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MODELLING APPROACH FOR PREDICTING LANDSCAPE CHANGES IN EXPANDING EUCALYPTUS PLANTATIONS IN BRAZIL

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Abstract

This paper combines remote sensing, environmental modeling, and landscape ecology to investigate the impacts of the expansion of eucalyptus reforestation. Using these techniques, a methodology was developed to analyze and predict future land cover and landscape structure trends. The study area was comprised of the river basin municipalities in Rio Piracicaba and the metropolitan region of Vale do Aço (RMVA), a region that is home to large steel, paper, and cellulose industries in Minas Gerais. This major hub of economic development in the state has altered the landscape through deforesting native vegetation and planting eucalyptus trees. Land cover data were taken from satellite image classifications (TM/Landsat) from 1985, 2010 and 2013 in order to study the land cover changes. A number of variables that stimulate or restrict these alterations and the eucalyptus expansion observed between 1985 and 2010 were used to simulate the eucalyptus expansion, through Multi-Layer Perception Neural Networking. The results showed that the areas of Eucalyptus reforestation increased by about 12% between 1985 and 2010, whereas forest areas contracted by approximately 9%, and pasture by 3%. The simulated eucalyptus expansion indicated that by 2035 the structure of the landscape will have changed, with an increased level of isolation of the forest patches and a decrease in their nuclear area.

Keywords: Land Change Modeler, Analysis of change, Simulation, Landscape ecology.

Resumo / Resumen

MODELAGEM DA EXPANSÃO DO REFLORESTAMENTO COM EUCALIPTO E EFEITOS NA ESTRUTURA DA PAISAGEM

Neste artigo trabalhamos uma metodologia combinada de sensoriamento remoto, modelagem ambiental e ecologia da paisagem para análise dos impactos da expansão do reflorestamento com eucalipto na estrutura da paisagem. O uso combinado dessas técnicas possibilitou a simulação de cenários futuros, utilizando-os não apenas como uma ferramenta de análise, mas, sobretudo, para auxiliar no planejamento. O trabalho teve como área de estudo os municípios da Bacia do Rio Piracicaba e da Região Metropolitana do Vale do Aço, região que abriga importantes indústrias do setor siderúrgico, de papel e celulose em Minas Gerais. Foram utilizados dados da cobertura da terra obtidos a partir de classificações de imagens de satélite (TM/landsat) para os anos de 1985, 2010 e 2013. Em conjunto à cobertura da terra foram exploradas diversas fontes de variáveis estimuladoras e restritivas à mudança para criação de um modelo de cobertura da terra capaz de simular a expansão das áreas de eucalipto considerando um cenário de manutenção da tendência de crescimento observada entre 1985 e 2010. Os resultados do mapeamento mostraram que entre 1985 e 2010 houve aumento de cerca de 12% nas áreas de reflorestamento com Eucalipto, ao passo que as áreas de floresta diminuíram aproximadamente 9% e as de pastagem 3%.

Palavras-chave: Detecção de mudança, Simulação, Ecologia da Paisagem.

MODELADO DE EXPANSIÓN DE REFORESTACIÓN DE EUCALIPTO Y EFECTOS SOBRE LA ESTRUCTURA DEL PAISAJE

En este artículo trabajamos una metodología combinada de teledetección, modelado ambiental y ecología del paisaje para analizar los impactos de la expansión de la reforestación con eucalipto en la estructura del paisaje. El uso combinado de estas técnicas posibilitó la simulación de escenarios futuros, utilizándolos no sólo como una herramienta de análisis, sino, sobre todo, para auxiliar en la planificación. El trabajo tuvo como área de estudio los municipios de la Cuenca del Río Piracicaba y de la Región Metropolitana del Valle del Acero, región que alberga importantes industrias del sector siderúrgico, de papel y celulosa en Minas Gerais. Se utilizaron datos de la cobertura de la tierra obtenidos a partir de clasificaciones de imágenes satelitales (TM / landsat) para los años 1985, 2010 y 2013. En conjunto con la cobertura de la tierra se exploraron diversas fuentes de variables estimuladoras y restrictivas al cambio a la creación de un modelo de cobertura de la tierra capaz de simular la expansión de las áreas de eucalipto considerando un escenario de mantenimiento de la tendencia de crecimiento observada entre 1985 y 2010. Los resultados del mapeamiento mostraron que entre 1985 y 2010 hubo aumento de cerca del 12% en las áreas de reforestación con Eucalipto, mientras que las áreas de bosque disminuyeron aproximadamente 9% y las de pastoreo 3%.

Palabras-clave: Palabras-Clave: Land Change Modeler, Detección de cambios, Simulación, Ecología del paisaje.

INTRODUCTION

From the 1940s onwards, the development of a steel, mining, paper, and cellulose industrial hub in the Vale do Aço (RMVA) and the Quadrilátero Ferrífero in Minas Gerais, Brazil, has created a high demand for charcoal and cellulose. This demand resulted in the deforestation of the Atlantic Forest biome and an increase in the areas of eucalyptus reforestation, the source of the raw material needed for these products.

The Atlantic Forest biome originally covered the eastern coastline along the southeast and south of Brazil, a total area of 1.3 million km², equivalent to 15% of the Brazilian territory. However, nowadays, only 12.4% of this forest habitat remains intact (Fundação SOS Mata Atlântica and INPE, 2017).

The clearing of vegetation in the Atlantic Forest started with the colonization of Brazil and expanded rapidly with every new economic cycle in the region. More recently, since 1985 deforestation rates have been steadily decreasing (Fundação SOS Mata Atlântica and INPE, 2017). According to the 2015-2016 Atlas of the Atlantic Forest Remains, Minas Gerais had an annual deforestation rate of 7,000 hectares, representing 24% of the total deforested area in the 17 states covered by this biome, which had an overall annual deforestation rate of 29,075 hectares (Fundação SOS Mata Atlântica and INPE, 2017).

Between 2002 and 2014, Brazil experienced an expansion in eucalyptus reforestation simultaneously with the increase in cellulose production, which rose from 8.0 to 16.4 million tons per year. In the same period, paper production increased from 7.8 to 10.3 million tons per year and charcoal production remained stable, between 17.6 and 17.8 million tons per year, according to data from the Brazilian Association of Forest Plantations (ABRAF, 2015).

Annual statistical data from this association show that the state of Minas Gerais has the largest area of planted eucalyptus trees in the country, 1,438,971 hectares, corresponding to 28.20% of the total planted area in Brazil (ABRAF, 2012). The growth of eucalyptus reforestation in the state has impacted on the river basin municipalities of Rio Piracicaba and Vale do Aço – RMVA, where large areas of planting occur. A comparative analysis of the region's terrain between 1985 and 2010 indicates an expansion in the area of eucalyptus and the deforestation of native vegetation, both of which have altered the landscape (LUIZ *et al*., 2016).

In order to better understand the changes to the vegetation cover and how it has fragmented the landscape's structure over time in the river basin municipalities of Rio Piracicaba and RMVA, this study uses an approach that integrates products and techniques from remote sensing, geoprocessing, landscape change models and landscape structure analysis to analyze the changes caused by the expansion of eucalyptus reforestation. The combined use of these techniques detects changes to the landscape, enabling simulations and plans to be made for its future. Structural analyses of real and simulated landscapes contribute toward monitoring ecological processes such as the increase in the isolation of patches of vegetation and the fragmentation of the topography.

Modeling and simulating changes to the vegetation cover are done by constructing models like Land Use and Cover Change (LUCC), which evaluate the effects of changes to the landscape's structure. This research uses the Land Change Modeler - LCM (CLARCKS LABS, 2009), a computer tool that creates Multi-Layer Perceptron Neural Network (MLPNN) models that estimate the probability of change by analyzing transitions in classes of land cover over a determined period of time. It takes into account the interaction of the changes with two groups of spatial determinants represented by variables that stimulate or restrict this dynamic. The result of this interaction is a Probability Surface of Change generated from the weight attributed to the explanatory variables in the spatial allocation of land cover changes.

This study employs a methodology that analyzes, measures and models the process through which native vegetation is substituted by eucalyptus trees. The study area is composed of the river basin municipalities of Rio Piracicaba and RMVA. This approach uses TM/Landsat images from 1985, 2010 and 2013 to map the land cover. Data from this mapping are used to assess land cover changes in LCM, which builds a model of the changes and uses it to project the expansion of eucalyptus reforestation areas. These forecasts are based on the continued demand for eucalyptus trees by the steel, paper and cellulose industries, and on the assumption that the growth in demand will persist at the same rate identified in the analysis period (1985-2010). The simulation of the land cover for the year 2035 is based on these suppositions. Landscape metrics are used to make a comparative evaluation of the mapped and simulated landscape structure to show potential changes to the landscape's structure and its impacts on conservation over time.

