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ARTICLE

ENVIRONMENTAL MODELING AND ANALYSIS FOR IMPACT SIMULATION OF THE BRAZILIAN FOREST CODE IN THE LANDSCAPE STRUCTURE OF DF

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Abstract

In this paper, we analyzed the impacts of changes in environmental legislation and the implementation of the Brazilian Forest Code – BFC, on the landscape structure. In order to achieve this, data from the Rural Environmental Registry – RER and vegetation/soil coverage maps were used, in addition to a series of other environmental variables, for the construction, calibration and validation of an environmental model capable of simulating the impacts of changes in the law in the Landscape structure, from the perspective of three distinct scenarios. Scenario 1 considers the recovery of Areas of Permanent Preservation – APP and percentages of Legal Reserves – LR in accordance with the current BFC, maintaining the excess of native vegetation – ENV, which are outside these areas; Scenario 2 considers the application of the current BFC and suppression of all remaining native vegetation – RNV which are not located in protected areas; Scenario 3 considers the full recovery of the APP and LR bands, regardless of the size of the property and maintenance of the ENV. As main results, it was identified that in the Federal District, in relation to APP, the change in law represents a loss of 5,285 ha that will no longer be recovered. Most of this unrecovered area, 53%, is located in properties with more than 15 fiscal modules – the larger properties. The amnesty in relation to LR represents 2,459 ha, mainly due to the exceptions found in article 67 of the BFC.

Keywords: Rural Environmental Registry, Environmental Regularization Program, Simulation.

Resumo / Resumen

ANÁLISE E MODELAGEM AMBIENTAL PARA SIMULAÇÃO DOS IMPACTOS DO CÓDIGO FLORESTAL BRASILEIRO NA ESTRUTURA DA PAISAGEM NO DF

Neste trabalho foram avaliados os impactos das mudanças na legislação ambiental e da implementação do Código Florestal Brasileiro - CFB, na estrutura da paisagem. Para isso são utilizados dados do Cadastro Ambiental Rural - CAR, mapas de uso e cobertura do solo, além de outras variáveis ambientais para a construção, calibração e validação de um modelo ambiental para simular os impactos das mudanças da Lei sob a estrutura da paisagem, em três cenários: 1) recuperação das Áreas de Preservação Permanente - APP e percentuais das Reservas Legais - RL em acordo com o CFB vigente, mantendo os excedentes de vegetação nativa - EVN que estão fora dessas áreas; 2) aplicação do CFB vigente e supressão de todas EVN que não estão localizadas em áreas protegidas; 3) recuperação integral das faixas de APP e de RL, independentemente do tamanho do imóvel e manutenção dos EVN. Como principais resultados, foi identificado que no Distrito Federal, em relação as APP, a mudança na Lei representa uma perda de 5.285 ha que deixarão de ser recuperados. A maior parte dessa área não recuperada, 53%, está localizada em imóveis acima de 15 módulos ficais - as grandes propriedades. A anistia em relação às RL é de 2.459 ha devido principalmente as exceções do Artigo 67 do CFB.

Palavras-chave: Precipitação, Anomalia, Desastre.

ANÁLISIS AMBIENTAL Y MODELACIÓN PARA SIMULAR LOS IMPACTOS DEL CÓDIGO FORESTAL BRASILEÑO EN LA ESTRUCTURA DEL PAISAJE DEL DF

En este trabajo, se evaluaron los impactos de los cambios en la legislación ambiental y la implementación del Código Forestal Brasileño – CFB, en la estructura del paisaje. Para ello, se utilizan datos del Registro Ambiental Rural – CAR, mapas de uso y cobertura del suelo, así como otras variables ambientales para la construcción, calibración y validación de un modelo ambiental para simular los impactos de los cambios a la Ley del Medio Ambiente. estructura del paisaje, en tres escenarios: 1) recuperación de Áreas de Preservación Permanente – APP y porcentajes de Reservas Legales – RL de acuerdo con la actual CFB, manteniendo los excedentes de vegetación nativa – EVN que se encuentran fuera de estas áreas; 2) aplicación del actual CBF y supresión de todos los EVN que no estén ubicados en áreas protegidas; 3) recuperación total de las franjas APP y RL, independientemente del tamaño del predio y mantenimiento de la vegetación nativa excedente – EVN. Como principales resultados, se identificó que en el Distrito Federal (DF), en relación a las APP, el cambio de Ley representa una pérdida de 5,285 ha que ya no serán recuperadas. La mayor parte de esta superficie no recuperada, el 53%, se ubica en propiedades con más de 15 módulos fiscales –grandes propiedades–. La amnistía en relación con LR es de 2.459 ha debido principalmente a las excepciones del artículo 67 de la CFB.

Palabras-clave: Registro Ambiental Rural, Programa de Regularización Ambiental, Simulación.

INTRODUCTION

The landscape is simultaneously a reality of physical magnitude and resultant from a social construction (BERTRAND, 1978), therefore, it is subject of, not only, natural processes, but also transformations from human interference. In this context, public politics, in special those concerning the usage and occupation of the land, and the protection of native vegetation, influence the landscape dynamics (COSGROVE, 1985); (COSGROVE, 2017).

From this perspective, it is important to consider the legal and political norms that may inform the processes of landscape transformation in different scales and scenarios, as the organization of territorial management goes through the analysis of its elements (MATA et. al. 2009); (MATA, 2012); (SANZ et. al. 2018); (YACAMÁN et. al. 2020).

In Brazil, the Brazilian Forest Code – BFC, Lei Federal 12.651/2012, determines the protection of areas of Legal Reserve – LR and Areas of Permanent Preservation – APP, as well as regulates the mechanisms for environmental compensation and recovery, which conveys to this legal instrument a definitive role in modeling the landscape and its constituent elements.

In 2022, the BFC completed ten years of implementation. In this period, the Rural Environmental Registry (RER) became its main public policy in environmental management. The RER facilitated the diagnosing, even if, at first, in a declaratory nature, of environmental attributes in rural properties on a national scale (SOARES-FILHO et al., 2014; TANIWAKI et al., 2018).

Reserved for further later were the analysis of declared information and the implementing of environmental recovery devices, as the Environmental Regularization Program – ERP, and the recognizing of environmental assets, with the Environmental Reserve Quota – ERQ. In SICAR (National System of Rural Environmental Registry) the following data can be found: property limits, land, APP and LR coverage and usage.

According to SICAR (2002) data, until December of 2021 there were a little over 6,9 million users in the platform, which corresponds to a registered area of approximately 492 million hectares (considering, already, an overlap of areas) – that represents 80% of the territory suitable for registration. Considering the number of users and area represented in the database, the information from RER allows for a diagnostic on the state of remaining native vegetation, APP and areas to be recovered, in Brazil. In this sense, RER, as a tool for public management, aggregates a gamut of environmental data, of which the potential needs to be explored through the development of research that also contributes to a better environmental management in Brazil (SOARES-FILHO et al., 2014).

