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ARTICLE

Deforestation processes in the livestock territory of La Vía Láctea, Matagalpa, Nicaragua

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ABSTRACT

Land-use change is considered one of the main causes of environmental degradation. Thus, its analysis will allow stakeholders to make reasonable decisions for land management. The objective of the present study was to understand the patterns of land-use/land-cover change and deforestation in a territory of importance for livestock development in Nicaragua: La Vía Láctea. The methodology was based on the digital processing of satellite images using the geographic information system that allowed the generation of the thematic cartography of land-use/land-cover for 1978, 1986, 1998, and 2011. Between 1978 and 2011, a total of 93% of the forest cover was converted to pasture for livestock development; this change has been influenced by socio-economic and political factors. This study, moreover, reinforces the idea that livestock is the main driver of deforestation. Landscape restoration requires increasing tree cover by adopting silvopastoral systems that improve biodiversity conservation and the provision of ecosystem services.

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Deforestation; land use/land cover; livestock; remote sensing; Nicaragua

Introduction

Land use is the result of anthropogenic actions and decisions to manage land and resources (e.g., agriculture, mining, grazing, etc.); whereas land cover change refers to the substitution of one cover for another. In spite land-use change dynamics suggest the modification of land cover, they do not denote a general change in the classification of land cover (for example, the intensification of agriculture). Therefore, land cover is directly observable through remote sensing (Turner, Meyer, & Skole, 1994; van Soesbergen, 2016). Land use is determined by the interaction, in space and time, of biophysical factors (such as soil, climate, and topography) and human factors (such as population, technology, and economic conditions) (Veldkamp & Fresco, 1996). This indicates that land-use and land-cover (LULC) change is one of the main factors that affect the conservation of biodiversity and the provision of ecosystem services. LULC changes can be divided into the following categories: 1) *modification*, when there is a change of conditions within a type of cover, e.g., the change from unprotected forests to protected forests; and 2) *conversion*, when one land cover is transformed into another type, such as the transformation of forests into pastures (van Soesbergen, 2016).

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The conversion of forests in Central America is a process that has developed over many centuries. In the last decades, the process of deforestation has been mainly generated by political and social factors. Since 1960, agriculture is one of the causes of the forest reduction, as well as the government policies that promoted the opening of roads for the establishment of commercial farms in the Central American territory (Armenteras, Espelta, Rodríguez, & Retana, 2017; Kaimowitz & Angelsen, 1998).

Deforestation has been associated with the capital inflow for the establishment of new areas for agricultural activities, which has generated an increase in road infrastructure. The latter facilities increase access to forests and improve the transportation of products to markets, which has resulted in the expansion of the agricultural frontier (Barber, Cochrane, Souza, & Laurance, 2014). Thus, social and economic policies, linked to globalization, have promoted changes in agricultural production systems to meet the local, regional, and global market needs. This situation has been favored by government incentives and migration policies, which have been the main drivers of deforestation in Central America and other regions of Latin America. These scenarios were evidenced in the Amazon, the high Andean ecosystems, and dry forests of the region (Armenteras, Cabrera, Rodríguez, & Retana, 2013; Grau & Aide, 2008; Vina & Cavelier, 2006). Deforestation is linked to new settlers due to political and economic incentives for the establishment of new areas for agricultural development. In the context of Central America, the relationship between the population and the high rate of deforestation is scale-dependent, due to the relatively low growth rates of the rural population (Carr, 2009). Deforestation causes a quarter of the total global greenhouse gas emissions (Carr, Barbieri, Pan, & Iranavi, 2006). Other drivers, such as pasture conversion, timber harvesting, and urban expansion have made deforestation a dynamic process (Armenteras et al., 2017). This trend, pointing to both urban population growth and urban food demand, is an increasingly important factor for the loss of forest cover in the region. According to recent population growth estimates, rural populations in Central America are likely to shrink or grow relatively slowly into urban populations in the coming decades (United Nations, 2019). Urban growth is likely to play an even greater role in the impact of future forest cover (Barber et al., 2014).

The deforestation process in the tropics has been a matter of interest and concern worldwide, due to the impact that LULC change has exerted on biodiversity loss (Bennett & Saunders, 2010; Naidoo et al., 2008) and the ecosystem service of provision (Hughes, 2017), such as the reduction of natural pollination (Kremen & Miles, 2012), carbon storage, and timber harvesting (Habib et al., 2016). In Nicaragua, deforestation has increased since 1960 due to the rise in land colonization for timber harvesting and agricultural development (Polvorosa & Bastiaensen, 2016). In the Amazon region, the extraction and use of wood with the consequent increase in the income of colonists has resulted in the expansion of the agricultural frontier (Soler, Verburg, & Alves, 2014).

The deforestation and LULC change analysis have become a central component of current strategies for natural resource management and monitoring of ecosystem services (Loran et al., 2017), representing a challenge for the conservation of forest cover and sustainable agricultural development in Central America, in this case in La Vía Láctea in Nicaragua. In this territory, natural forests have had come under strong anthropogenic pressure, caused by 1) the migration of producers from the northern part of Nicaragua during the 1960s and 1970s, 2) the redistribution of land for the peace process of the 1980s, and 3) the amendment of the agricultural development policies and programs during the 1980s (Bastiaensen, Merlet, & Flores, 2015; MARENA, 2017; Zeledon & Kelly, 2009), leading to an increase in agricultural land in the region.

Therefore, the objective of this study was to analyze LULC changes through a multitemporal analysis between 1978 and 2011 in La Vía Láctea, Nicaragua. This is a territory located in the central zone of the country where dairy farming is the dominant economic activity, and 80% of this is being managed by small and medium producers. The understanding of the dynamics of LULC will improve the actions for the conservation of the forest remnants and the management strategy of the territory to reduce the pressure on forests for livestock management.

Materials and methods

Study area

The study was conducted in the municipalities of Matiguás (12°50′N – 85°27′W), Muy Muy (12°45′N – 85°37′W), and Río Blanco (12°56′N-85°07′W), located in the department of Matagalpa, Nicaragua (Figure 1). These municipalities comprise the territory of La Vía Láctea, where the main economic activity is milk production (Bastiaensen et al., 2015). The relief of the area is varied, with rolling, flat, and broken lands (MARENA, 2008). These municipalities have a rainy season of around eight months from May to December and a dry season between January and April (INIDE, 2015). The area is classified as sub-humid tropical forest, with a mean annual temperature of 24°C and mean annual rainfall of 1915 mm. The dual-purpose livestock system is the most common in the area; the 80% of dairy farmers is small farmers (7–25 ha), and the 15% is medium farmers (25 – 100 ha). There are various breeds of cattle, being Brahman, Holstein, Jersey and Brown Swiss crossed the predominant species. In addition, there is a mean stocking rate of 1.3 AU/ha and a mean milk production of 3.5 kg/cow/day (Polvorosa & Bastiaensen, 2016).

