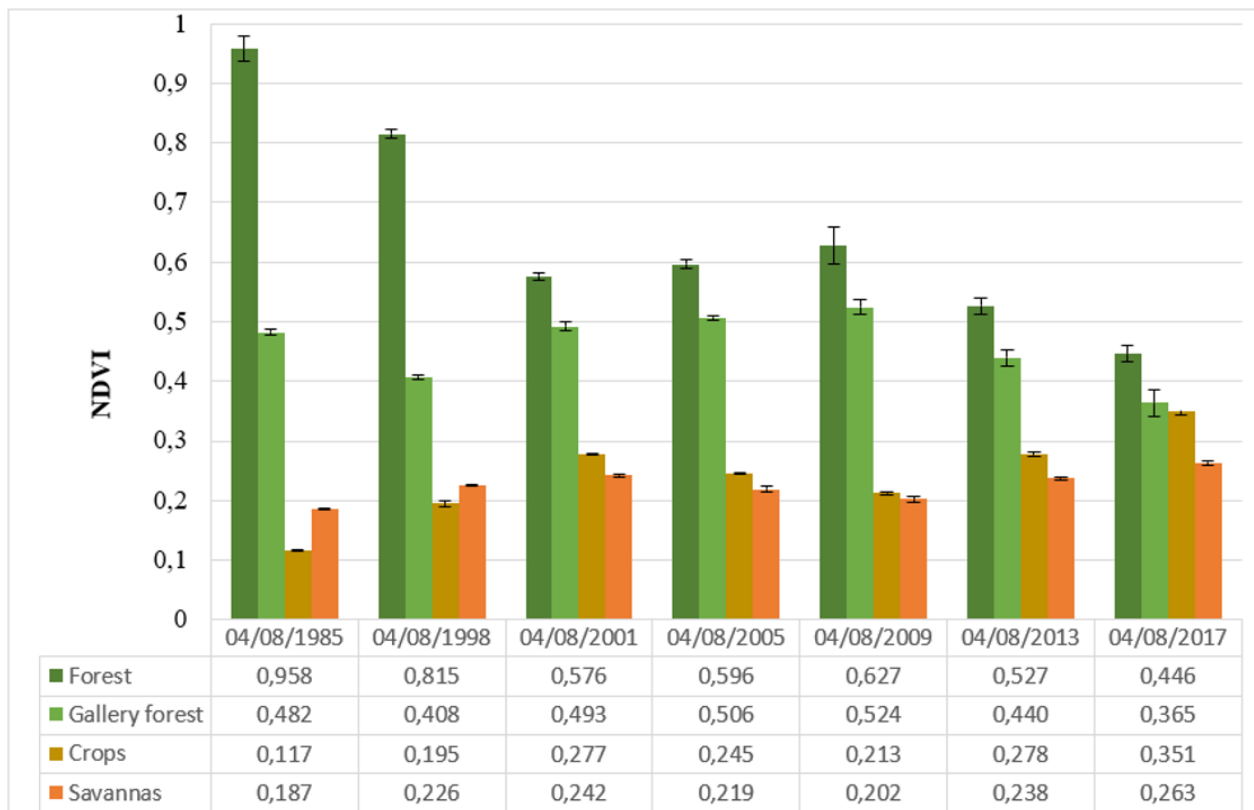Forest plantations have emerged since 2005 when government incentives were

	04/08/1985	04/08/1998	04/08/2001	04/08/2005	04/08/2009	04/08/2013	04/08/2017
■ Forest	0,958	0,815	0,576	0,596	0,627	0,527	0,446
■ Gallery forest	0,482	0,408	0,493	0,506	0,524	0,440	0,365
■ Crops	0,117	0,195	0,277	0,245	0,213	0,278	0,351
■ Savannas	0,187	0,226	0,242	0,219	0,202	0,238	0,263

Figure 4. NDVI temporal profiles for the plant-covers in the Vichada department.

Source: authors.

implemented to promote non-native species, such as teak, tropical Caribbean pine, eucalyptus, and acacia, for timber purposes (Duarte, 2016). In 2016, almost 70000 ha of these trees were planted and about 24% of them are on the Bita's river basin (Gómez, 2015; MADR, 2004). In fact, in the present study, the transformation of natural forest into croplands and forest plantations can be observed near the basin (Fig. 5).