THE STUDY AREA

The study area selected for this research is in the river basin municipalities of Rio Piracicaba and Vale do Aço (RMVA), both shown on the map in Figure 1. This area partially coincides with the Quadrilátero Ferrífero region.

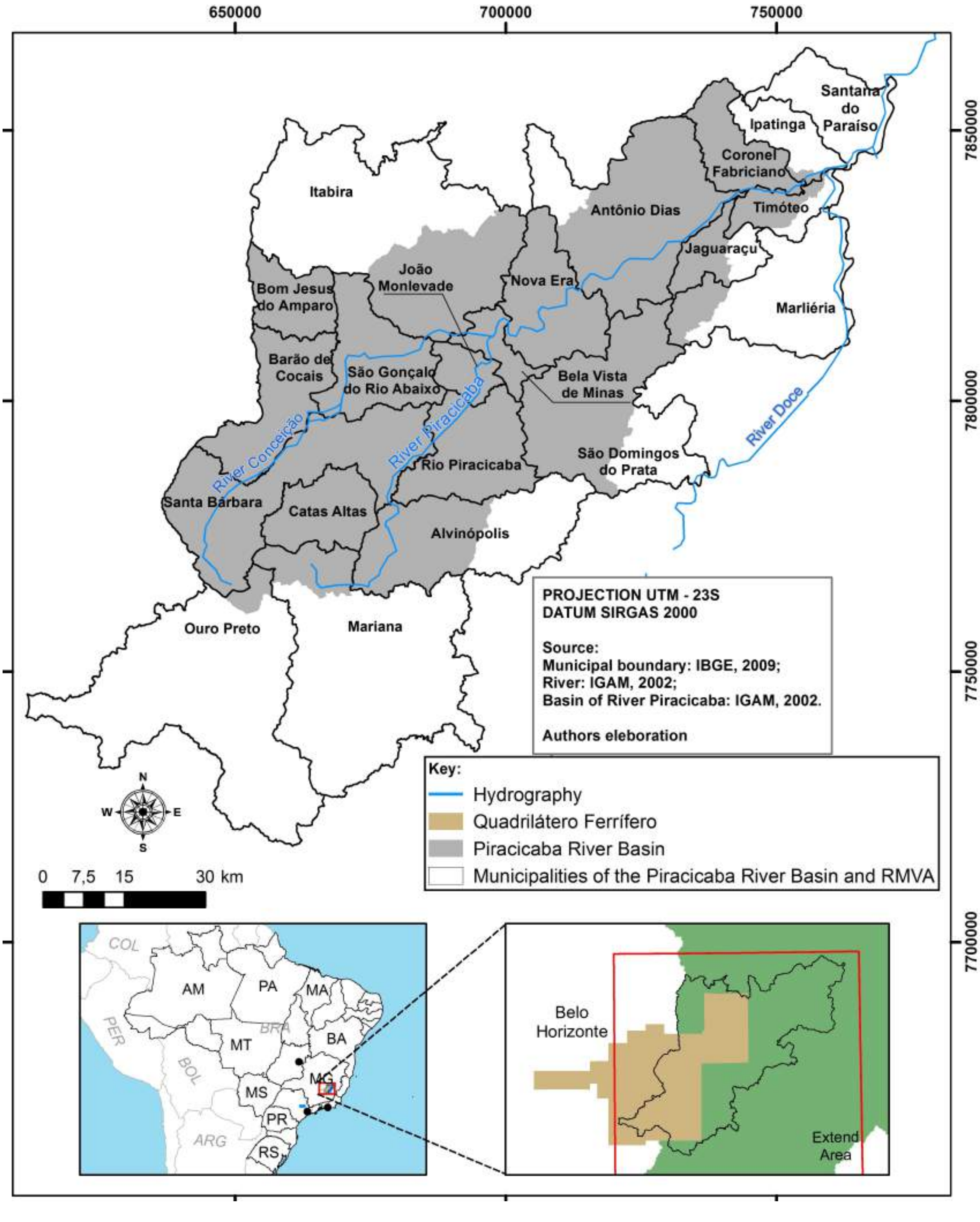

Figure 1 – Map of the study area.

The territorial occupation of this area occurred during the Gold Cycle in the seventeenth-century colonial period, with the beginning of mining and agricultural activities, especially in the vast pastures used for cattle farming. However, changes to the land cover intensified at the beginning of the twentieth century with the construction of highways and the advent of the steel, mining, paper, and cellulose industries. With the arrival of these industries, the grasslands became eucalyptus plantations and the native vegetation was cleared and used to fuel the steel industry's furnaces. Another consequence was population growth and the unplanned expansion of the urban areas. According to census data from the Brazilian Institute of Geography and Statistics (IBGE, 2010), the study area's population rocketed from 613,662 to 926,861 inhabitants between 1980 and 2010; an increase of 33.79% over 30 years.

The current landscape is mainly covered by pasture, eucalyptus reforestation, and forest, as shown in the photos in Figure 2 taken during fieldwork in 2013.

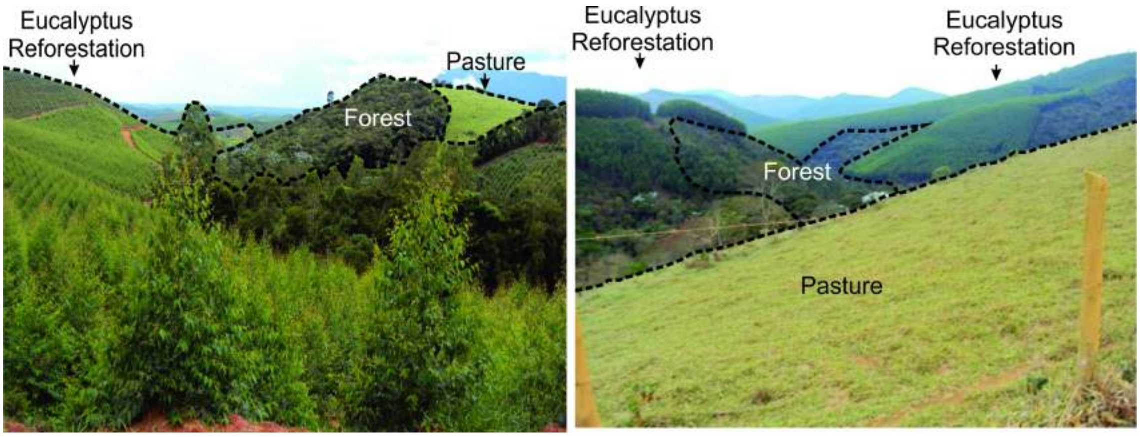

Figure 2 – The most representative land cover in the study area.

METHODOLOGY

The methodology adopted in this work is based on remote sensing techniques, digital image processing, land cover modeling, and landscape metrics.

Land cover mapping

Table 1 presents the Landsat images used to map the land cover on the three dates.

Satellite/Sensor	Orbit/Point	Date
LANDSAT 5/TM	217/73 and 217/74	04/07/1985
LANDSAT 5/TM	218/73 and 218/74	25/06/1985
LANDSAT 5/TM	217/73 and 217/74	26/08/2010
LANDSAT 5/TM	218/71 and 218/74	01/08/2010
LANDSAT 8/TIRS	217/73 and 217/74	02/08/2013
LANDSAT 8/TIRS	217/73 and 217/74	25/08/2013

Table 1 – Images used in the land cover mapping.

These images were georeferenced with 2010 images from the RapidEye satellite and normalized using the dark object method as described by Chavez (1988).

The following classes of land cover were defined for the mapping: Water, Pasture, Exposed Soil, Urban Area, Semi-deciduous Seasonal Mountain Forest (FESM), Eucalyptus Reforestation, Natural Field Vegetation, Rock Formations, and Mining. Once these classes were defined the images were segmented using the regional growth technique (RICHARDS, 1993), then the Bhattacharya distance classifier (GONZALES and WOODS, 1992) was applied. The preliminary maps were assessed with data collected in the field: 114 areas were visited in October 2013 and January 2014 and interviews were conducted with residents from the region about the history of the land cover. Uncertainties regarding some classifications were identified in the satellite images and verified in the field. The evaluation of the image classification was carried out using the Confusion Matrix and the Kappa index (ROSENFIELD and FITZPATRICK-LINS, 1986). According to Congalton (1991) and Congalton and Green (1999), these procedures determine the differences between the classification results and the reality in the field. The land cover mapping was adjusted based on this data.

Land cover mapping was obtained for the three dates: 1985 (*t*1); 2010 (*t*2) and 2013 (*t*3). Mappings *t*1 and *t*2 were used to identify changes in land cover and to calibrate the model. Mapping *t*3 was used to validate the model for predicting land cover change, described in the next section.