Considering the implementation phase of the Brazilian Forest Code (BFC), a full conformity of legal obligations, especially related to the recovery of environmental liabilities, has not been fully reached yet for the greater part of properties (SICAR, 2022). Therefore, the usage of environmental models can offer an important simulation of resulting impacts from alterations following the BFC, as well as the RER and its associated mechanisms, like the Environmental Regularization Program (ERP) and Environmental Reserve Quota (ERQ). These models can offer valuable information regarding changes in soil usage and vegetation coverage, and their respective effects on the structure of landscapes (YANG et al., 2016; GOUNARIDIS et al., 2019; MILLINGTON et al., 2021), allowing the mapping and understanding of impacts following possible environmental changes, be those positive or negative, which have arisen from applying the BFC in different scenarios. The use of computational models facilitates the understanding of the dynamics of changes in vegetation coverage, allowing for the exploration of variables related to processes of change and projections based on varied scenarios (ARONOFF, 1989); (LONGLEY e BATTY, 1997); (CHRISTOFOLETTI, 1999); (GOODCHILD, 2000) (JELOKHANI-NIARAK, 2021).

Following an approach which integrates model construction and the simulation and analysis of the landscape, some questions related to the future impact of deforestation and/or landscape recovery can be answer, such as:

I) how does the recovering of deforested APP impact the degree of isolation for the remaining native vegetation? II) how did the amnesty offered by the BFC impact the landscape structure? III) which are the impacts on the structure of landscapes associated with a hypothetical scenario of deforestation of everything legally allowed by the current BFC?

It is worth mentioning, however, that the construction of models should represent a simplified form of reality, following certain suppositions, and that, therefore, it shows some inherent fragility from this process of representing complex variables in a computational environment. In this manner, the simulation of different scenarios cannot be taken as prophecy, but as an exercise, a type of analysis which can preview adverse effects and offer actions towards its mitigation, as well as highlight the effects of positive impacts (JAKEMAN et al., 2008); (IWANAGA et al., 2021).

As there are more than 6,9 million properties in the SICAR database, an analysis, modeling, and simulation which would consider all of the data for Brazil remains impracticable. Considering this limitation, and also considering the federal unit wherein the capital of Brazil is (Distrito Federal – DF), the territory cutout for the creation of a simulation that should contribute towards environmental planning was selected.

According to data available in SICAR (2021), until December of 2020 there were 15,091 properties in the DF. Evaluating the declared information for these properties, the conclusion is that there are around 2,500 ha of APP to be recovered, in a scenario of integral recovery as permitted by the BFC. On the other hand, around 3,900 ha are in the process of amnesty due to their overlap with consolidated areas, as per article 61 of the BFC. Likewise, the amnesty permitted in areas of LR should cover thereabouts of 2,012 ha, as per article 67 of the BFC.

In an effort to measure the impact of amnesties allowed by the BFC in the DF and how the landscape should be structured in case changes in policies had not happened, this research intends to create a model based on three different scenarios, as a way to simulated changes in vegetation coverage and soil, and its possible effects on the structure of landscapes for the following years.

The proposed scenarios, detailed in Table 1 and Figure 1, attempt to measure the impact on landscape structure for the year 2040, following the construction of a model that uses Multi-Layer Perception Neural Network – MLPNN (TIUMENTSEV, Y. e EGORCHEV, M., 2019), artificial neural networks, in an effort to associate an observed change in patterns for vegetation and soil coverage, with environmental variables explaining those changes, considering the legislation.

Scenario	APP	LR	RNV – Remaining Native Vegetation
Scenario 1	Proportional recovery of APP, according to article 61 of the current BFC	Recovery of LR areas, according to the amnesty permitted by article 67 of the BFC	Preservation of current excess remaining native vegetation
Scenario 2	Proportional recovery of APP, according to article 61 of the current BFC	Recovery of LR areas, according to the amnesty permitted by article 67 of the BFC	Deforestation of areas legally passive – excess RNV
Scenario 3	Integral recovery of APP	Integral recovery of LR areas	Preservation of current excess remaining native vegetation

Table 1 - Proposed scenarios for analysis, modeling, and simulation of impacts considering the environmental legislation.