LAND-COVER CHANGE ON A MULTI-TEMPORAL SCALE (1985-2017) IN THE BITA RIVER BASIN AND ITS RELATION WITH AGRIBUSINESS

Table 4 lists the estimated areas for each land-cover class in the Bita's river basin, based on the analysis of satellite imagery of this study. The results showed that the forest areas decreased in the first period (from 1985 to 2001), changing from 42.84 % of the total territory to 11.86%, and increased in the second period (from 2001 to 2017) to 16.7%. Overall, considering the first forest area in 1985 (347994 ha), and the last forest area in 2017 (135656 ha), there was a loss of 212338

ha, hence, 61% of the forest was lost. As a result, pastures (scattered vegetation) and croplands were increased in the first period and decreased in the second period. In both periods, savannas (natural and introduced) were increased. The savannas expanded at a higher rate in the first period and then slowed down in the second.

Regarding to that situation, Perz et al. (2005) stated that, in the 90s, the Orinoquía region suffered a deforestation rate almost three times higher than the Colombian Amazon. The destruction of native forests can be directly related to agricultural progress in the department, and to the implementation of policies that boosted economic development. This is also consistent with the results of Santacruz-Delgado, (2019), who found that annual crops and pastures increased at the expense of forests, between 2000-2015, in the high plains of the department of Vichada. Moreover, change in the forest cover caused by the increase of pastures for livestock was also found in the Amazon deforestation processes (Dávalos et al., 2014).
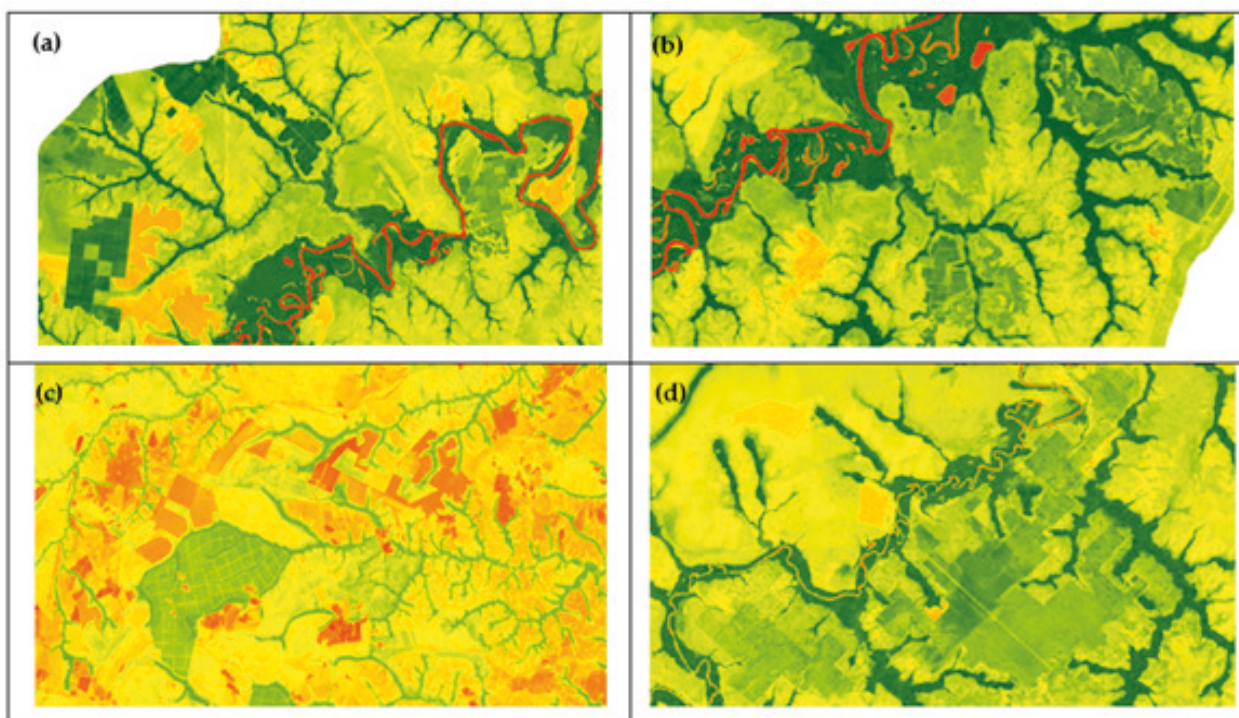
Figure 5. Zoom in NDVI layer stack images from the Bita river basin with forest plantations and monocrops (2017): (a) East area of the basin; (b) Middle part of the basin; (c) West area of the basin; (d) South area of the basin. Despite the intense green colour of forest plantations, which could be confused with natural forest, they can be easily distinguished by the plot edges.

Source: authors.