Modeling and simulating the land cover change

This stage began with a comparison of the areas of land cover classes *t*1 and *t*2, and then the calculation and mapping of the changes between the classes so as to understand the land cover changes. This was important to define the transitions associated with the study: the expansion of eucalyptus reforestation. Some types of transitions are omitted from the model, leaving only those required: Forest to Pasture and Eucalyptus Reforestation; Pasture to Forest and Eucalyptus Reforestation; and Natural Field Vegetation to Eucalyptus Reforestation and Pasture.

The pertinent transitions and the descriptive variables of land cover change presented in Table 2 were used to calibrate the model for training a neural network (Multi-Layer Perceptron Neural Network – MLPNN – HAYKIN, 2001) that identifies the patterns of change. The Cramer-V spatial association test was employed to select the variables: (LIEBERTRAU, 1983). This is a non-parametric statistical test, which measures a variable’s importance in explaining a particular land cover change (EASTMAN, 2009).

Many different sets of variables were evaluated and the set which proved to be the most relevant to the transitions was selected.

After calibration, the potential transitions between land cover were obtained and the Markov chain (BAKER, 1989) was used to allocate the spatial change for *t3*.

The land cover simulation was based on the following assumptions: i. Growth in demand for eucalyptus reforestation according to the rates for the time period studied (1985 – 2010); ii. A greater chance of land cover changes in the areas adjacent to those that had changed during the period studied (1985 – 2010); iii. The conservation areas will be respected and have an almost zero possibility of change; iv. The areas of land cover mapped represent the reality in the field, according to the proposed validation methodology (Kappa index and Confusion Matrix).

Variables	Description	Unit /type	Source
Altitude	MDE ASTER, categorized in 100m intervals	m	ASTER GDEM (2014)
Gneiss-Granite Foundation	Taken from geological mapping in MG	Categorical data	CODEMIG (2014)
Declivity	Generated using MDE ASTER in intervals established in IBGE publication (2009).	%	ASTER GDEM (2014)
Latosol	Taken from soil mapping in MG	Categorical data	FEAM (2010)
Average Annual Rainfall	Taken from weather patterns	mm	INMET
Distance from Roads	Variable obtained from map of road distances	m	IBGE (2013)
Distance from Waterways	Variable obtained from map of river network distances	m	IBGE (2013)
Distance from Protection Conservation Unit	Variable obtained from map of distances of conservation units	m	IEF (2011)
Distance from Sustainable Use Conservation Unit			
Distance from Urban Areas	Variable obtained from map of distances taken from the mapped land cover class	m	-
Distance from Eucalyptus Areas			
Distance from Pasture Areas			
Area of Change	Variable obtained by comparing mapped land cover (1985 x 2010)	m	–
Municipal Production of Wood for Cellulose	1990 – 2010 distributed per river municipality of Piracicaba river	m^3	IBGE (2011)
Municipal Production of Charcoal	1990 – 2010 distributed per river municipality of Piracicaba river	ton	IBGE (2011)
Municipal Population 2010	Number of habitants per river municipality of the Piracicaba river	Number of inhabitants	IBGE (2010)
GDP % in Municipal Industry	Average for 1999 – 2010 distributed per river municipality of the Piracicaba river	%	IBGE (2011)
GDP % in Municipal Agriculture	Average for 1999 – 2010 distributed per river municipality of the Piracicaba river	%	IBGE (2011)
People employed in Municipal Industry	Number of people accounted for in 2010 distributed per river municipality of Piracicaba river	Number of people	IBGE (2010)

Table 2 – The descriptive variables assessed to create and calibrate the potential transition model.

The validation of the land cover models was performed by cross tabulating the simulated mapping and satellite image mapping and field data for *t*3. This matrix is composed of hit and miss indexes associated with the model's predictions, which correspond to the situations below (PEARSON, 2007): i. The model predicts the presence and is confirmed by the test data (hit); ii. The model predicts the presence, but the test data shows none (false-positive); iii. The model predicts an absence, but the test data shows a presence (false-negative); iv. The model predicts an absence and is confirmed by the test data (hit).

In this paper, the validation was performed using a spatial resolution grid of 0.25 x 0.25 km. One set of mapped and simulated pixels was evaluated for each cell on the grid. The hits and misses were calculated, indicating the locations where the model either overestimated or underestimated the land cover changes. These differences were then measured by standard deviation norms and the averages of the areas that did not coincide with the two mappings. This evaluation was carried out for the most representative classes which are the focus of this study: Eucalyptus Reforestation, Forests, and Pastures.

The analysis of landscape structure

A comparative analysis of the landscape structure was performed for the principal classes of land cover (FESM, Natural Field Vegetation, and Eucalyptus Reforestation) in three time periods: 1985 (*t*1); 2010 (*t*2) and 2035 (*t*4). This analysis assessed the extent of the changes to the landscape structure using the following metrics: area, number of patches, number of nuclear areas and the level of isolation of the patches (FORMAN and GODRON, 1986; McGARICAL and MARKS, 1995; RIBEIRO, 2010). These metrics enabled the level of fragmentation of the landscape to be assessed, providing data that can be used to discuss the implications of land cover changes in relation to conservation and providing information about the area of natural cover that is home to native species, as well as its spatial arrangement and the amount of subdivision and isolation of this vegetation (Lang and Blaschke, 2009). These metrics were applied in research analyzing the fragmentation of the landscape in the Atlantic Forest biome, such as Ribeiro (2010), Maciel (2011), Juvanhol *et al*. (2011), and Silva and Sousa (2014).

The metric area is used to calculate the representativity of patches in different landscape covers, whereas the metric number of patches measures the level of subdivision of a particular landscape cover. Even though it is not a spatial measurement of the area, the stratification of the number of patches by size is useful to explain the landscape fragmentation processes. The metric number of nuclear areas assesses the stability of these patches. The assumption is that the areas on the outside edge of the patches suffer more external influences. Therefore, in the inner part, the predominant ecological conditions preserve an environment closest to the original habitat and favor the conservation of the forest fragment. Due to this, the outer 100m strip of the original area of the patch is not included in the calculation (MCGARIGAL et al., 2005). The area that remains after excluding this band is the nuclear area. The metric isolation of patches assesses the level of isolation by calculating the Euclidian distance from its closest neighbor, which is measured in meters from the focal patch to the closest neighboring patch with the same vegetation cover (McGARICAL and MARKS, 1995).

RESULTS

The following section presents the results of the land cover mapping for 1985, 2010 and 2013, the modeling of land cover changes, which resulted in a projected simulation for 2035, in a scenario of growing demand for eucalyptus, and the landscape features for 1985, 2010 and 2035, using landscape metrics (area, number of patches, number of nuclear areas and the isolation of the patches). This allowed the evaluation and discussion of the potential effect of alterations on the future landscape structure and its possible impacts on the conservation of the remaining vegetation.

Land cover

Table 3 shows the areas (in hectares) of the nine land cover classes defined and mapped by remote sensing imaging for 1985, 2010 and 2013.

Land Cover Class	Area					
	1985		2010		2013	
	ha	%	ha	%	ha	%
Water	6,636.33	0.65	7.280,84	0,71	7.189,35	0,71
Outcrops of rock	23,925.38	2.37	22.849,16	2,26	22.849,16	2,26
Exposed Soil	14,761.29	1.45	7.401,60	0,73	7.707,26	0,76
Natural Field Vegetation	60,246.78	5.96	53.972,99	5,34	53.867,30	5,33
Eucalyptus Reforestation	157,260.00	15.55	274.999,04	27,19	277.884,99	27,47
Semi-deciduous Seasonal Mountain Forest (FESM)	397,674.03	39.32	305.126,80	30,17	303.884,24	30,04
Pasture	333,813.31	33.00	297.902,72	29,45	295.313,91	29,20
Mining	5,216.26	0.52	14.768,52	1,46	15.405,99	1,52
Urban Area	11,957.32	1.18	27.189,03	2,69	27.388,50	2,71
Total	**1,011,490.70**	**100.00**	**1.011.490,70**	**100,00**	**1.011.490,70**	**100,00**

Table 3 – Area of land cover classes for 1985, 2010 and 2013

The cover classes in Table 3 that most closely represent the study area are Semi-deciduous Seasonal Mountain Forest (FESM), Pasture and Eucalyptus Reforestation. However, there is a variation among these classes over time. Figure 3 shows that in general, between 1985 and 2010 there was a significant increase in Eucalyptus Reforestation areas (+11.6 %) and a reduction in Pasture (–3.55 %)

and FESM (–9.15 %) areas, which suggests that the reforested areas expanded into the forests and pastures.