We selected as an analysis unit, the territory of the three municipalities, due to the importance they have for livestock production. These municipalities form the territory of La Vía Láctea, whose name was generated in the middle of 2000, due to the increase in milk collection centers. The farmers are organized as co-operatives of milk producers, such as San Jose, Nicacentro, and three artisan cheese companies that became semi-industrial companies to export fresh cheese to Central America and the United States (Bastiaensen et al., 2015).

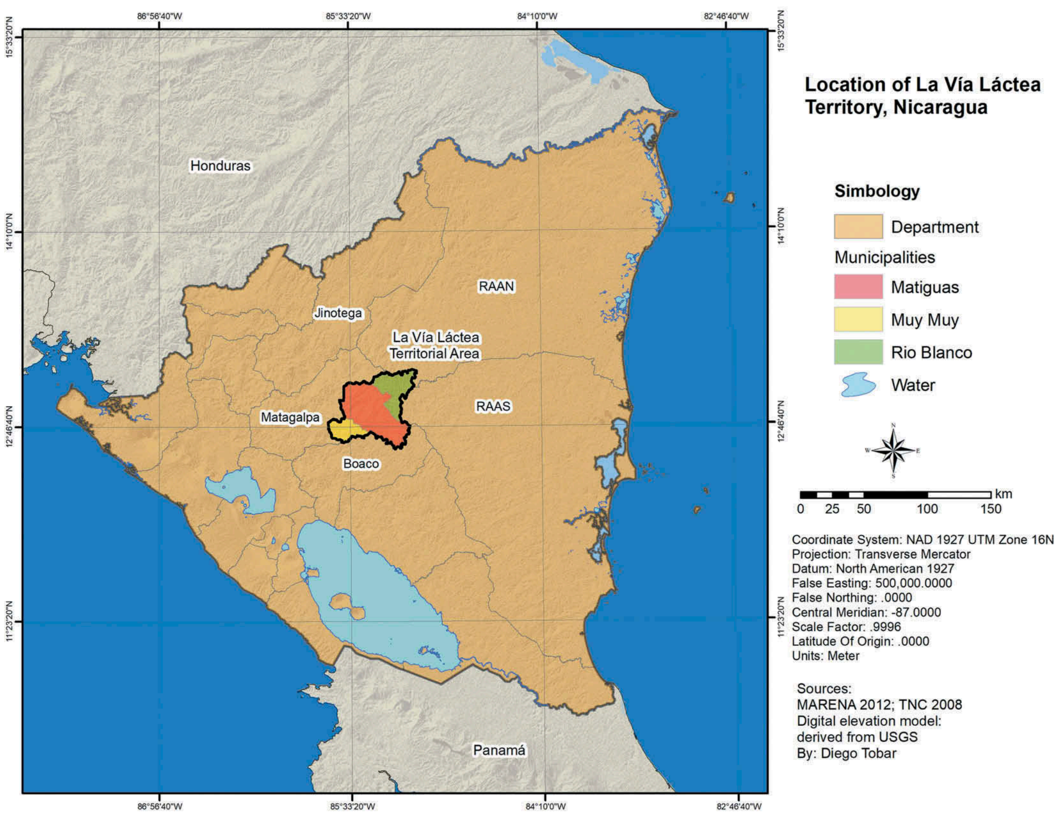

Figure 1. Location map of La Vía Láctea territory, Matagalpa, Nicaragua.

Data collection and satellite imaginary analysis

Figure 2 illustrates the framework of the methodological process. The major steps are the following: (1) data preparation, (2) the determination of the classification results of four years (1978, 1998, 1986, and 2011), (3) the application of the Land Change Model to obtain the LULC analysis, and (4) the determination of the landscape metric.

The study was delimited based on municipal limits at a scale of 1:50,000 considering the geopolitical limit of the three municipalities. The analysis of time series data of land use and land cover (LULC) was carried out using multispectral Landsat images (Landsat 3 [MSS] for 1978 and 3 Landsat 5 [TM] for 1986, 1998, and 2011), from the United States Geological Survey (USGS) and through the Global Visualization Viewer (GloVis). The working images were considered for the same season with less than 20% of cloud cover. Prior to interpretation, atmospheric correction and geometric rectification were performed. The dates selected for the processing of LULC changes depended on the availability of images and the presence of clouds. Remote sensing image data were preprocessed and processed using ERDAS Imagine 2011 software, by applying the basic image preprocessing techniques (image rectification, restoration, enhancement, image classification, and accuracy assessment). We had to take into account that removing the influence of the atmosphere is a critical pre-processing step in analyzing images of surface reflectance.

The multispectral images were projected to the coordinated system defined for Nicaragua, which is UTM 17N. The image space signature separability was computed to support the supervised image classification (maximum likelihood method) (Janssen & van der Wel, 1994). Subsequently, an AOI (Area Of Interest) layer was made with the shape of the three municipalities, previously adjusted geometrically with a satellite image, to facilitate the precise cutting of the study area. With this process, we defined the types of cover supported by the methodology of the Corine Land Cover Legend (Rosales-Ibarra, 2013).