Native tropical forest areas are being rapidly transformed into mosaics dominated by pastures and agricultural matrices (Etter et al., 2005). This habitat loss has affected more ecosystems than the climate change scenarios (Newbold et al., 2015). The alteration of ecological processes due to forest lost can generate coextinctions, and hence, affect the balance and functionality of ecosystems, and the services they provide for human beings benefit (Bradshaw et al., 2008). For example, Robinson, (2018) identified in the Tumbes-Chocó-Magdalena bioregion of Ecuador, a 30 % reduction of local biodiversity richness as a result of human activities and land-use changes since the 16th century. In this context, it is worth mentioning that in the Bita's river basin there are several endemic species, currently under some threat of extinction and of great biological importance, such as the plant Pepinia heliophila, the fish Pseudoplatystoma metaense, and the mammals Inia geoffrensis, Pteronura brasiliensis, Lontra longicaudis, Panthera onca, Puma condor and Tapirus terrestris (Trujillo & Lasso, 2017).

Furthermore, some of the effects related to the implementation of large-scale agro-industrial projects are soil degradation, disappearance of water streams, contamination by agro-toxins and biodiversity lost (Dayrell, 2012). Specifically for river basins, land-use changes result in organic matter losses, erosion, decrease in the water flow and in the availability of resources (Benstead & Pringle, 2004; Dominati et al., 2010). Those changes have already been reported by the environmental corporation in charge of the Vichada territory, CORPORINOQUIA (Gómez, 2015). Agro-industrial processes in places with similar biophysics characteristics and land occupation dynamics as Vichada and the Bita river, such as the Cerrado region in Brazil, have resulted in drying of wetlands and selective effect in the wildlife survival (Dayrell, 2012; Ferraz et al., 2010). Therefore, the present study recommends special attention to the currently threatened ecosystems in the Bita's river basin.

Analysis of present data also showed that the forest cover had a recovery from

88704 ha (almost 12 % of the territory) to 135656 ha (almost 17 % of the territory) between 2001 and 2017. However, the same consideration from the previous section should be noted, this presumed forest recovery could be due to forest plantations of non-native species with extraction purposes. It is estimated that Vichada has 569653 ha suitable for commercial forest plantations, located mainly in the municipalities of Cumaribo, La Primavera and Puerto Carreño (near the Bita's river basin). In these places, plantations started in 2006 through carbon credits commercialization. These plantations were prioritized after the creation of these programs: the Forest Incentive Certificate (CIF) (implemented by the law 1337), the "Action Plan for Commercial Reforestation" in 2011 (MADR, 2011), and the "CONPES 3797" strategy (CONPES, 2014). Altogether, these policies supported more than 70% of the investments made in forest plantations in Vichada (Gómez, 2015).

Another factor that contributes to the deforestation in the Bita's river basin is the livestock production. The economy of La Primavera municipality (where part of the Bita's river is located) is based on extensive livestock farming, with a disproportionate land-use for this activity that covers 90% of the territory (Álvarez, 2016). After major technological advances, and the Laws 135 of 1961 and 30 of 1988, the livestock farming frontier was enlarged covering the forested areas of Vichada (Gómez, 2015). During the evaluated period in this study (1985-2017), an increase of more than 100 % in the pasture cover was proposed in the "Strategic Plan of Colombian Livestock Farming". The purpose of this policy was the introduction of improved African pastures, mainly of the genus Brachiaria, and burn natural savannas (Arias, 2004; Andrade-Pérez et al., 2013; Fedegan, 2021). This is shown in Table 4, noticing the increase in savannas, because it is not possible to distinguish endemic savannas from introduced pastures. In addition to deforestation, pastures without proper management can increase soil degradation, destroying native fauna and flora (Trillos, 2010).

On the other hand, population growth in poorly occupied territories, as is the case of Vichada, produces drastic land-use changes, not only due to agricultural expansion, but also because of communication and trade routes construction (Perz et al., 2005). Since the dynamics of landscape transformation can be accelerated by rapid population growth, the increase of urban area (infrastructure) in the Bita's river basin is noteworthy (Table 4). Also, an increase of 34 % in the population between 1980 and 2000, and 70 % between 2001-2017, is directly related to the social and economic opportunities provided by agribusiness (DANE, 2015). Moreover, roadway constructions such as the highway between the municipalities of Puerto Carreño and Puerto Gaitán (department of Meta), that promotes the economic development of the Altillanura, and the mega-road project that will connect Colombia and Venezuela with a total length of 2 661 km, represent additional threats for the Bita river basin (DNP, 2018).

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Table 4. Area and percentages of land-covers from 1985 to 2017 in the Bita river basin.

Land-cover class	1985		2001		2017	
	ha	%	ha	%	ha	%
Forest	347994	42.84%	88704	11.86%	135656	16.70%
Savannas	315339	38.82%	376327	3.08%	477639	58.80%
Soil/Scattered vegetation	38097	4.69%	162608	2.61%	28349	3.49%
Cropland	93497	11.51%	165350	0.28%	151090	18.60%
Water	16327	2.01%	16327	8.59%	16327	2.01%
Infrastructure	1056	0.13%	2994	4.70%	3249	0.40%

Source: Authors.