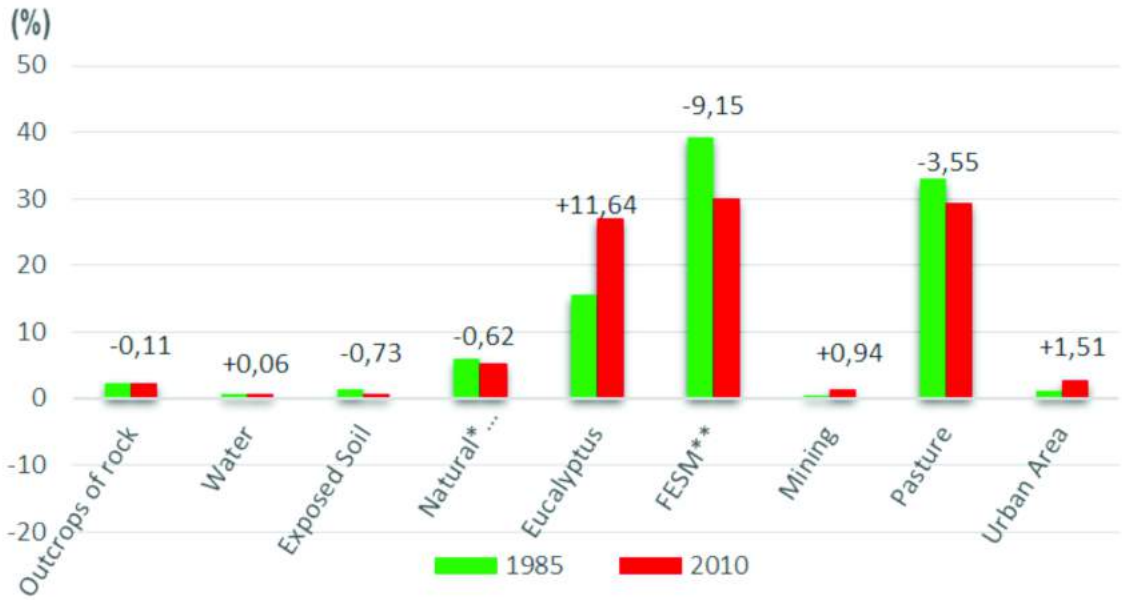

Figure 3 – Percentage of land cover variation between 1985 and 2010.

Modeling and simulating changes to land cover

Table 4 presents the Cramer-V test result described in Section 3 for evaluating the relation of the variables (Table 2) with regards to land cover changes and the selection of the explanatory variables of the potential transition model. According to Eastman (2009), a Cramer value greater or equal to 0.10 is recommended for the addition of an explanatory variable to the potential transition model, as it is more closely correlated to a change in land cover.

Explanatory Variable	Cramer – V	Selection Status
Altitude	0.1523	Selected
Gneiss-Granite Foundation	0.1482	Not Selected
Declivity	0.0281	Not Selected
Latosol	0.1683	Selected
Average Annual Rainfall	0.1324	Not Selected
Distance from Roads	0.0928	Not Selected
Distance from Waterways	0.0760	Not Selected
Distance from Protection Conservation Unit	0.1033	Not Selected
Distance from Sustainable Use Conservation Unit	0.0829	Not Selected
Distance from Eucalyptus Areas	0.3815	Selected
Distance from Urban Areas	0.5113	Selected
Distance from Pasture Areas	0.5560	Selected
Areas of Change	0.3513	Selected
Municipal Production of Wood for Cellulose	0.1354	Selected
Municipal Production of Charcoal	0.1561	Selected
Municipal Population 2010	0.1506	Selected
GDP % in Municipal Industry	0.1360	Not Selected
GDP % in Municipal Agriculture	0.1278	Not Selected
People employed in Municipal Industry	0.1499	Selected

Table 4 - Cramer V, values and explanatory variables included in the potential transition model

The land coverage in 1985 and 2010, together with the explanatory variables selected, were used for MLPNN training and to identify patterns of change. After 5,000 iterations the best MLPNN setting obtained was 94.28%, taking into consideration the set of selected variables.

Creating the potential transition model involved mapping transitions between cover classes. Figure 4 presents a graph with the potential transition for the most representative classes (Eucalyptus Reforesting, Pasture, and FESM).

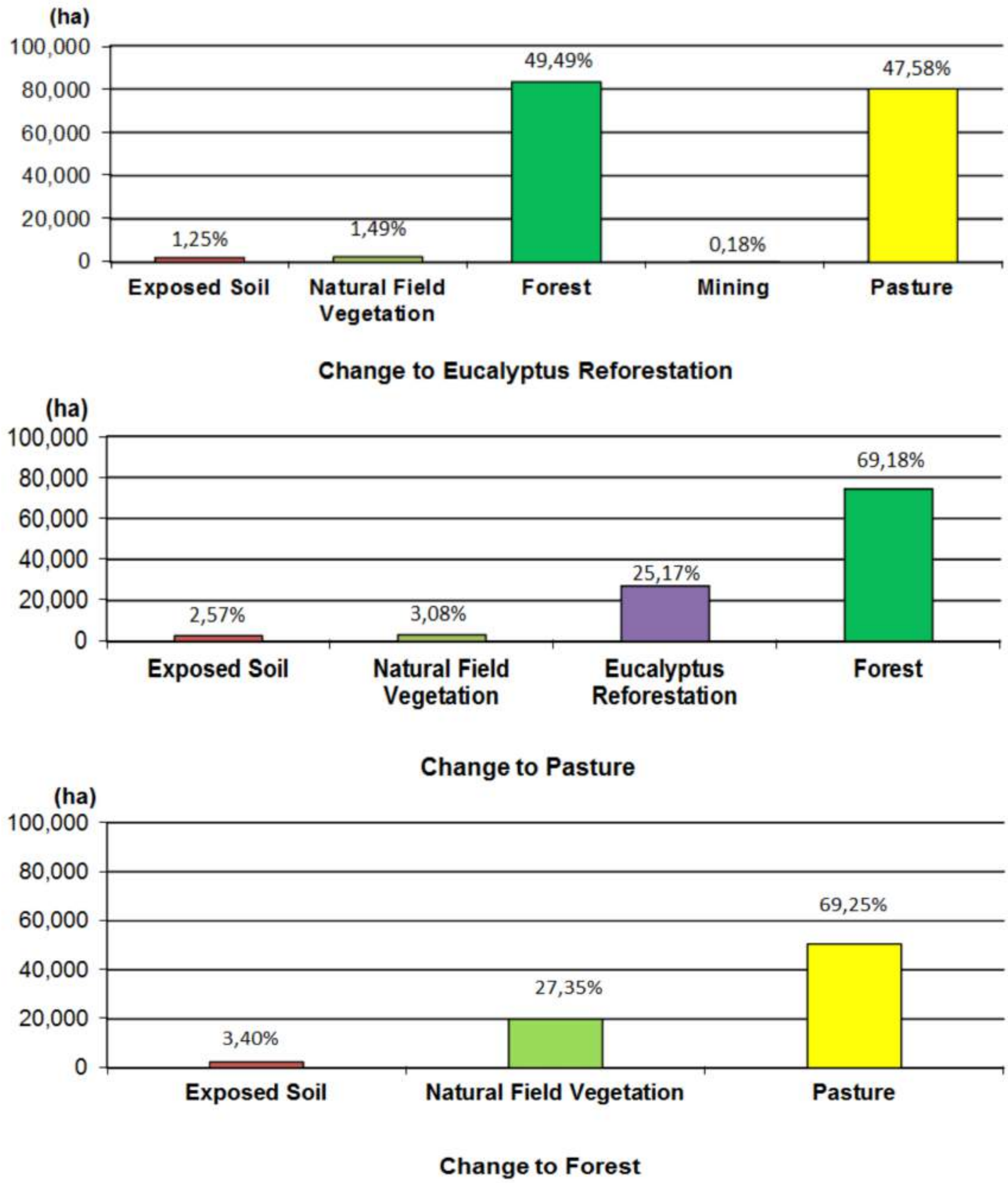

Figure 4 – Potential change from land cover classes to Eucalyptus Reforestation, Pasture and FESM classes.

The potential transition model in Figure 4 shows the cover classes which contribute the most to the growth in areas of Eucalyptus Reforestation: FESM (49.49%) and Pasture (47.58%). The changes to Pasture originate mostly from FESM areas (69.18%) and Eucalyptus Reforestation areas (25.17%), while changes to FESM mostly occur from the regeneration of Pasture (69.25%) and Eucalyptus Reforestation (27.35%) areas.

Validation of the model

Based on the methodology described in section 3, the model was validated through a cross tabulation between the simulated map for 2013 and the map obtained from image classification in the same year. The results are presented in Figure 5. The false-positive and false-negative areas are highlighted on the grid with a spatial resolution of 0.25 km. Each map in Figure 5 represents one of the classes of interest, the areas of concurrence and the false-positive and false-negative areas.