This process also took place with the combination of the RGB bands 432 and 342 and, in TM, the bands 432 and 453, which enabled the best visual interpretation of the images, as they enhanced and discriminated different land cover and differentiated them from others, such as agricultural and urban areas. The interpretation was supported by spectral curves, textures, sizes, spatial context, and

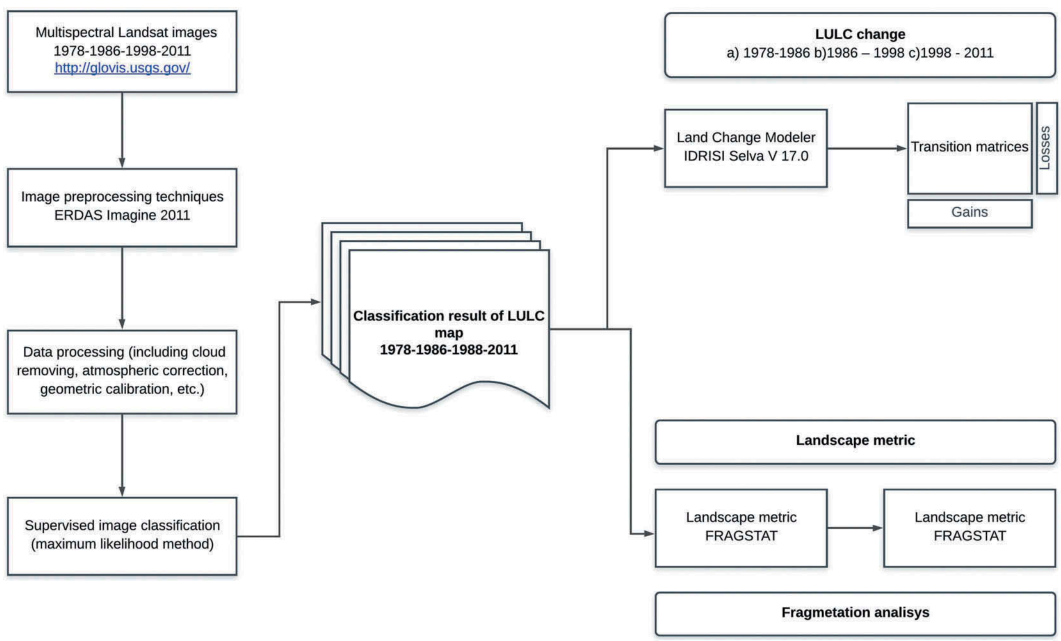

Figure 2. Data processing flowchart.

geometries displayed in the image, and the plotting of the vectors was done in the Arc Coverage format taking care of the topological integrity of the polygons with a Fuzzy tolerance of 0.00001.

The images were classified into seven land uses, which are the following: 1) forest, 2) pasture with high tree density, 3) pasture with low tree density, 4) degraded pastures, 5) agriculture areas, 6) monoculture pastures, and 7) urban areas (Table 1). Regarding the evaluation of the map's trustworthiness, we employed the methodology created by Mas, Velázquez, and Couturier (2009). Once the maps were digitized, we identified the sites with the greatest number of LULC changes. Subsequently, on the digitized image, 65 random points were generated to evaluate the classification categories, following the procedure recommended by Salas (2010). This allowed us to guarantee the concordance of the reality with the maps generated. In each site, we identified the LULC and their geographic coordinates were estimated for future analysis. The overall accuracy for the development of the land-use cover maps was evaluated using the Kappa coefficient, obtaining acceptable values (0.88, 0.80, 0.82, and 0.89 for 1978, 1986, 1988, and 2011, respectively). This means that the accuracy was acceptable for further LULC analysis (Ruppert, Hussain, & Heimo, 1999). The maps are available in the Mendeley database at http://dx.doi.10.17632/rbtcpwxshy.3 (Tobar-López, Bonin, Andrade-C, Pulido, & Ibrahim, 2019).

For the last step, two workshops were held with a stakeholder (a farmer), who had greater historical knowledge of the region, and a workshop with the technical staff from institutions providing technical assistance in the region, including the Multisectorial Dairy Cooperative (NICACENTRO), the Nicaraguan Institute of Agricultural Technology (INTA), the National Livestock Commission of Nicaragua (CONAGAN), and the Ministry of Family, Community, Cooperative, and Associative Economy (MEFCCA). The purpose of these workshops was to obtain information about the historical process of colonization and management of the forest and agricultural areas that they hold and to see the actual situation for natural resource management in the territory.

Land-change modeler (LMC)

Through the LCM module of Idrisi Selva V 17.00 (Eastman, 2012), the dynamics of LULC change were analyzed. The LULC maps generated for 1978, 1986, 1998, and 2011 were used for this purpose. Analyses

Table 1. Description of land use and land cover classes types and bands combination.

Land cover	Land use	Description	Band combination[a]
Forest land	Forest	Native forest with interventions for wood exploitation during the last year. Fragments of different sizes.	RGB 453 RGB 432
Agricultural land	Pastures with high tree density	Pasture cover with dispersed trees with more than 30% of cover, associated with small areas of forest fallow and used for grazing.	RGB 453 RGB 432
	Pastures with low tree density	Pasture cover with dispersed trees with less than 30% of cover, associated with small areas of forest fallow and used for grazing.	
	Degraded pastures	Areas without permanent vegetation. These are the covers represented by lands with pastures and weeds, forming associations of secondary vegetation, which is connected to the extensive management of livestock.	
	Monoculture Pastures	Pasture dominated by improved grass species without tree.	
	Agricultural areas (annual and perennial crops)	Annual, transitory, or permanent crops, in which the parcel sizes are very small, and the distribution pattern of the lots is too intricate to represent them cartographically in an individual way.	RGB 453 RGB 432
Urban Areas	Urban Areas	Lands modified by human activities, including all kinds of habitation, transportation facilities, and interior urban green zones and water bodies.	RGB 453 RGB 432

[a]Band combination used for identification in the satellite image. Source: (Rosales-Ibarra, 2013)

of changes or conversions were performed for each period separately as follows: 1) 1978–1986, 2) 1986–1998, 3)1998–2011. As a result, it was possible to graphically identify conversion of one land use to another and to analyze the magnitude and direction of the net. The results of these analyses are expressed in total area and percentage by land use.

The preliminary analysis was carried out using a use coverage model for each year (1978, 1986, 1998, and 2011), with the employment of only two types of cover: forest and agricultural cover. This allowed us to appreciate the dynamics of change in coverage at a general level. With the second analysis, we could make comparisons of change and transition of LULC between the evaluated periods. With this matrix, it was possible to estimate the persistence, losses, and gains of each LULC over each period (Pontius, Shusas, & McEachern, 2004).

The estimated change rate reflects the severity of land-use change in the study area over a given period of time. The annual rate of change (*rc*) for each land use was calculated with the following equation (FAO, 1995):

$$rc = \left[\left(\frac{S_2}{S_1} \right)^{1/n} - 1 \right] \cdot 100 \tag{1}$$

In this equation, *rc* is the change rate, S_1 and S_2 are the land-use surfaces at the initial time and at the final time, respectively. The variable *n* corresponds to the amplitude of the period evaluated, that is, the number of years between periods. This parameter expresses the percentage change of the area at the beginning of each year and shows the conversion rates between coverage data or identified uses in a very clear way. The values that were set below zero indicate losses and those that are greater than zero show gains (Velázquez et al., 2002).