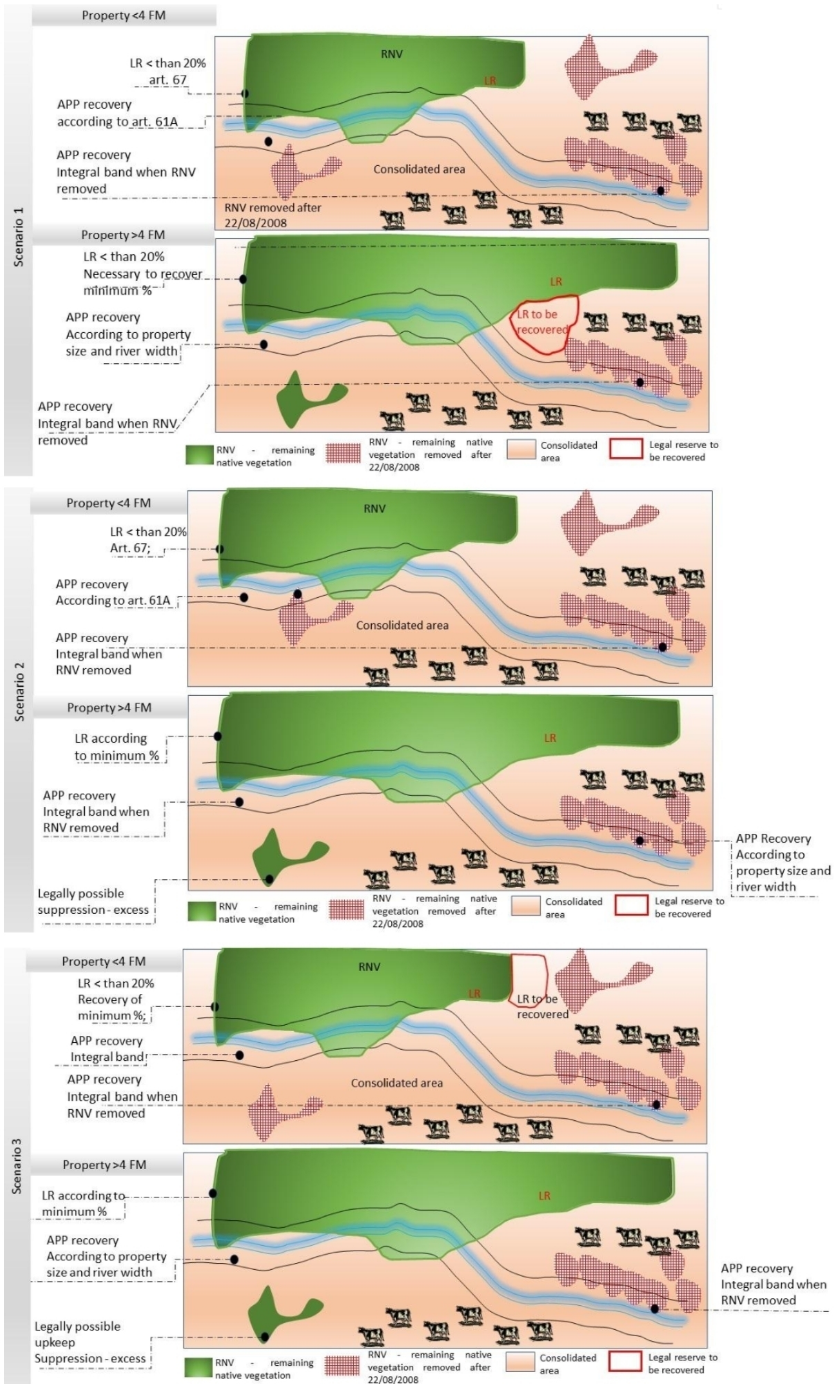

Figure 1 - Proposed scenarios for analysis, modeling and simulation of the impacts of environmental legislation.

METHODOLOGY

The proposed methodology intends to analyze the impact of the legislation on the landscape of Distrito Federal, considering different scenarios. Figure 2 shows a methodological flowchart which synthetizes this study. Initially, data from properties registered in RER was collected, then, from SICAR, property limits and areas of legal reserve were gathered. The information about APP was downloaded from the website of Secretaria de Desenvolvimento Urbano e Habitação do DF. As for vegetation/soil coverage, MapBiomas was consulted. All of the data is organized observing fiscal modules, as the Forest Code separates them in different groups of recovery according to properties size. Soil usage was also reclassified, following RER's coverage separation in classes.

Information on vegetation/soil coverage gathered from three different days was used to construct a prediction model for changes in vegetation cover. This model was adjusted through a multilevel neural network, which associates the observed change patterns and the socioeconomical variables that stimulate or restrict these changes. This model's validation comes from comparing the mapped vegetation/soil cover and the simulated one for the year 2020. After this step a simulation for the three proposed scenarios was conducted.

For each of the three proposed scenarios, landscape metrics which intent to evaluate the structure of the landscape were applied.

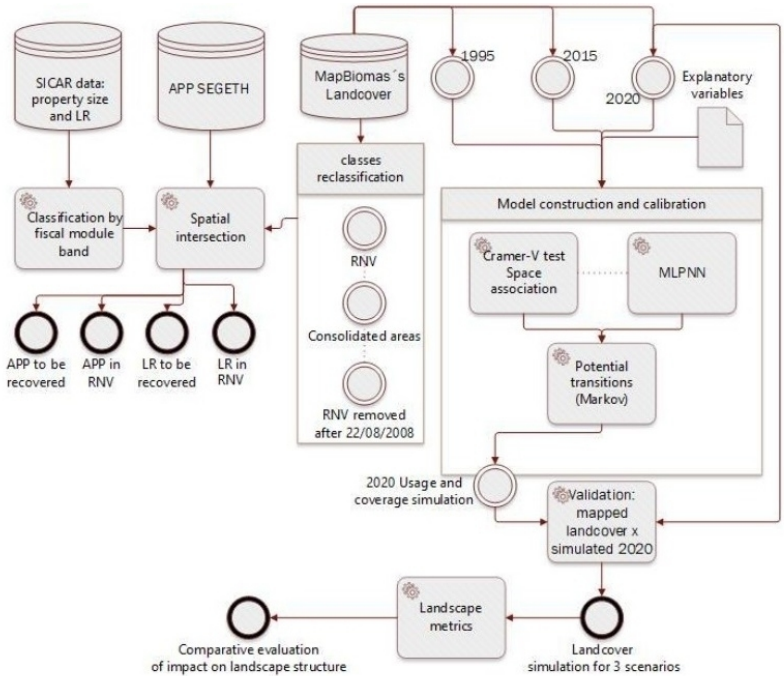

Figure 2 - Methodological Flowchart

DATA

In order to obtain data on rural properties, a search was conducted in SICAR, from which the following information was collected: property limits, property total net area and legal reserve. Data such as APP and vegetation/soil coverage and usage were not considered, as they fall under declaratory information, which can be inconsistent and could potentially harm the analysis. For this reason, vegetation/soil coverage information was gathered from the mapping in MapBiomas (2021), under coleção 5.

From the mapping of use and cover, for the year 2020, remaining native vegetation information was collected, and for the year 2008, the consolidated area. After comparing this data, information on removed native vegetation, after July 22nd, 2008, was inferred, considering the establishment of Decreto Federal 6.514, a temporal landmark which defined violations and administrative penalties concerning environmental rectification.

Concurrently, data on vegetation/soil coverage for the years 1995, 2015 and 2020 was collected from MapBiomas, which was then utilized to construct, calibrate, and validate the prediction model for changes in vegetation/soil cover. In order to evaluate APP, information mapped by SEGETH – Secretaria de Estado de Gestão do Território e Habitação do DF – was used, considering typologies and characteristics as under article 4 of the BFC.

CONSTRUCTION, CALIBRATION, AND VALIDATION OF THE MODEL FOR PREDICTING CHANGES

Using the platform LCM – Land Change Modeler (CLARCKS LABS, 2009), we constructed a model based on change patterns identified by vegetation/soil coverage for 1995 and 2015, with explanatory variables. These can be limiting, when restricting changes in vegetation/soil cover, as in, for example, the existence of areas of integral protection, or stimulating to changes, as in, for example, the existence of a highway or areas of urban or farming expansion (EASTMAN, 2009).

The different change patterns and explanatory variables are used for training a MLPNN, which allow us to create a map of potential transition, permitting a simulation based on Markov chains (BAKER, 1989).

As a way to evaluate the informative power of environmental explanatory variables, a spatial association test was conducted, test ERQmer-V (LIEBERTRAU, 1983), in order to select those better correlated to changes in vegetation/soil usage and coverage. These variables are presented in Table 2.

Variable	Description	Unit/type	Source
Altitude	MDE ALOS Palsar (100 m intervals)	m	Alaska Satellite Facility
Slope	Processed from MDE ALOS Palsar	%	Alaska Satellite Facility
Distance from streets	Street distances map	m	IBGE (2019)
Distance from water courses	Water courses map	m	SEGETH-DF (2021)
Types of soil	Soil map	m	IBGE (2019)
Distance from conservation units	Attained from conservation units map	m	CNUC (2020)
Distance from urban areas	Attained from vegetation/soil usage and coverage map	m	MapBiomas (2020)
Areas of change	Comparative map of vegetation/soil coverage (2020-1995)	m	MapBiomas (2020)
Distance from legal reserves	Attained from legal reserves	m	SICAR (2021)
Economic Environmental Zoning	Economic environmental zoning map	m	SEGETH-DF (2021)
Areas of hydric recharges	Map of wellsprings in the DF		SEGETH-DF (2021)

Table 2 - Environmental variables evaluated according to informative power in observed vegetative/soil coverage changes.