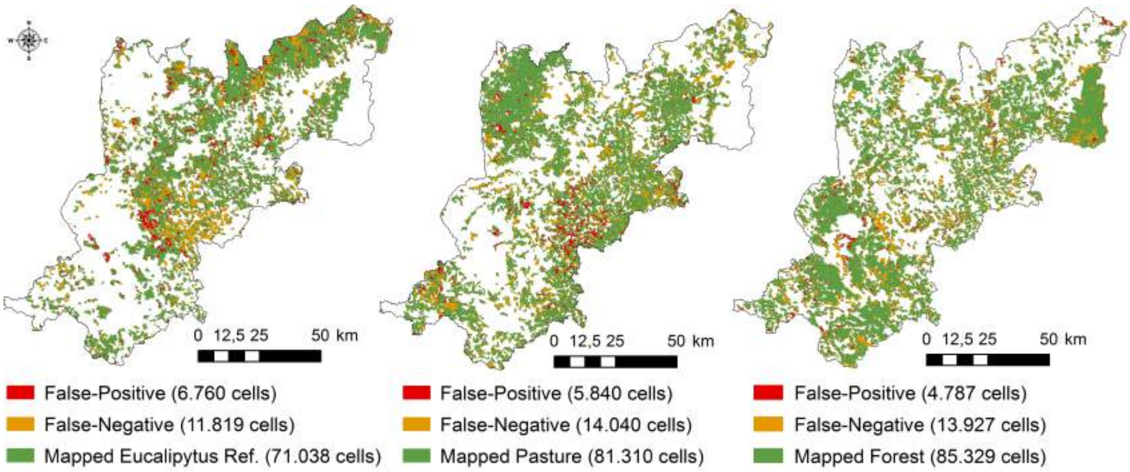

Figure 5 – Maps of false-positive and false-negative areas for simulated land cover classes with a spatial resolution of 0.25 km: (a) Eucalyptus Reforestation; (b) Pasture; (c) FESM.

As shown above, for Eucalyptus Reforestation, out of a total of 71,038 cells (0,25 x 0,25 km, 6,780 (9.51%) are false-positive and 11,819 (16.63%) false-negative. The Pasture category has a total of 81,310 cells (0.25 x 0.25 km), 5,840 (~7%) are false-positive and 14,040 (17%) are false-negative. The FESM group has a total of 85,329 cells (0.25 x 0.25 km), 4,787 (6%) are false-positive inclusion mistakes and 13,927 (16%) are false-negative. As the analysis encompasses neighboring pixels, a 0.25 x 0.25 km cell may have different hit percentages for mapped and simulated land covers. Therefore, it is possible to classify each cell in different concurrence intervals, as shown in Table 5.

Concurrence between Mapped and Simulated Cover (%)	FESM		Pasture		Eucalyptus Reforestation	
	Number of Cells	(%)	Number of Cells	(%)	Number of Cells	(%)
0	381	0.45	474	0.58	736	1.04
0 – 25	1	0.00	0	0.00	4	0.01
25 – 50	8,131	9.53	10,789	13.27	12,597	17.73
50 – 75	1,704	2.00	1,634	2.01	1,438	2.02
75 – 85	7,877	9.23	6,508	8.00	3,578	5.04
85 – 95	620	0.73	475	0.58	226	0.32
95 – 100	66,615	78.07	61,430	75.55	52,459	73.85
Total	**85,329**	**100.00**	**81,310**	**100.00**	**71,038**	**100.00**

Table 5 – The concurrence intervals between mapped (2013) and simulated land cover (2013) for FESM, Pasture and Eucalyptus Reforestation classes on a grid with a spatial resolution of 0.25 km.

Table 6 evidences that more than 95% of the cells present a concurrence between mapped and simulated land cover, greater than 70%. These results were considered satisfactory and the land cover simulation for 2035 was performed based on the transitions between 1985 and 2010. The main change was the expanding areas of eucalyptus reforestation. This simulation also considered that the rising demand for eucalyptus would remain until 2035, even though the annual cellulose production data (Figure 6) shows a retraction in the sector over the last two years due to the economic crisis in the country. Nevertheless, as with other crises, the general trend is for demand to increase once the political, economic and financial scenarios start showing signs of recovery.

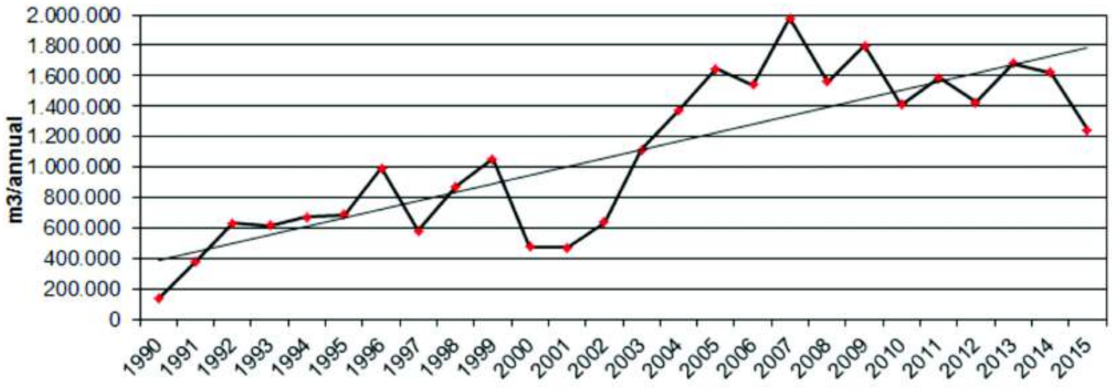

Figure 6 – The annual eucalyptus production for cellulose. Agriculture Research – IBGE (2017).

Based on these premises, Table 6 presents the potential transition simulation matrix between land cover classes for 2010 and 2035.

	Aflo	Camp	SExp	Reflo	FESM	Water	Min	Pas	Urb
Aflo	**0,955**	0,0000	0,023	0,0000	0,0000	0,0000	0,022	0,0000	0,0000
Camp	0,000	**0,888**	0,005	0,034	0,0000	0,000	0,020	0,044	0,009
SExp	0.000	0.0000	**0.090**	0.170	0.168	0.007	0.154	0.190	0.221
Reflo	0,0000	0,0000	0,003	**0,677**	0,13	0,001	0,008	0,172	0,009
FESM	0,0000	0,0000	0,004	0,209	**0,580**	0,004	0,007	0,190	0,006
Water	0,0000	0,0000	0,0000	0,0000	0,007	**0,971**	0,022	0,0000	0,0000
Min	0,0000	0,0000	0,010	0,06	0,016	0,011	**0,868**	0,021	0,014
Pas	0,0000	0,0000	0,01	0,240	0,149	0,002	0,005	**0,569**	0,025
Urb	0,0000	0,0000	0,012	0,020	0,040	0,007	0,006	0,045	**0,870**

Table 6 – Potential transition matrix for land cover classes between 2010 and 2035.

As Table 6 illustrates, the forecast for 2035 is that the cover classes least likely to suffer alterations will be: Outcrops of rock (95.6%), Natural Field Vegetation (88.9%), Mining (86.8%), and Urban Areas (87.0%). The most significant transitions will still be the three land cover classes that have continuous exchanges with each other: Semi-deciduous Seasonal Mountain Forest, Pasture and Eucalyptus Reforestation.

Figure 7 presents a graph comparing mapped land cover classes from 2010 and the simulations for 2035.

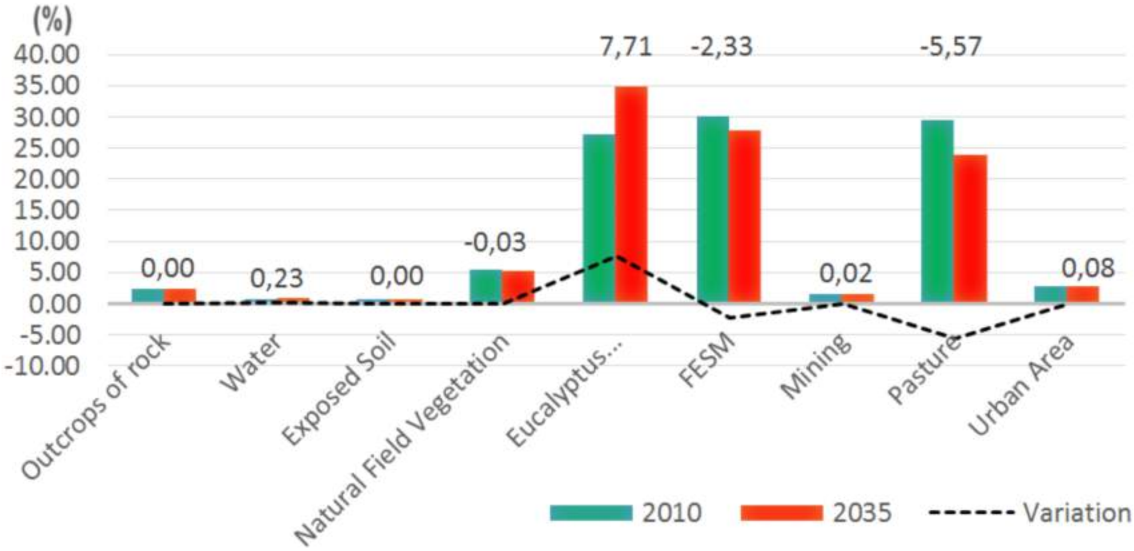

Figure 7 – Land cover classes for 2010 and 2035.