Landscape metrics

Landscape metrics provide information about the structure of the landscape, such as compositional properties (types of elements that make up the landscape) and configuration (spatial arrangement of that element). The results of these indices allowed us to analyze the changes of the structure of the landscape over a given period of time and provide support in the collection of information for the management of the landscape (Bennett & Saunders, 2010; Li et al., 2009). FRAGSTAT software V4.2 was used to select and compute the landscape and class metrics (McGarial & Marks, 1995). In this study, the selected metrics were based on those that enabled the analysis of the effects of the fragmentation on the structure and the function of forest cover in the territory (Table 2).

Results

Land-cover and land-use change

The period with the highest deforestation rate was between 1978 and 1986; whereas in 1986–1998, the conversion from forests to pasture cover continued. During 1998–2011, forest cover stabilized, maintaining less than 10% of the total area of the territory (Figure 3). The distribution of forest cover is discontinuous, with a clear fragmentation of forest cover in the landscape (Figure 4). There was 86% forest loss between 1978 and 1986 was of 86%. During the period 1986–1998, forest loss was found to be of 3.8%, with an annual deforestation rate of −0.01%. For the last period (1998–2011), forest loss had a rate of −0.04%.

In 1978, 60.9% of the surface of the territory of La Vía Láctea was covered by forest and 38.1%, by pasture, where pastures with scattered trees prevailed (26.1%). By 1986, the forest cover decreased to 8.4%, while the areas of forested pastures increased considerably to 72.3%. Subsequently, for 1998, forest cover decreased to 4.9% of the total area. In addition, pasture cover had modifications, mainly from pasture with high tree density towards degraded pasture (Table 3; Figure 4).

Table 2. Landscape metrics used for fragmentation analysis, selected from Fragstats (McGarial & Marks, 1995).

Name of the Metric	Description
Number of patches (NP) $NP = n_i$ (2)	Number of Patches in the Landscape. n_i: Number of class *i* patches in the landscape
Average patch size (MN) $MN = \frac{\sum_{j=i}^{n} x_{ij}}{n_i}$ (3)	Sum of the areas of all patches present in the landscape divided by the number of patches (ha).
Area-weighted Mean Shape Index (AWMSI) $AWMSI = \sum_{i-l}^{m} \sum_{j=l}^{n} [\frac{0.25 \cdot p_{ij}}{\sqrt[2]{a_{ij}}} * \frac{a_{ij}}{A}]$ (4)	Weighted patch calculation based on size. Larger patches have greater weighting than smaller patches; it is calculated by averaging the shape of the patch. If the values are close to 1, the shape patterns are not circular; they are actually fragmented areas. Aij: average patch area, A: total patch area.
Mean Shape Index (MSI) $MSI = \frac{\sum_{i-l}^{m} \sum_{j=l}^{n} [\frac{0.25 \cdot p_{ij}}{\sqrt[2]{a_{ij}}} * \frac{a_{ij}}{A}]}{NP}$ (5)	Calculates the complexity of the average patch shape compared to a standard shape, such as the circumference in the vector environment or the pixel in the raster environment. The shape of a patch is characterized by the length of its edges. Fragments that have an irregular shape as a result of the fragmentation of the forest, they tend to have longer edge lengths. it is interpreted that if the values are equal to 1, the shape patterns are circular and increase as the irregularity of the patch shape increases.
Edge Density (ED) $ED = \frac{E}{A}(10000)$ (6)	It is the sum total of the edge meters included in the landscape divided by the total landscape (square meters) multiplied by 10,000.
Shannon's Evenness Index (SHEI) $SHEI = \frac{-\sum_{i=1}^{m} (p_i - LnP_i)}{\ln m}$ (7)	SHEI is equal to the sum, for all types of patches, of the proportional abundance of each type of tesserae multiplied by the Neperian logarithm of such proportional abundance.
	The measurement of area distribution among patches. It equals 1 when the distribution among patches is uniform, while it equals 0 when the landscape is dominated by a single type of patch.
Euclidean nearest neighbor distance (ENN)	Nearest neighbor distance is defined using simple Euclidean geometry as the shortest straight-line distance between the focal patch and its nearest neighbor of the same class. Even though nearest neighbor distance is often used to evaluate patch isolation, it is important to recognize that the single nearest patch may not fully represent the ecological neighborhood of the focal patch.

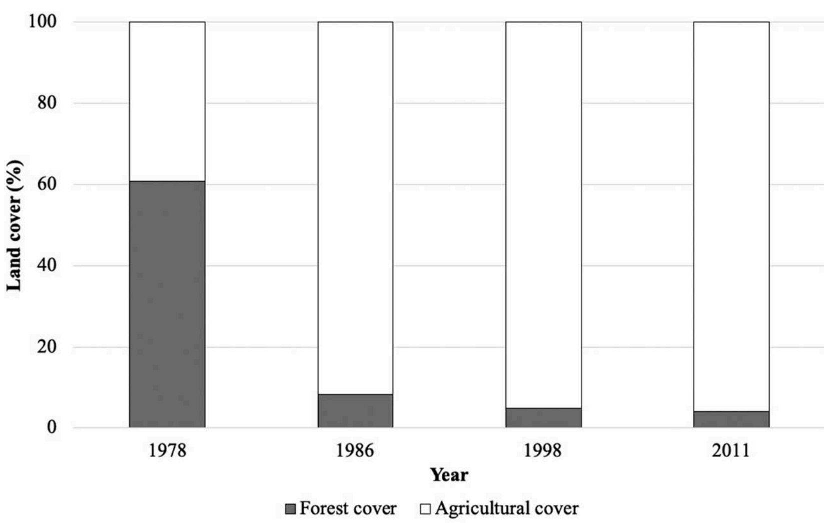

Figure 3. Land cover change (forest cover and agricultural cover) for the period 1978–2011, in La Vía Láctea territory, Nicaragua.