Table 5. Classified images validation and percentages of user's accuracy and producer's accuracy. Where g.a. means general accuracy and k.i. means Kappa index.

Land-cover class	1985-2001 g.a. 86.1% k.i. 0.81		2001-2017 g.a. 96.4% k.i. 0.95	
	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)
Forest	99	99	98	96
Savannas	100	100	99	98
Soil/Scattered vegetation	89	87	90	88
Cropland	44	100	97	96
Water	100	100	100	100
Infrastructure	100	100	100	100

Source: *Authors.*

Table 5 shows validation of the image classification process for the evaluated periods, through a cross-tabulation matrix containing the Kappa index, general accuracy, user's accuracy and producer's accuracy, finally, indicating a statistical validation above 85% for the MLC both periods. Considering this, the maps in Fig. 6 (see Annex) were constructed. These maps provide a comparison of the land-cover classes distribution in the selected periods (1985-2001 and 2001-2017). A transition from forests to savannas, pastures (scattered vegetation) and croplands, especially during the 1985-2001 period, as well as a replacement of natural savannas for pastures (scattered vegetation), croplands and bare soil during the same period is shown. In the 2001-2017 period, a change from bare soil/scattered vegetation to savannas and pastures was observed too.

The management of basins should tend to maintain mature and productive forest areas, as well as to decrease tensors (Sánchez et al., 2015). Therefore, maintaining the forest cover is important to preserve the current state of conservation in the Bita's river basin. This is especially relevant since the wetland can provide ecological balance to endure the high pressure of climate change in the region, where the dry season is particularly strong, due to the high evaporation rates and the runoff, and to avoid future problems due to water demand (CIAT & Cormacarena, 2017; Yepes-Mayorga, 2012).

Although the Bita's river currently has a protection figure, since it was included in the Ramsar list of wetlands of international importance (Decree 1235, 2018), this type of protection does not have a management plan with defined zones. Thus, environmental authorities cannot exercise control over the territory. The promptness of the land-use transformations makes current environmental regulations and laws useless. Hence, the biodiversity at the river basin is exposed to the effects of the agricultural frontier expansion (CIAT & Cormacarena, 2017). Moreover, the Ramsar convention is mainly based on migratory bird activities, which leaves out a great part of the biodiversity that this basin encompasses (Ramsar, 2015). Therefore, despite the existence of a protection figure in the Bita river, a greater knowledge of the ecosystems and a well-designed management plan oriented towards environmental recovery is needed for this area.

Finally, the inadequate use of land is partially caused by the lack of environmental awareness in the local communities. Another important aspect is that environmental government entities have not made enough efforts to investigate the territory. Currently, there is little to non- existent information regarding the biodiversity of this area, since there is only one real scientific research available (Trujillo & Lasso, 2017). This is why the present research seeks to provide information that encourages others to do investigations in the area, so they can contribute to the conservation and sustainability of important ecosystems of Vichada.

CONCLUSIONS

The present study monitored the land-cover changes in Vichada (Colombia) within a 32-year period. As a result, were obtained classified maps of the years 1985-2017, using satellite images and information regarding agribusiness. It was identified that the land-cover change, and land-use change in Vichada reflects several processes at different scales, such as an initial use of land for subsistence farming, a population growth that responded to national development policies, changes in the regional economy mainly due to extensive livestock farming, and finally, large-scale agro-industrial projects that resulted from national stimulus. Therefore, both, policies and economic practices, promote changes in the forest cover. The results showed a transition from forests to other land-cover classes, such as croplands and pastures. A great loss of forest cover was noted, about 60 % during the last 32 years. Hence, the effects of deforestation on these natural ecosystems should be from now on a matter of research.

The Bita's river basin should become a priority area for conservation since it is currently affected by anthropogenic stressors (that reduced its forested area to one-third) and is vital for water availability. Moreover, it was found that a great part of the intervention in this area is located nearby Puerto Carreño municipality, which raises a challenge for ecological conservation because it is there where a great part of the biodiversity is concentrated. In addition to the need for more research, is fundamental more attention to the development of policies for resources management. The lack of regulation from environmental authorities is a relevant issue as well. Also, in this context, it should be mentioned that to resolve conflicts of land-use in Vichada, land ownership of local communities must be clarified, considering their needs and the preservation of natural resources. Lastly, despite its limitations, this study provides useful findings for territory planning and decision-making.

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Conflicto de intereses
Los autores declaran no tener ningún conflicto de intereses.

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