Landscape structure analysis

The landscape structure analysis was carried out for mapped (1985 and 2010) and simulated (2035) land cover. The categories were grouped together and reclassified as shown in Table 7. This reclassification grouped Outcrops of Rock and Natural Field Vegetation into Ecological Mountain Refuge and Urban Area, Exposed Soil and Mining into Anthropized Area. This was done because all these classes play a similar role in the composition of the landscape.

Land Cover Class	Reclassification
Outcrop of rock and Natural Field Vegetation	Mountain Ecological Refuge
Semi-deciduous Seasonal Mountain Forest	Forest
Eucalyptus Reforestation	Reforestation
Pasture	Pasture
Water	Water Body
Urban Area, Bare Soil and Mining	Anthropized Area

Table 7 – Reclassification of the grouping of land cover classes.

The new land cover classes in Table 8 used area metrics for 1985, 2010 and 2035. The result is presented in Figure 8.

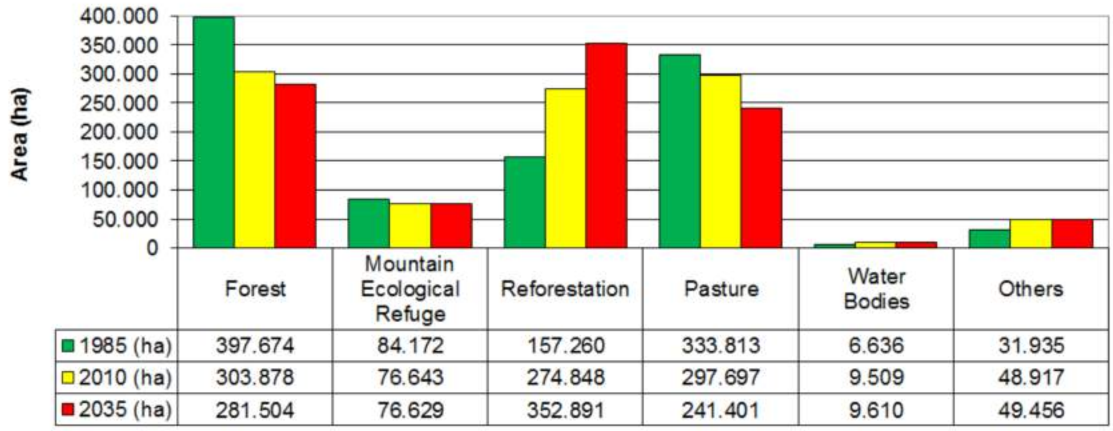

Figure 8 – Area for land cover classes in 1985, 2010 and 2035.

Figure 8 shows the evolution of the landscape changes in 1985, 2010 and 2035. In 1985 and 2010, Forest was the most representative class. According to the premises of the land cover change model (Section 3), Reforestation will predominate in 2035, meaning a significant decrease in pasture and, to a lesser extent, forest cover areas. The Water Bodies and Mountain Ecological Refuge classes vary less. There are not expected to be major variations in water bodies as there were no significant changes between 1985 and 2010. The Mountain Ecological Refuge category will vary little as it is located in hard-to-reach areas, that is, at higher elevations interspersed with rocky outcrops.

From these results, the classes which best represent and prioritize conservation in the study area (Forest, Reforestation and Mountain Ecological Refuge) were evaluated both by the number of patches, number of nuclear areas and the level of isolation of the patches.

Table 8 presents the number of patches according to size (area).

Area (ha)	Forest			Mountain Ecological Refuge			Reforestation		
	1985	2010	2035	1985	2010	2035	1985	2010	2035
< 50	708	723	2,764	168	216	292	481	478	6,439
50 – 100	257	316	289	69	71	55	222	282	273
100 – 200	150	204	182	37	36	24	128	147	181
200 – 500	92	127	95	35	34	20	77	91	80
500 – 1,000	46	33	35	14	11	6	22	28	27
1,000 – 10,000	38	34	28	15	15	12	26	21	21
10,000 – 20,000	1	2	3	1	1	1	0	1	1
> 20,000	4	3	2	0	0	0	0	1	2

Table 8 – The number of patches by land cover class and size (area).

The results in Table 8 show an overall increase in the number of patches of less than 50 ha for all land cover classes over time. This indicates the fragmentation of the landscape between 1985 and 2010. As expected, in 2035 this trend will be maintained with an increase in the number of patches less than 50 ha in area and a decrease in the number of patches larger than 100 ha.

If a nuclear area is considered to be the total area of a patch once a 100-meter strip has been subtracted (McGARIGAL and MARKS, 1995; RIBEIRO, 2010), it is still possible to evaluate the stability of the patches based on the premise that the areas closest to the perimeter are more influenced by external factors. Table 9 presents the number of nuclear areas and the difference in relation to the number of patches for the class interval of up to 50 ha. This analysis was only performed in smaller areas because they are the most sensitive to the landscape fragmentation process. The numbers of patches are the result of the subdivision of larger patches, which generates a greater number of patches in smaller nuclear areas.

Nuclear areas up to 50 ha								
Forest			**Mountain Ecological Refuge**			**Reforestation**		
1985	**2010**	**2035**	**1985**	**2010**	**2035**	**1985**	**2010**	**2035**
429	422	849	107	104	107	339	428	1,208

Table 9 – Number of nuclear areas up to 50 ha.

The data in Table 9 show an increase in the number of nuclear areas up to 50 ha in size for all the cover categories on the dates analyzed. This is related to the fragmentation of larger patches based on the data in Table 8. Figure 9 shows a graph comparing the variation of the total area of patches for each cover class with the nuclear area. It is clear that there has been a progressive increase in the reforested areas. In 2010, even though the total area of Forest patches was greater than the Reforestation area, the nuclear area of both classes is similar, indicating that although the Forest category is more representative, it is composed of isolated patches and has a smaller nuclear area than the Reforestation fragments. The simulated Reforestation expansion for 2035 predicts that the Reforestation patches will be the most representative in the landscape.

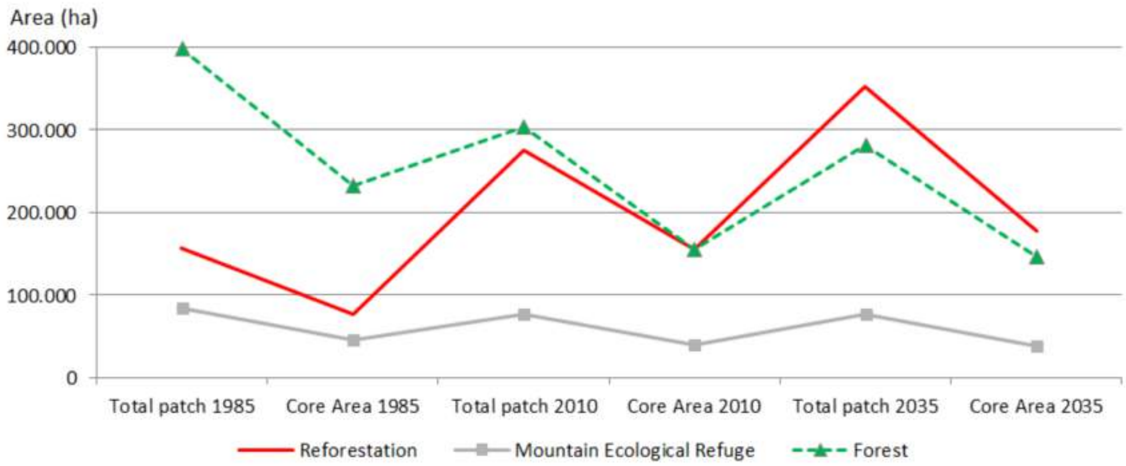

Figure 9 - Area versus nuclear patch area over time for forest, mountain ecological refuge and reforestation

The results of the analysis of isolation for the Forest, Mountain Ecological Refuge and Reforestation classes are presented in Figures 10, 11 and 12, respectively. The analysis allowed the level of isolation between patches to be evaluated (RIBEIRO, 2010) by calculating the shortest distance to the closest neighbor. The maps and graphs show the evolution of the level of patch isolation for the Forest, Mountain Ecological Refuge and Reforestation classes between 1985, 2010 and 2035.