During the model calibration process, varied variable groups were tested, considering changes identified between 1995 and 2015. Different combinations of variables were conducted and tested for soil usage in 2020, for the validation process, comparing the simulate usage and the usage mapped in 2020. When the simulated model reached a 90% success, then a simulation for vegetation/soil usage and coverage for 2040 was created, considering the three proposed scenarios.

IDENTIFICATION OF APP TO BE RECOVERED

In order to determine the APP to be recovered, we carried out a crossover between APP data in consolidated areas , considering soil usage and the fiscal module (FM) of each property, as extracted from SICAR. For APP in consolidated areas, article 61 of the CBF is applied, so the area to be recovered is determined according to property size, as shown in Table 3.

Type	Up to 1 FM	Up to 2 FM	2 to 4 FM	> 4 FM
Water course	5 m	8 m	15 m	Corresponding APP space, observing the minimum of 20 m
Lake/Lake	5 m	8 m	15 m	Corresponding APP space, observing the minimum of 30 m
Wellspring	15 m	15 m	15 m	15 m
Vereda	30 m	30 m	30 m	50 m
Slope >45°, *chapadas*, hilltops and altitude > 1.800 m	Upkeep of consolidated usage for the whole APP, disregarding the necessary recovery of áreas			

Table 3 - APP to be recovered

EVALUATION OF LEGAL RESERVES

Each property was evaluated according to areas of LR considering two criteria: the percentage demanded for this biome and the vegetation/soil usage inside the LR. After this evaluation it was possible to identify deficit areas of LR, amnesty areas according to article 67 of the BFC, and areas of LR which complied to the legal criteria in the BFC.

EVALUATION METRICS FOR POTENTIAL IMPACTS IN DIFFERENT LANDSCAPE STRUCTURE SCENARIOS

After simulating the vegetation/soil coverage considering the three aforementioned scenarios, we conducted a comparative analysis subscribing to the Landscape Ecology approach (FORMAN e GODRON, 1986; TURNER E GARDNER, 1991). This methodological theory allows the evaluation of impacts in landscape structures through the use of landscape metrics, which measure possible alterations in its composing elements: matrix, patch, and corridor (FORMAN e GODRON, 1986).

Our chosen metrics were the Euclidean distance to the closest neighbor, which measures the degree of isolation in remaining native vegetation, and the number of landscape patches, which measures the cohesion of a landscape (LANG e BLASCHKE, 2009).

RESULTS

Until December of 2020, considering only RER with an active status, there were 15,091 registered properties in the DF, based on the information from SICAR. From this total, 11,319 are small properties of up to 2 FM, 1,281 are between 2 and 4 FM, 1,444 between 4 and 15 FM, and 1,047 are above 15 FM. In this scenario, the DF’s land ownership structure is primarily composed of small properties (up to 4 FM), and, for this reason, is more likely to receive amnesty for small environmental violations occurred until 22/07/2008, like interventions on APP and the conversion of remaining native vegetation in alternative soil usage, which can lead to the inexistence of land for recovery, integrally or partially (areas of LR).

DIAGNOSIS OF ENVIRONMENTAL LIABILITIES AND THE ESTABLISHMENT OF AN INTEGRAL SCENARIO – APP

The APP in an integral scenario recover an area of 45,639.87 ha, as quantified (in different groups of property size and total) in Table 4 and represented in Figure 4, which shows that the biggest concentration of APP occurs in properties of size bigger than 15 FM.

The evaluation of vegetation/soil coverage in APP indicates that its biggest part is RNV, approximately 74%, with the biggest percentages found in properties over 15 FM. In the DF, 22.66% of APP are in consolidated areas, in properties over 15 FM, which hold the biggest part environmental

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liabilities. An APP in a consolidate area in this group size occupies around 6 thousand ha, which represents 64.25% of the over 10 thousand ha of APP in consolidated areas of the DF.

Property Size	Area of APP (ha)	Area of APP in RNV (ha)	APP in RNV (%)	Area of Consolidated APP (ha)	Consolidated APP (%)
Up to 1 FM	1,900.80	1,377.10	3.02	528.75	1.16
1 a 2	1,465.95	1,049.57	2.30	416.38	0.91
2 a 4	2,384.92	1,716.60	3.76	668.31	1.46
4 a 15	7,598.21	5,510.82	12.07	2,082.,34	4.56
>15	32,289.99	25,645.64	56.19	6,644.36	14.56
	45,639.87	**35,299.73**	**74.33**	**10,340.14**	**22.66**

Table 4 - Quantity of APP in different property size groups

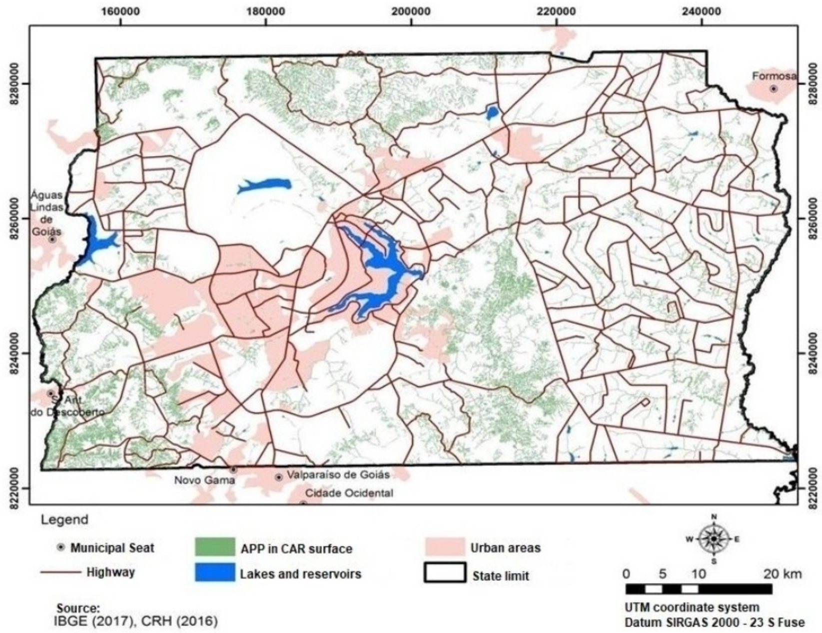

Figure 3 - Areas of Permanent Protection in the DF: Integral Scenario

Considering Scenarios 1 and 2, areas to be recovered in APP vary according to the property size and the quantity of APP in areas of consolidated use. According to the data in Table 5 for an integral recovery – Scenario 3, the DF has a little over 10 thousand ha of APP in consolidated areas. Of this total, considering the amnesties in Scenario RER/BFC, the area to be recovered represents 2,527.32 ha.