In 2011, forest areas continued to fall, in which only 4.1% of the original forest present in 1978 was maintained. Regarding pasture cover modifications, degraded and improved pasture areas increased by 39% and 13.5%, respectively, and the land use of pasture with high tree density decreased by

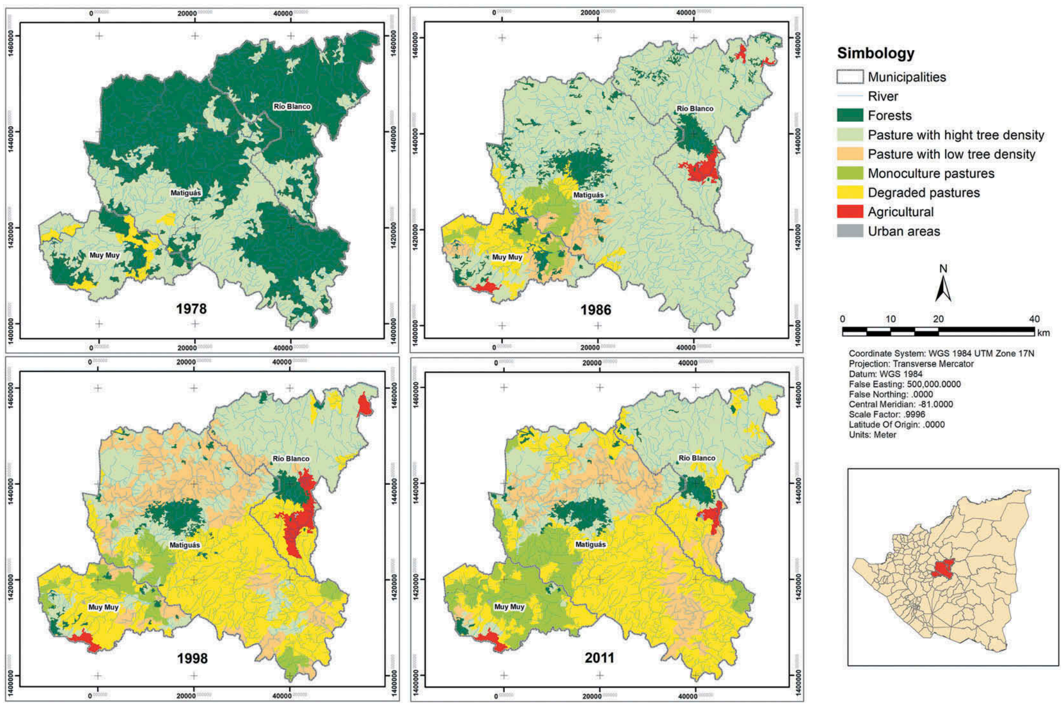

Figure 4. Dynamics of LULC change by year in La Vía Láctea territory, Matagalpa, Nicaragua (1978–2011), resulting from the interpretation of Landsat satellite images.

Table 3. Changes in land-use between 1978 and 2011 in La Vía Láctea territory, Matagalpa, Nicaragua. Area in hectares per use/year.

Year	1978		1986		1998		2011	
Land use	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forests	158,092.4	61.5	21,741.0	8.5	12,650.7	4.9	10,556.4	4.1
Pastures with high tree density	67,877.3	26.4	187,809.9	73.0	77,101.7	30.0	80,119.9	31.1
Pastures with low tree density	24,742.0	9.6	12,020.0	4.7	51,410.6	20.0	36,881.1	14.3
Degraded Pastures	6,466.4	2.5	19,628.3	7.6	88,854.6	34.5	89,391.3	34.8
Monoculture pastures	0	0	11,573.3	4.5	19,395.8	7.5	35,456.4	13.8
Agricultural Areas	0	0	4,337.1	1.7	7,649.9	3.0	4,534.3	1.8
Urban areas	50.3	< 0.1	118.8	< 0.1	165.1	< 0.1	289.0	0.1
Total	257,228.4	100.0	257,228.4	100.0	257,228.4	100.0	257,228.4	100.0

26.9% in the same period (Table 3). In fact, the area of forest was reduced from 158,092.7 ha in 1978 to 10,556.4 ha (–93.3%) in 2011, and the area of pasture increased from 99,085 ha in 1978 to 246,382 ha (135%) in 2011.

Land-cover and land-use transition

According to the land-use change matrices developed for the period 1978–2011 (Table 4), in 1978, the forest had an area of 158,092.4 ha, and, in 1986, it was only 20,986.5 ha, which evidences a process of deforestation. Therefore, the forest cover lost was a total of 137,105.9 ha, which became pasture, mainly with a high density of trees (Table 4).

For the period 1986–1998, the forest cover continued shrinking; its 11,848.4 ha remained, which showed that some forests were transformed to pastures and that the deforestation process continued.

Table 4. Changes transition matrices in La Vía Láctea territory from A) 1978–1986, B) 1986–1998, C) 1998–2011 showing the area (hectares) of land-use change between categories: (FO) Forests, (PHD) Pastures with high tree density, (PLD) Pastures with low tree density, (MP) Monoculture pasture, (DP) Degraded pastures, (AA) Agricultural areas, (UA) Urban areas, (cr) Change rate. The bolded figure is the sum of diagonals and represents the overall persistence (i.e., the landscape that did not change).

		To final state (1986)							
A		FO	PHD	PLD	MP	DP	AA	UA	Total 1978
From initial state (1978)	**FO**	**20,986.5**	130,962.0	1,763.1	770.0	2,224.0	1,386.8	0	158,092.4
	PHD	538.9	**53,369.0**	5,077.5	2,289.6	4,466.7	2,123.5	12.1	67,877.3
	PLD	70	3475	**3803**	4973	12,365	0	56.4	24,742.0
	MP	0	0	0	**0**	0	0	0	0
	DP	145.3	4	1376.5	3540.7	**573.1**	826.8	0	6466.4
	AA	0	0	0		0	**0**	0	0
	UA	0	0	0		0	0	**50.3**	50.3
Total 1986		21,741.0	187,809.9	12,020.0	11,573.3	19,628.3	4,337.1	118.8	257,228.4
cr (%)		−22	13.6	−8.6	0	14.9	0	11.3	

		To final state (1998)							
B		FO	PHD	PLD	MP	DP	AA	UA	Total 1986
From initial state (1986)	**FO**	**11,848.4**	5,689.6	1,696.3	387.3	1,933.9	185.5	0	21,741.0
	PHD	693.7	**66,726.1**	46,298.2	4,310.0	66,223.6	3,558.3	0	187,809.9
	PLD	56.0	2090.8	**2438.8**	944.9	6480.0	0	9.5	12,020.0
	MP	0	0	0	**11,085.1**	488.2	0	0	11,573.3
	DP	52.6	2285	814.5	2,648.8	**13,728.9**	78.8	19.7	19,628.3
	AA	0	310.2	162.8	19.7	0	**3,827.3**	17.1	4,337.1
	UA	0	0	0	0	0	0	**118.8**	118.8
Total 1998		12,650.7	77,101.7	51,410.6	19,395.8	88,854.6	7,649.9	165.1	257,228.4
cr (%)		−6.5	−10.5	19.9	6.7	20.8	7.4	4.2	