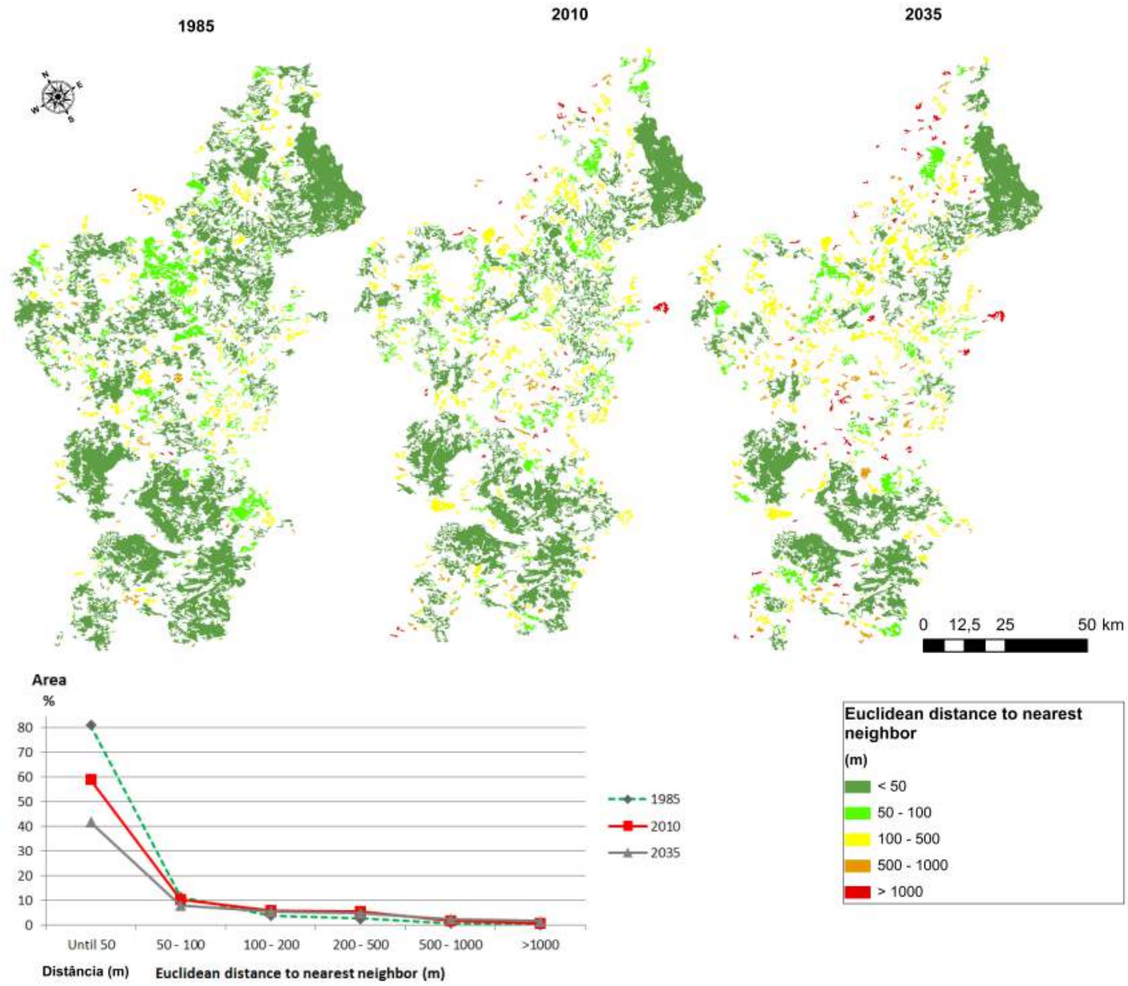

Figure 10 - Level of patch isolation for Forest class: 1985, 2010 and 2035.

The graph in Figure 10 shows that in 1985 almost 80% of Forest fragments were located up to 50m from each other. In 2010, this proportion fell to slightly less than 50% and in 2035 it dropped to 45%. This shows a trend for the isolation of patches to increase within this class. In the simulation of 2035, 60% of Forest patches are located less than 500m from each other, while in 2010 and 1985, 70% and 98% of the patches were located less than 500m apart, respectively. These figures also show a trend for the isolation of patches to increase, which is harmful as it reduces the metapopulations' access to these areas and increases the risk of local extinction, making it difficult to recolonize patches.

Figure 11 shows the result of the level of patch isolation for the Mountain Ecological Refuge class.

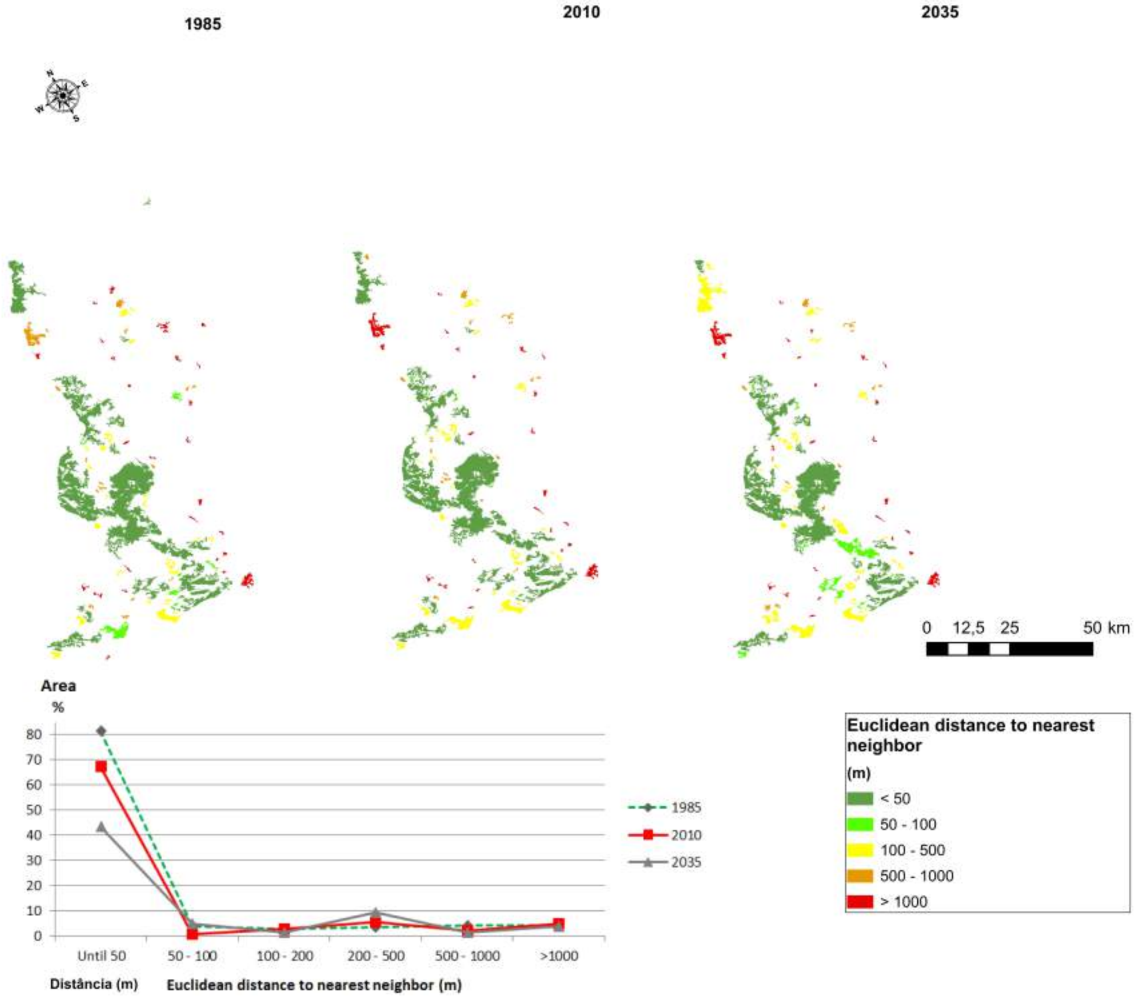

Figure 11 – The level of patch isolation for the Mountain Ecological Refuge class: 1985, 2010 and 2035.

The maps and the graph in Figure 11 show the evolution of patch isolation in the Mountain Ecological Refuge class over time. This is the class that has altered the least and also demonstrated a tendency for increased patch isolation. The greatest variation for this indicator is in the distance range of 50m. In 1985, more than 80% of the patches in this category were concentrated within this 50m range. In 2010, this number had decreased to a little over 70%, and in 2035 it is expected that only 60% of the patches will be located less than 50m apart from each other.