Property Size (FM)	APP in consolidate area	Band to be recovered (m)	Area to be recovered (ha)	Area not to be recovered
Up to 1 FM	528.75	5	221.84	306.91
1 a 2	416.38	8	239.24	177.14
2 a 4	668.31	15	515.13	153.18
4 a 15 FM	2,082.34	20[1]	1,772.95	309.39
>15 FM	6,644.36	20	5,574.74	1,069.62
Total	**10,340.14**	-	**8,323.90**	**2,016.24**

Table 5 - Quantity of APP in consolidated areas separated by property size and area to be recovered.

From the data shown in Table 5, we can observe that over 2 thousand hectares of APP will not be recovered, which represents over 20% of APP in consolidated areas.

Still according to the data in Table 5, the following graph in Figure 4 shows that considering the percentage of area not to be recovered separated by property size, properties over 15 FM are responsible for over 53% of APP which will not be recovered. Properties between 4 and 15 FM, of medium size, will be responsible for over 15% of APP not to be recovered, and properties under 4 FM, of small size, will be responsible for approximately 31% of APP which will not be recovered.

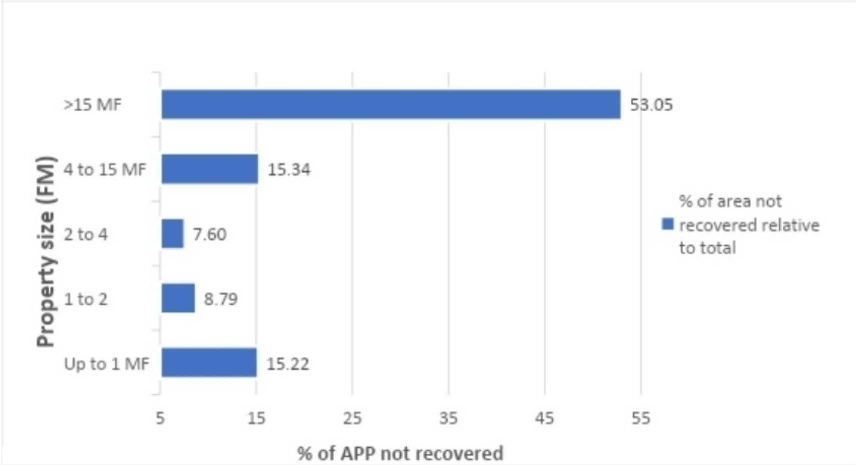

Figure 4 - Percentage of APP which will not be recovered, separated by property size

DIAGNOSIS OF ENVIRONMENTAL LIABILITY AND THE ESTABLISHMENT OF AN INTEGRAL SCENARIO – LR

In terms of LR areas, from the 15,091 properties, the total net area covered by RER (eliminating overlaps) comes up to 380,948.46 hectares. Considering the demanded percentage for LR for the biome Cerrado, according to Lei Federal 12.651/2012, is of 20% of the property size, the DF in an integral scenario should possess at least 76,189.69 ha of LR areas. As per the declared data on SICAR – eliminating overlaps – currently there are 85,934.64 ha destined for LR in the DF. Although this LR area is bigger than demanded, this number does not reflect the reality of many properties, as though some offer excess, others show an LR deficit.

The LR deficit can be divided according to the data presented in Table 6. The recovery of LR amnesty predicted in the BFC pertains to properties under 4 FM and that previous to 22/07/2008 possessed native vegetation in percentages inferior to the minimum legally demanded.

Situation	Quant.	Properties Size (ha)	Areas of LR (ha) to be recovered – Scenario Integral	Areas of LR (ha) to be recovered – Scenario RER
Properties < 4 FM which did not declare LR and do not have RNV available - article 67	1,958	5,790.46	1,158.09	0
Properties < 4 FM which did not declare LR and have RNV available, but under the minimum %	1,637	12,973.01	2,594.60	1,293.65
Total	**3,595**	**18,763.47**	**3,752.69**	**1,293.65**

Table 6 - LR situation in the DF

In this context, we identified 1,958 properties which are totally comprised of consolidated areas, that is to say, have received full amnesty for areas of LR, as per article 67 from the BFC. These properties occupy an area of 5,790.46 ha, which means that according to the previous iteration of the BFC they should recover 1,158.09 ha in areas of LR.

In 1,637 properties, we could identify a number of declared LR areas under the minimum percentage allowed. In this case, the current version of BFC, the LR areas are comprised of preexisting RNV in 2008, which, for the DF, equates to 1,293.65 ha. In the integral recovery scenario, there properties should equate to 2,594.60 ha of LR. Considering the LR areas to be recovered as per the current BFC, which was demanded in the previous iteration, there is a loss of 2,459.04 ha in LR areas.

MODELLING AND SIMULATION OF FUTURE SCENARIOS

Evaluating the vegetation/soil coverage dynamic of alteration, represented in Figure 5 and Figure 6, we can observe that in the period between 1995 and 2020, the main transformations were related to the expansion of urban areas; there was an expansion of 26% for this coverage class. The pressure of urban expansion has been the cause of suppression in areas of Savana and Natural Grassland Formation Natural, of which surfaces have decreased by 10% and 16%, respectively for the same time period. Forest areas, as they are related to APP, have suffered little variation. The same pattern can be observed in the class of Farming Land, which has remained stable for the aforementioned period.

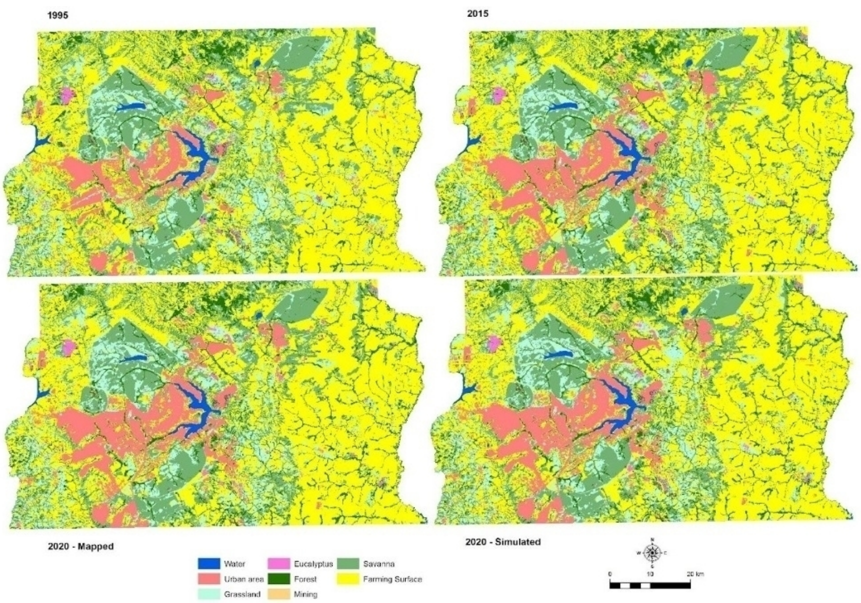

Figure 5 - Vegetation/soil coverage and usage Dynamics, between 1995 and 2020. This figure also compares mapped soil usage X simulate usage for the year 2020. Source: mapped soil coverage and usage for the years 1995, 2015 and 2020: MapBiomas (2021). Usage and coverage simulate for the year 2020, elaborated by the authors (2021).