		To final state (2011)							
C		FO	PHD	PLD	DP	AA	MP	UA	Total 1998
From initial state (1998)	**FO**	**9,574.8**	2,048.6	65.4	842.8	0	119.1	0	12,650.7
	PHD	870.9	**67,213.2**	6,616.9	0	60.3	2340.4	0	77,101.7
	PLD	110.7	7,962.4	**22,016.2**	18,274.6	0	3046.7	0	51,410.6
	DP	0	2,339.6	7,908.8	**62,698.9**	150.2	15,722.3	34.8	88,854.6
	AA	0	0	0	3,293.3	**4323.8**	0	32.8	7,649.9
	MP	0	556.1	273.8	4,281.7	0	**14,227.9**	56.3	19,395.8
	UA	0	0	0	0	0	0	**165.1**	165.1
Total 2011		10,556.4	80,119.9	36,881.1	89,391.3	4,534.3	35,456.4	289.0	257,228.4
cr (%)		−2.2	0.5	−4.1	0.1	−6.3	7.8	7.2	

There was an increase in pastures with high tree density. These pastures were transformed, by a degradation process, to degraded pastures (Table 4). These dynamics are a typical consequence of the management of extensive livestock production in the region, which rotates along the landscape.

Pasture cover transition occurs when livestock practices lead to overgrazing, which, in turn, causes the degradation of grasslands and, thus, an increase in degraded pasture areas. Between 1998 and 2011, land-use changes were lower compared to previous periods (1978–1986; 1986–1998). Although degraded pastures were dominant, a recovery process took place through 1) the use of improved pastures and 2) pastures with high tree density (Table 4; Figure 4).

These results show that, between 1978 and 1986, the forest cover loss rate was the highest; however, the forest exchange rate dropped until the end of 2011. In addition, pasture areas have undergone high dynamic conversion over time. The analysis of gains and losses of LULC, in the first period (1978–1986), showed an increase in pasture cover and a decrease in forest cover. For the second period (1986–1998), modifications in pasture cover were observed, mainly from pasture with high density of trees to degraded pasture. The last period (1998–2011) was characterized by small changes in grazing land (changes from degraded pastures to improved pastures and pastures with high tree density) and no change in the proportion of forest area as in the previous period (Figure 5).

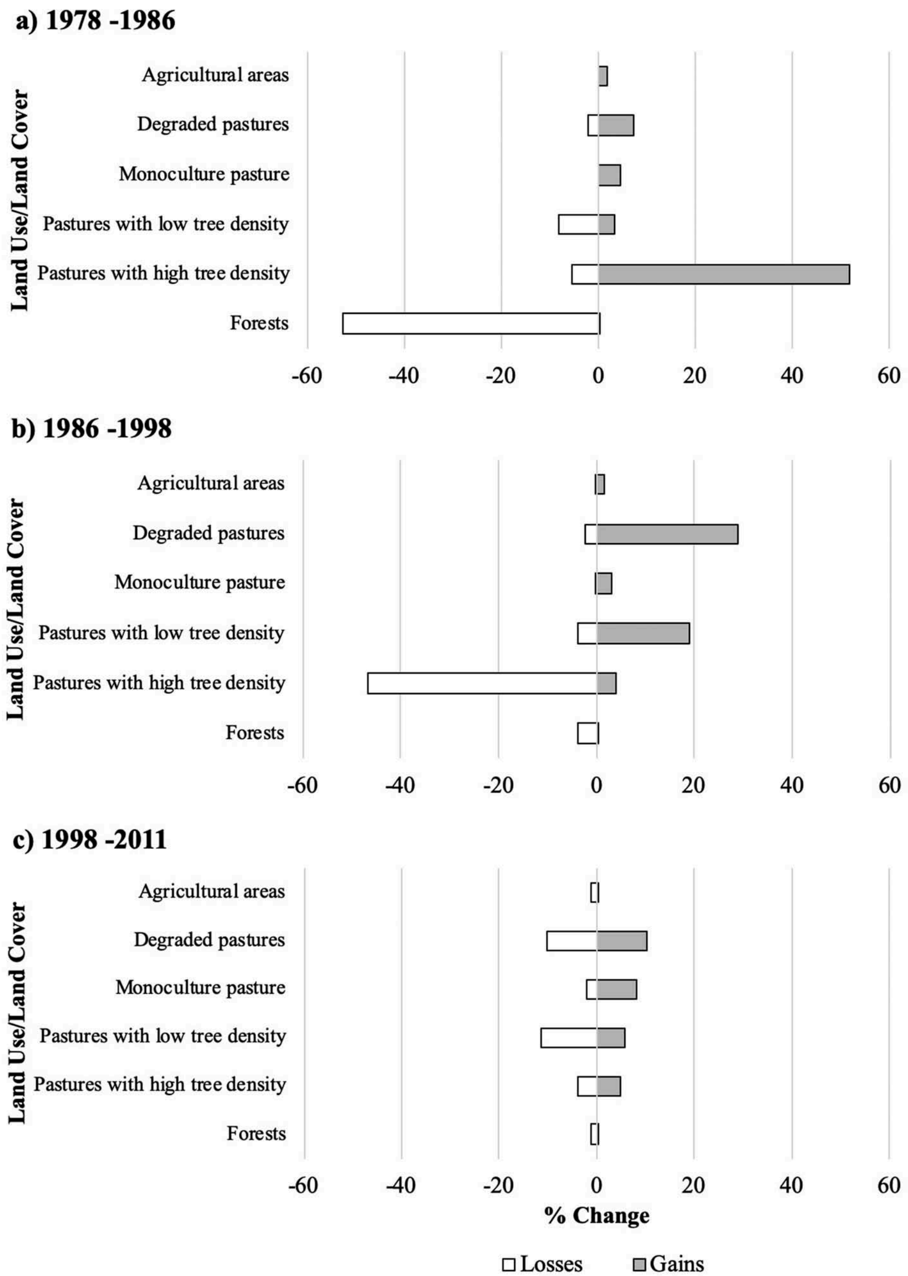

Figure 5. Magnitude (%) of land-use gains and losses for each LULC in La Vía Láctea territory, Matagalpa, Nicaragua (a) 1978–1986, b) 1986–1998 and c) 1998–2011.