Contrary to the trend observed in the Forest and Mountain Ecological Refuge classes, the level of patch isolation decreased in the Reforestation category, as demonstrated in the maps and graph in Figure 12.

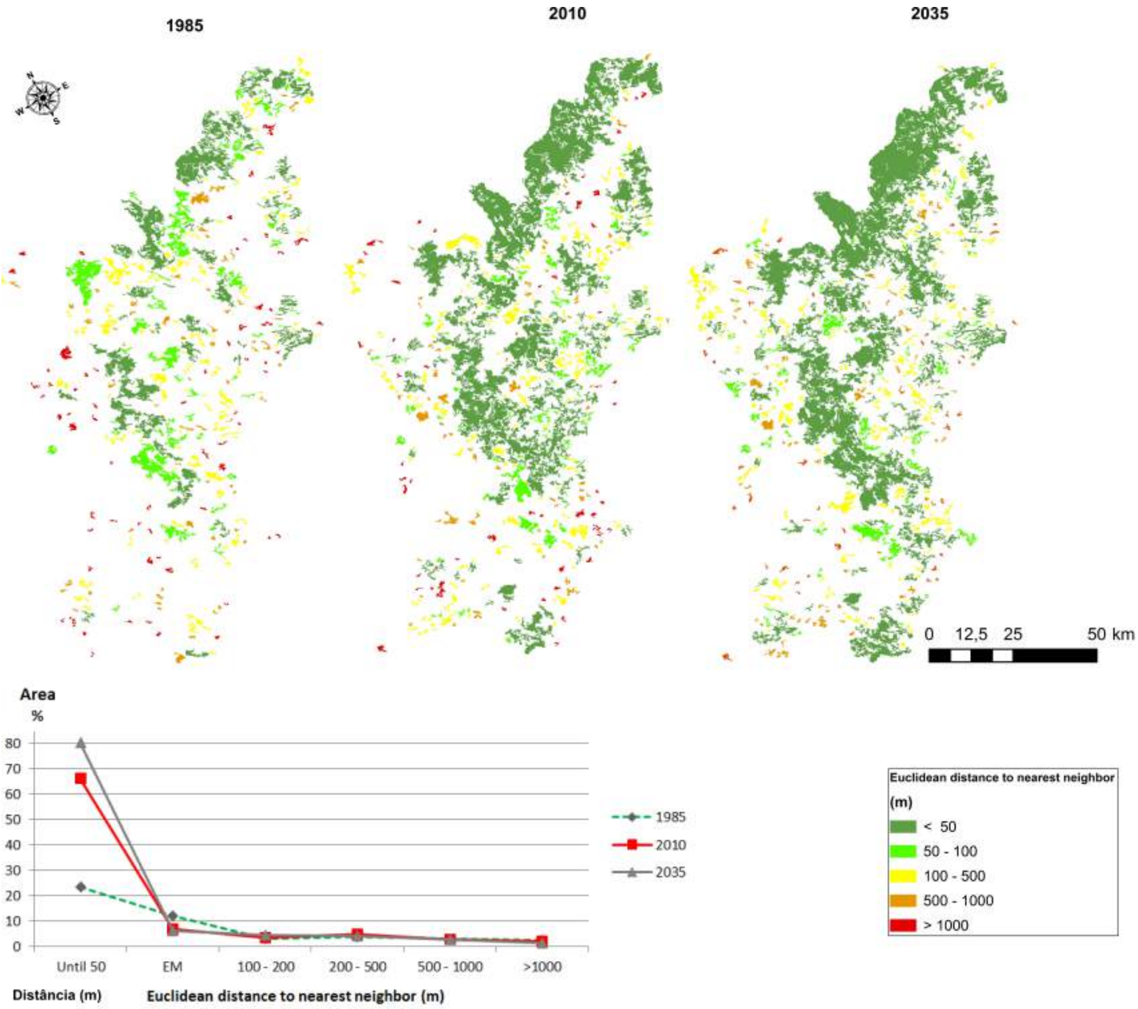

Figure 12 –The level of patch isolation for the Reforestation class: 1985, 2010 and 2035.

The areas in all the distances have increased over time. This increase is even more significant in the percentages of patches located up to 50m apart. In 1985, around 20% of patches were located up to 50m away from each other, in 2010 this number had increased to around 65%, and in 2035 the forecast shows that 80% of the patches will be located up to 50 m from each other.

The Reforestation patches expanded in the simulated landscape (2035), forming a "reforestation corridor" which decreased the isolation of patches in this class. This result should be analyzed carefully as it implies that the arboreal vegetation cover could expand with a more complex structure than that of the grassland of the pasture areas, which predominated in 2010. It is necessary to evaluate to what extent these areas might be useful for conservation. Overall, eucalyptus plantations have less variety of flora than the native forests that they substitute and a greater variety of flora when substituting pastures, areas with other agricultural crops or degraded land.

When these plantations are established in areas of native vegetation there is definitely a negative effect on the flora and fauna, since the environment is altered by soil disturbances, changes to the shade patterns, variations in the competition for water and nutrients, and chemical modifications. (POORE and FRIES, 1985). The extent of these impacts vary according to the planted area, but this monoculture is not able to provide the same diversity of services as native forests. Thus, techniques are needed to preserve native vegetation corridors with indigenous fruit trees and flora that can supply the fauna in the region (DAVIDSON, 1985). It is also important to consider that these strips are frequently cut down and may not be able to offer the quality or quantity of resources required to act as habitats for various populations. However, they might function as a corridor between native vegetation patches, favoring connectivity.

CONCLUSIONS

The land cover mapping results indicate that the cover changes in the study area occur mainly in the Eucalyptus Reforestation, Pasture, and Semi-deciduous Seasonal Mountain Forest classes. Between 1985 and 2010, there was a decrease in the Pasture and Semi-deciduous Seasonal Mountain Forest areas, and a rise in the Eucalyptus Reforestation areas. The Eucalyptus Reforestation area grew the most during this 25-year period. The expansion in the area of this category is strongly linked to the installation and expansion of the steel, paper and cellulose industries.

The potential transition model showed that the variables that best explain the changes to the study area are the distance from areas with eucalyptus, the distance from pastures, the distance from urban areas and the distance from areas where changes in land cover had occurred between the study dates. The last variable had the highest rates and it is aligned with the First Law of Geography: “everything is related to everything else, but near things are more related than distant things” (TOBLER, 1970).

The land cover simulation for 2035 assumed that eucalyptus demand will continue to rise at the same rates as those observed between 1985 and 2010. This simulation points to a scenario where Forest, Pasture, and Eucalyptus Reforestation will still be the most representative land cover classes. However, by 2035, according to the model’s assumptions, the most representative cover is expected to be Eucalyptus Reforestation rather than Forest and Pasture.

The results of the simulation include some limitations regarding the modeling process and tools used, which are based on presuppositions and do not take into account all the variables involved in land cover change dynamics. Consequently, the simulation’s results are based on a set of explanatory variables and an economic scenario of growing eucalyptus expansion. Even Brazil’s economic downturn over the last two years does not distort the global trend of growth in the sector, which is more closely linked to the external market than the domestic one. These variables do not represent all the complex relationships that shape the process of alteration of land cover and the landscape; instead, they characterize only a small portion of them. They are comprised of physical, biotic and socioeconomic factors that attempt to portray the complex natural phenomenon of land cover change in an idealized form.

Results from the analysis of landscape change showed a decrease in patch isolation in reforestation and an increase in patch isolation in forests. The trend is for a growing number of large forest patches to become more isolated in the landscape and progressively restricted to conservation units. On the other hand, the reforestation areas are expanding from their current area to adjacent areas, forming large patches of planted forests.

The possibility that the demand of the steel mills and the pulp and paper industries for eucalyptus will continue to grow in the region is real, given that the sector has been growing steadily since the early 2000s. So, the socio-economic benefits and environmental impacts of monocultures such as eucalyptus need to be assessed in view of the need for conservation. Eucalyptus plantations generate economic wealth and employ local people, and in environmental terms, they contribute to mitigating the greenhouse effect by carbon sequestration until they are harvested. On the other hand, they have less environmental diversity than forest areas, as their ecological functions for fauna and flora produce a simpler and poorer eco-system than native forests. Accordingly, the long-term consequences of the continuous increase in eucalyptus demand should be evaluated, as it may alter the region’s environmental balance.

Therefore, public policies that combine social, environmental and economic demands are needed, employing regional planning that takes the landscape and its spatial arrangement seriously, offering the local populations and communities better connectivity and offer habitats within the remaining forests, including eucalyptus areas, and reducing patch isolation. Studies based on environmental models and landscape analysis are tools that help in the diagnosis and prognosis of a region and lead to better planning and management of land occupation.

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