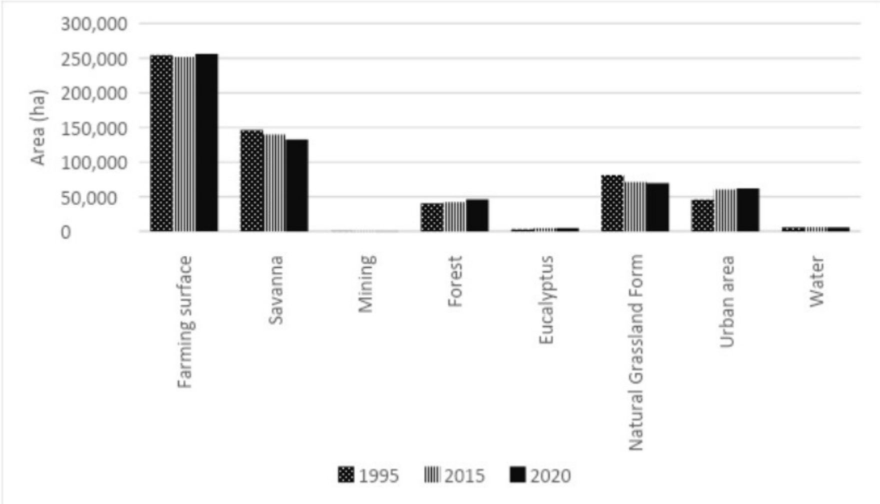

Figure 6 - Vegetation/soil coverage in the DF: 1995, 2015 and 2020. Source: MapBiomas (2021)

After evaluating the dynamics of vegetation/soil coverage for the selected period, we constructed a simulation model. According to what was previously explained in the methodology section of this paper, it is necessary to associate the patter of changes in vegetation/soil coverage to explanatory variables through an MLPNN neural network. As a way to test which environmental variables are better connected to these changes, we conducted the space association test ERQmer-V, of which the results are presented in Table 7.

Variable	ERQmer-V	Unit	Selection Status
Altitude	0.68	m	Selected
Slope	0.16	%	Not Selected
Distance from streets	0.62	m	Selected
Distance from watercourses	0.15	m	Not Selected
Soil types	0.09	m	Not Selected
Distance from conservation units	0.64	m	Selected
Distance from urban areas	0.54	m	Selected
Areas of change	0.62	m	Selected
Distance from legal reserves	0.11	m	Not Selected
Economic Environmental Zoning	0.64	m	Selected
Areas of hydric recharge	0.69	thematic	Selected

Table 7 - Results of ERQmer-V test

Variables with a bigger ERQmer-V value were selected for training the MLPNN. According to Eastman (2009), an ERQmer vale of 0.10 or bigger is recommended for the variable to be added as explanatory in the model of potential transition, even though that will not guarantee its best performance, which depends on the repetition between different layers of the overlapping multilayer neural network – MLPNN. After 15,000 repetitions, the best result for the training of the MLPNN was of 99%, according to the graphic shown in Figure 8, considering the simulation of vegetation/soil cover for the year 2020 and comparing it to real mapping for the same year.

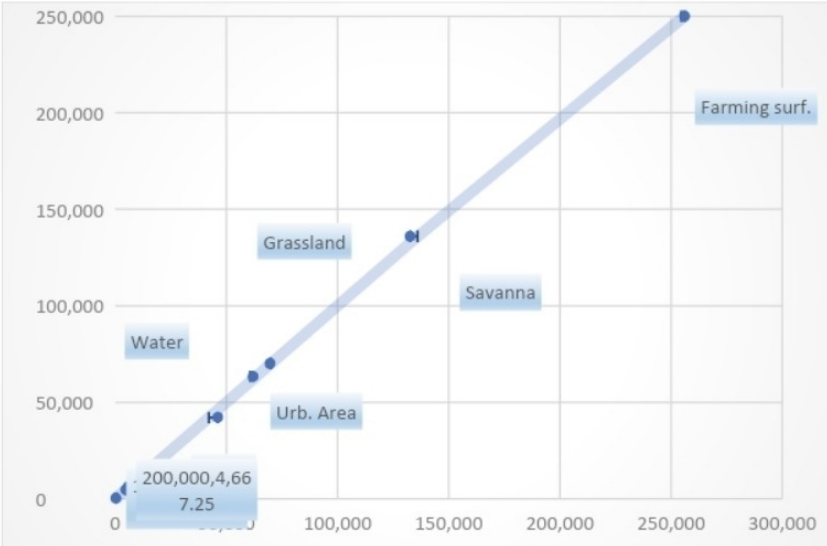

Figure 7 - Comparative mapped vegetation/soil cover X simulated: 2020

After reaching this level of adjustment, three future scenarios were generated for vegetation/soil coverage and usage for 2040, shown in Figure 8 and Figure 9, as per the aforementioned methodology.

Scenario 1 considers amnesties conceded by the current BFC and the upkeep of current native vegetation; scenario 2 considers the same amnesties, but with the elimination of native vegetation localized outside of areas of legal protection; and scenario 3 considers the upkeep of current native vegetation and the recovery of total areas of LR and APP.

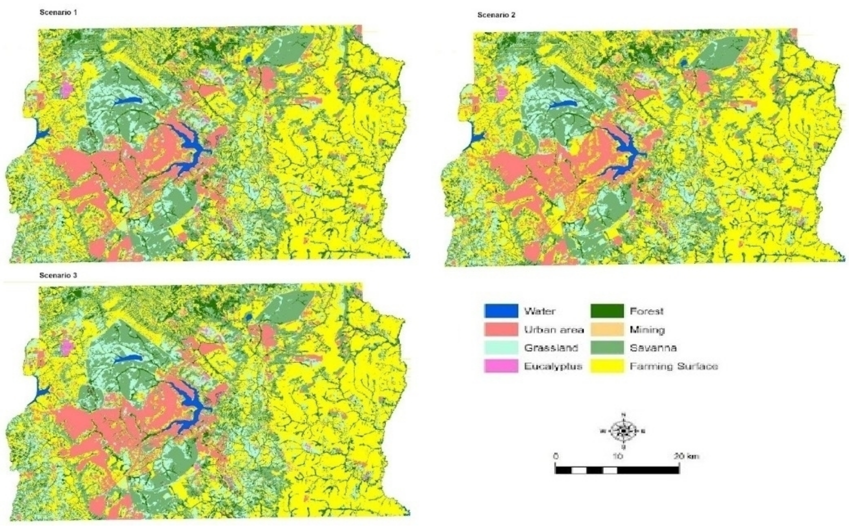

Figure 8 - Simulated usage of vegetation/soil for 2040 in the DF: Scenarios 1, 2 and 3.