Fragmentation analysis

The metrics selected and calculated from LULC generally showed an increase in landscape fragmentation (Table 5). In 1978, forest cover dominated the region and, in 1986, the configuration changed, and the dominant matrix was pasture cover (Figure 4). Patch density (NP) increased, while the average patch area (NM) decreased between the years evaluated. This is evidenced by the

Table 5. Calculated landscape metrics from LULC classifications in La Vía Láctea territory (Matagalpa, Nicaragua) for 1978–2011. Number of patches (NP), Average patch size (MN), Index of the weighted average of the form by area (AWMSI), Index of the form average (MSI), Edge Density (ED), Shannon Equity Index (SHEI), Euclidean Mean Distance Nearest Neighbor (ENN).

	Composition		Shape				Configuration
Year	NP	MN	AWMSI	MSI	ED	SHEI	ENN
1978	187	1388.6	535	283	93.1	0.57	642.4
1986	252	1030.4	867	280	113.9	0.50	966.6
1998	268	1047.1	505	269	117.7	0.73	1389.1
2011	345	954.1	516	274	120.9	0.72	1363.3

deforestation process in the area where the forests were transformed into pasture, with the fragmentation of the landscape (Table 5).

With landscape shape metrics (AWMSI and MSI), it is evident that the shape of land-use classes are irregularly formed: there are polygons with higher areas (> 10 ha), and patch density (ED) increased. These values are related to the management of pasture areas.

The SHEI evidences the reduction in the heterogeneity of the landscape, due to the fact that pasture cover, being the dominant matrix, causes the homogenization of the landscape configuration. This can be appreciated with the processes of modification of the pasture cover; the use of wooded pastures and degraded pastures predominated between 1978 and 2011 (Figure 3). The Euclidian distance index (MNN) shows that, as grassland and agricultural area cover expand, the connectivity of forest patches is reduced in the evaluated period (Figure 3; Table 5).

Discussion

Land-use change (1978–2011)

Considering the methodology used for the development of the LULC maps for the years 1978, 1986, 1998, and 2011, the percentage of acceptance of the Kappa coefficient was met (Mas et al., 2009). That allowed us to establish a LULC classification to understand the dynamics of the deforestation process in the region. This was also important for the validation of the visits to the territory, the revision of secondary information, and the development of the workshops with the stakeholders. This helped us understand the dynamics of LULC change in the territory of La Vía Láctea. Our study is consistent with previous works that documented extensive deforestation in the tropics, particularly in Central America (Armenteras et al., 2017; Kaimowitz, 1996), where forest cover declined at an average rate of 1.2% per year between 1961 and 2001 (Carr et al., 2006) mainly for crops and livestock. Most of the expansion of the agricultural frontier is due mainly to livestock (Carr et al., 2006; Wassenaar et al., 2007) and, at the national level, it is related to the growth of the cattle herd between 1978 and 2017 (FAO, 2019).

The results obtained were related to the historical processes of colonization in the region (between 1960 and 1970), which enabled the access to the forests for:1) timber exploitation and 2) the arrival of farming families from the north of the country to establish agricultural plots, which was considered as the first process of land privatization (Bastiaensen et al., 2015).

In the mid 1970s, the first milk production industries began to develop in the region, which encouraged the expansion of livestock farming in the territory; in turn, economic growth caused forest cover to be transformed into grassland (Levard, Marin-López, & Navarro, 2008; Polvorosa & Bastiaensen, 2016). Livestock production was related to the use of natural resources and the extensive management of the pasture area. Deforestation in the territory of La Vía Láctea, was, moreover, related to the expansion of the agricultural frontier and the exploitation of timber, which is one of the main agents of deforestation in tropical areas (Polvorosa & Bastiaensen, 2016; Rudel & Roper, 1997).

In the period 1978–1986, after the defeat of the dictatorship of Somosa in 1979, the territory was one of the main sites of the civil-war conflict that occurred during the 80's. During this period the demand for livestock products increased (Bastiaensen et al., 2015; Levard et al., 2008), together with the agrarian reform policy of 1981. These factors influenced the loss of forest cover for the expansion of pasture areas and allowed the maintenance of tree cover within pastures. Therefore, it is evident that social and political factors influenced the deforestation of the area and the increase in pasture areas (Naidoo et al., 2008; Velázquez et al., 2002).

During the period 1986–1998, at the end of the civil war (1989), and in the mid 1990s, the improvement of the road infrastructure of La Vía Láctea territory allowed the increase in the demand for agricultural products and the gradual transformation of almost all the wooded areas within the farms into pastures (Bastiaensen et al., 2015; MARENA (Ministerio del Ambiente y Recursos Narturales), 2017). These changes were influenced by the processes of land distribution to war veterans under the peace agreement of 1990. Many of them, for lack of economic resources, opted to sell the land to livestock producers. Another factor was the migration from other places to buy land at a cheaper price than in other regions (Bastiaensen et al., 2015), which influenced the forest-cover loss in this territory (Bilsborrow, 2002). In other words, deforestation in this area was related to political factors such as agrarian reforms, peace agreements, livestock development policies, and the improvement of road infrastructure. Furthermore, migration has favored deforestation, although the extensive management of livestock influenced the increase in degraded pastures (Bilsborrow, 2002; Carr et al., 2006; Kaimowitz, 1996; Kaimowitz & Angelsen, 1998). Lambin et al. (2001) argued that deforestation and land use change are related to population growth, poverty, and shifting agriculture in large areas of forests and that these processes are influenced by national policies that promote rural development or the use of natural resources, which leads to the deterioration and fragmentation of forest cover.

In the territory, the process of deforestation has been generated with easily accessible forested areas (product of roads for logging), where immigrants clear and cultivate land for household consumption and eventual sale, to the extent that the soil becomes less fertile, and the producers introduce pastures and adopt livestock. Also, these immigrants have the option of selling their land to other producers who accumulate and possess large farms exploited under extensive livestock systems (Bilsborrow, 2002; Polvorosa & Bastiaensen, 2016).

Between 1998 and 2011, although deforestation was still observed in the area, regional policies that facilitated the exportation of milk and its derivatives mainly to El Salvador and Honduras may be related to the recovery of degraded pastures through improved pastures. In addition, the use of silvopastoral systems favored the improved management of production systems, which increases the profitability of livestock farms (Armenteras et al., 2017; Bastiaensen et al., 2015).