The class better represented in all scenarios is Farming Land, occupying 38.03 %, 55.50 % and 37.40 % in scenarios 1, 2 and 3, respectively. In Scenario 2, this class represents a bigger area as it considers the elimination of remaining native vegetation outside of legally protected areas, as per the BFC

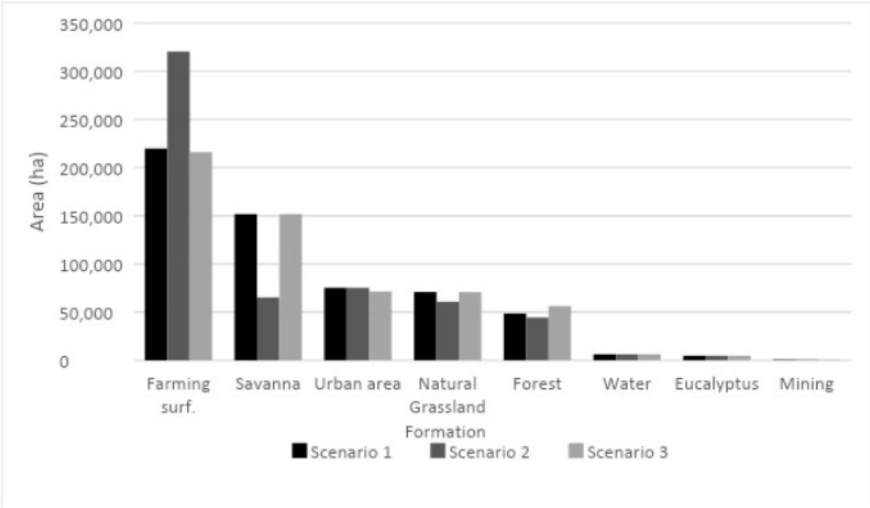

Figure 9 - Simulated soil usage for 2040 in the DF: Scenarios 1, 2 and 3.

The natural covers of Savanna, Forest, and Natural Grassland Formation show a significant reduction in Scenario 2; while in Scenario 1 and 3 theses coverage classes represent 46.97% and 48.27%, respectively – in Scenario 2, their percentage is of 29.50%.

The consolidation of Scenario 2 would mean a significant reduction in native vegetation cover, impacting the landscape structure, which would start to show patches more isolated from each other, which in turn would lead to consequences for the upkeep of fauna and flora diversity. As a way to measure the degree of isolation for the remaining native vegetation, we present, next, a comparative evaluation of the impact on landscape structure for the three aforementioned scenarios.

DEGREE OF ISOLATION IN LANDSCAPE STRUCTURE – A COMPARATIVE EVALUATION

After evaluating the degree of isolation in remaining native vegetation, it is possible to analyze the impact on landscape structure by calculating the area of accumulated native vegetation in different distance intervals, as presented in Figure 10 and Figure 11.

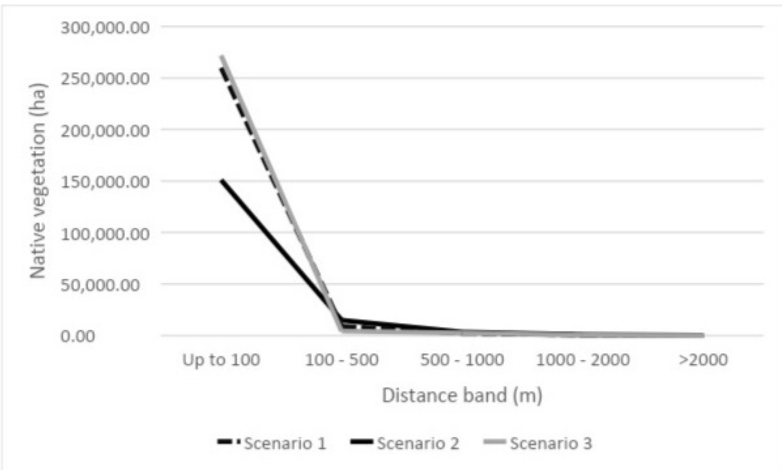

Figure 10 - Area of remaining native vegetation separated by distance.

The main difference between scenarios is the quantity of native vegetation in a distance of up to 100m, the minimum value adopted for the upkeep of connectivity between distinct patches

(McGARIGAL e MARKS, 1995; RIBEIRO, 2010).

In Scenario 1 and 3, 259,851 ha and 271,971 ha, respectively, of remaining native vegetation are found in a distance of up to 100m. In Scenario 2, for the same band of distance there are 151,076 ha, an area of native vegetation 41% smaller than Scenario 1 and 44% smaller than Scenario 3.

Scenario 3 is the one which presented the biggest percentage of native vegetation in a distance of up to 100m, which occurs, mainly, due to the impact of an integral recovery of areas of LR and APP, simulated for this scenario.

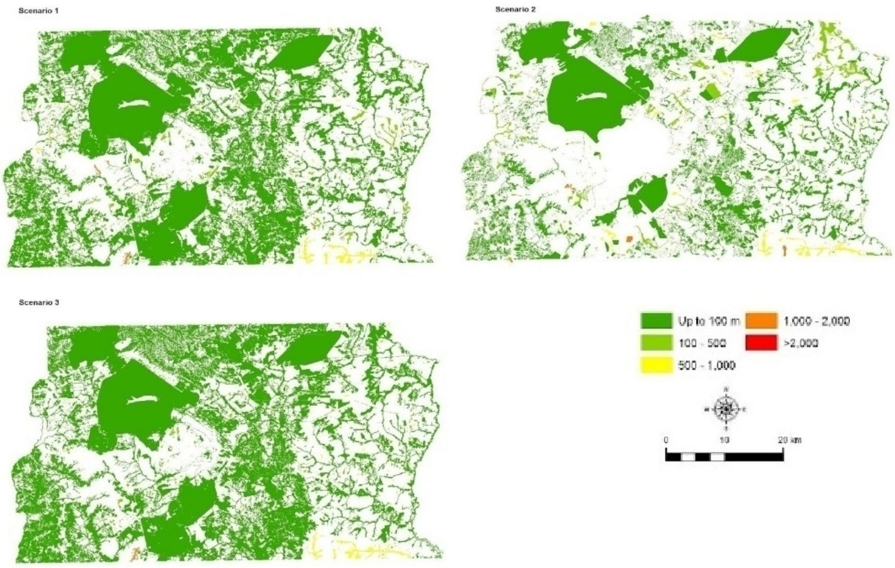

Figure 11 - Degree of isolation for patches in native vegetation

As a way to evaluate the effects of landscape fragmentation, besides considering the distance band, we studied the quantity of patches per distance band in those three scenarios, of which the results can be seen in Table 8.