Nevertheless, the dynamics of pasture management are related to the adoption of silvopastoral systems (SPS) or their abandonment to establish systems of monoculture, even though the first one has the potential to improve productivity and to generate ecosystem services (Ibrahim et al., 2011). However, there is a favorable behavior which consists in including trees in the pastures and reducing the rate of change from degraded pastures to improved pastures or trees in the region. In spite of the existence of scientific studies and successful cases, the adoption of silvopastoral systems in farms is low. This has been attributed to the lack of capital and knowledge of technology (Acosta, Ibrahim, & Pezo, 2014; Ibrahim, Villanueva, & Casasola, 2007). However, two factors that affect the limited number of farmers that apply silvopastoral systems are their high initial economic cost and the difficulties of establishing them (training and labor), which leads to extensive livestock management (Acosta et al., 2014; Ibrahim et al., 2011).

The analysis of cover change rates through the cross-tabulation matrix showed that the LULC was dynamic, which caused the loss of forest cover for livestock expansion (Armenteras et al., 2017; Lira, Tambosi, Ewers, & Metzger, 2012). In addition, the persistence of the forest was lower than the transitions between the LULC classes in the territory immersed in a matrix of pastures. LULC transitions were constant in time and space, which was influenced by social, economic, and political changes in the territory (Armenteras et al., 2017; Bastiaensen et al., 2015; Lambin et al., 2001). We consider that such facts must be taken into account in order to improve the sustainable management of the territory.

Fragmentation

In the territory, as regards the effect of the LULC change between 1978 and 2011, it should be appreciated that forest fragments were under strong pressure by the expansion of the agricultural frontier (MARENA, 2017). There was a reduction in the size of the forest patches. We must take into account that the management of these pastures resulted in the isolation of forest patches. This is reflected in different environmental problems that have been avoided by different factors, such as the loss of biodiversity, the change in the composition of species of fauna and flora (Harvey et al., 2011; Pérez-García, Benjamin, & Tobar-López, 2018; Tobar-López & Ibrahim, 2010; Vilchez et al., 2014), the increase in GHG emission (Andrade, Brook, & Ibrahim, 2008; Andrade, Marín, & Pachón, 2014), and the loss of livestock yield (Betancourt, Ibrahim, Villanueva, & Vargas, 2005; Ibrahim et al., 2007).

Forest remnants are irregularly shaped in the territory, which is related to the process of fragmentation of the landscape; however, the conservation of these areas is important to maintain the flows and movements in the ecosystems (Bennett & Saunders, 2010). On the other hand, the irregular and heterogeneous forms of pasture cover classes are related to the management of grassland for animal feed. Therefore, for the restoration and management of the landscape, it is necessary to consider the analysis of the territory metrics, to promote the increase of the forest cover and to assure the movements and flows provided by the natural ecosystems.

Challenges for the restoration of the territory

This study can serve as a representation of the deforestation processes in the Central American territory, which is linked to the historical processes of colonization and the social and economic policies. This work showed that the main driver of deforestation was livestock. The deforestation process has been linked to the historical context of occupation and the geographical location of the regions, which influence the use and access to resources, respectively. The loss of forest cover has impacted the ecosystem services, such as those derived from conservation of biodiversity, and has caused the loss of carbon sinks. Moreover, deforestation is one of the main emitters of greenhouse gases (Magnago et al., 2015; Pearson, Brown, Murray, & Sidman, 2017), which are directly linked to climate change.

Among the actions to reduce deforestation, there is the Reduction of Emissions from Deforestation and Forest Degradation (REDD) mechanism, which promotes forest carbon saving initiatives in an attempt to reduce the rate of carbon release and, therefore, mitigate climate change. Since then REDD has been revised as REDD+ considering biodiversity conservation, through the protection of carbon stocks (Grainger et al., 2009).

One of the problems faced in Latin America, and especially in Central America, is the process of deforestation (Armenteras et al., 2017; Kaimowitz, 1996), as evidenced in this study. The fragmentation of the landscapes, generated by the expansion of agricultural frontiers, produces a reduction of forest areas, which implies losses in carbon sinks and conservation of biodiversity. Magnago et al. (2015) suggest that, in fragmented landscapes, it is important to protect forest remnants to maintain the biodiversity value to ensure the provision of ecosystem services, especially carbon storage. To achieve the conservation of these areas, it is crucial to improve the management of livestock activity by promoting the increase in tree cover under the REDD+ framework. This goal can be achieved through the adoption of silvopastoral systems, which enables the improvement of the management of pastures and the protection of forest fragments. This, in turn, brings environmental benefits such as the restoration of soil nutrients, carbon storage, the conservation of biodiversity, the mitigation of greenhouse gases from enteric fermentation of cattle, and the improvement of the livelihoods of livestock producers (Ibrahim et al., 2011). These benefits can generate employment opportunities in local communities under the REDD+ framework and enable the development of sustainable low-emission livestock.

It is necessary to eliminate the barriers that the producers tend to face, such as the lack of investment capital, which can be solved through economic incentives such as green credits and payment for environmental services. These measures have shown to have a positive impact on the conservation of forest remnants and the adoption of silvopastoral systems in the region (Pagiola, Honey-Rosés, & Freire-González, 2016).

Conclusions

This study showed that the loss of forest cover between 1978 and 2011 was mainly attributed to the conversion of forest into pasture. Such a process was focused on the development of livestock, which is the main agricultural activity in the studied area. The increase in pasture cover is related to extensive livestock management, which causes a loss of forest cover. This shows that the management of pastures for livestock is responsible for the dynamics of change in land use, which are influenced by economic, political, and social factors.

The territory has undergone a process of fragmentation, where the forest relics that are currently maintained are immersed in a matrix of pastures, which have been generated by the change in land use. These changes in the territory over a period of 33 years have allowed us to understand the development in the structure of the landscape and how they have been influenced by different factors (of environmental, political, and socioeconomic nature), which provides inputs to improve the management of the landscape.

In Central America, policies such as the REDD+ strategy are aimed at reducing deforestation generated by the expansion of the agricultural frontier. Deforestation can be mitigated by increasing tree cover in agricultural production systems, through the adoption of silvopastoral practices. Such practices can contribute to the increase of livestock production and the provision of ecosystem services such as those derived from biodiversity conservation and carbon storage. However, this should be complemented by economic incentives to improve the management and conservation of forest areas in landscapes dominated by agricultural activities.

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