	Scenario 1		Scenario 2		Scenario 3	
Distance (m)	**Quant. of patches**	**Area (ha)**	**Quant. of patches**	**Area (ha)**	**Quant. of patches**	**Area (ha)**
Up to 100	3,476	259,851.79	5,207	151,076.11	2,186	271,971.15
100 - 500	1,496	8,829.75	2,107	14,927.12	1,129	4,256.12
500 - 1000	109	2,197.00	183	3,428.68	82	2,282.18
1000 - 2000	22	358.50	38	704.84	14	246.58
>2000	2	5.75	7	227.89	0	0.00
-	**5,105**	**271,242.79**	**7,542**	**170,364.65**	**3,411**	**278,756.03**

Table 8 - Quantity of native vegetation patches by distance band

The quantity of patches which compose the landscape indicate how cohesive is each of the simulated landscapes; the bigger the number of patches, the more fragmented the landscape is.

It can be observed that the simulated landscape most fragmented is Scenario 2, with a bigger number of patches, but smaller areas. After evaluating the average size of the area occupied by these patches which comprise the three simulated scenarios, we noticed that the average area in Scenario 1 is of 53.13ha, 22.58ha in Scenario 2, and 81.72 in Scenario 3. That is to say, comparative to Scenario 2, the average size of patches in Scenario 1 is 57% bigger; and comparative to Scenario 3, 72% bigger. Scenario 3 possess patches 35% bigger comparative to Scenario 1, which demonstrates it is the more cohesive, relative to the degree of isolation for remaining native vegetation.

The evaluation of the quantity of patches in different distance bands shows that for all simulated scenarios the number of patches is bigger in a distance of up to 100m, however, each scenario has a significant variation in quantity of patches and areas. Even though Scenario 2 presents a bigger quantity of patches in that distance interval (5,207), its vegetation area is the smallest of all scenarios (151,076.11ha). Scenario 3 show the smallest quantity of patches (2,186), and the biggest area (271,971.15ha), for the same distance interval, demonstrating that this simulated landscape is the most cohesive. Lastly, Scenario 1 presents 3,476 patches and an area of 259,851.79ha, an intermediate value amongst the simulate scenarios.

CONCLUSION

This research was constructed from an integrated methodology of geoprocessing, landscape ecology and environmental modelling, in order to simulate the impacts of changes, brought about the environmental legislation, in remaining native vegetation and landscape structure. We utilized data for property limits and areas of LR (SICAR), data for vegetation/soil cover (MapBiomas) and APP (SEGETH-DF).

Considering three different scenarios, it was possible to identify, between losses and gains, the outcome of the application of the current BFC as compared to its previous iteration. Pertaining to APP, the DF still possess almost 75% of remaining native vegetation, a little over 22% in consolidated areas. These APP in consolidate areas were separated by property size and evaluated under the BFC's older and newer versions, allowing for a conclusion that there is a loss of 5,285.50 ha of APP, considering amnesties imposed by the 2012 BFC. This loss in APP, to be recovered, can have direct and indirect impact on fauna, flora, and hydric resources.

The distribution of APP in consolidate areas by property size showed that APP liability is bigger in larger properties (above 15 FM), which detain more than 53% of APP in consolidated areas; smaller properties (under 4 FM) are responsible for 31% of APP in consolidated areas; and properties of medium size (between 4 and 15 FM) are responsible for approximately 15% of APP in consolidated areas.

Through modelling and simulation, using data for vegetation/soil cover and environmental variables, we produced a simulated model of future soil usage, related to the application of the current environmental legislation, for the year 2040. Simulating the vegetation/soil usage and coverage in three different scenarios, we could attain a prognosis of different legislature applications and their impact on the landscape structure for the year 2040. In all scenarios, the coverage class better represented is farming land. In Scenario 2, which evaluated the possible suppression in all legally allowed areas, this coverage class would represent 55.50% of all landscape, whereas in Scenario 1 this percentage would be of 38.03% and in Scenario 3 of 37.40%.

The remaining native vegetation areas represent the smallest percentage in Scenario 2, 29.50%, In Scenario 1 and 3 these coverage classes represent 46.97% and 48.27%, respectively.

The analysis of landscape structures following a metric application, allowed us to evaluate the impact of landscape connectivity and cohesion. Considering the degree of isolation for the remaining native vegetation, we identified that a distance of up to 100m holds the biggest concentration of area in the three scenarios, though with varying number of patches and (in) different areas. The number of patches in this distance interval for Scenario 2 is 41% smaller than Scenario 1 and 44% smaller than Scenario 3.

These analyses allowed us to conclude that Scenario 3 would be the more environmentally restrictive scenario, considering an integral recovery of APP and areas of LR. As the environmental legislation took on a different path (Scenario 1), this scenario serves only to measure how much of APP and areas of LR were lost due to legislation changes.

In Scenario 1, we considered the recovery of APP and the percentages of areas of LR in accordance with the current BFC, while keeping the excess of native vegetation outside of those areas. This resulted in an intermediate scenario, however unlikely to be kept integrally, considering the possible pressure, in the following years, from the expansion of urban areas, mainly due to housing deficit. In order to avoid bigger pressure on remaining native vegetation localized outside of protected areas, it is necessary to direct new areas of urban expansion towards areas of farming land, instead of opening new areas by eliminating native vegetation.

Scenario 2 considers the application of the current BFC and the suppression of all areas of excess native vegetation which are not localized in protected areas. In this scenario, the impact on the degree of isolation for remaining native vegetation is bigger, resulting in a more fragmented landscape, and, consequently, showing more impact connected to habitat reduction, escape of fauna, loss of rare, endemic, and threatened species, and the decrease of flora diversity.

The incentive of conservation and recovery measures would offer a preventive measure from the consolidation of Scenario 1. It is fundamental to create public policies of payment for environmental services, remunerating producers that preserve the excess of native vegetation in their land, as the full elimination of those areas would have a significant impact on the landscape structure and all its chain of environmental relationships.

NOTAS

1 - Area of rural property with human occupation (resulting from human action) pre-existing on July 22, 2008, with buildings, improvements or agroforestry activities.

2 - For properties above 4 MF, 20 m is the minimum range to be recomposed of APP in a consolidated area

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