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Determinants of the Brazilian Amazon deforestation

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The Amazon rainforest is the world's largest biome, containing almost 50% of the planet's known biodiversity and is the biggest source of fresh water, which is approximately one-fifth of the global reserves. However, the sustainable use of this ecosystem is threatened by several factors, and deforestation is the main problem. This study addresses the deforestation of the Brazilian Amazon forest, in particular evaluate the determinants of the deforestation process, using for this purpose, time-series of several socioeconomic factors from 1990 to 2015. The methodology applied included statistical analyzes based on the application of multivariate discriminant analysis with the stepwise criteria. The results showed that in order of importance cattle, roads network, population, logging and crop areas were the determinant variables of the deforestation in the amazon.

Key words: Cattle, population, deforestation, Brazilian Amazon.

INTRODUCTION

The Amazon rainforest is the world's largest biome, containing almost 50% of the planet's known biodiversity and its biggest source of fresh water, which is approximately one-fifth of the global reserves. However, the sustainable use of this ecosystem is threatened by several factors, being deforestation its main reason, since it affects natural resources availableness for future generations and jeopardizes a wide range of environmental services, like hydrological cycle, regional climates maintenance and global carbon stocking (Davidson, 2012).

On a regional scale, deforestation promotes ecosystem alterations, such as rainfall decreasing, evapotranspiration reduction, hydric resources contamination (Roulet et al., 2000) and a significant biodiversity loss (Portela and Rademacher, 2001), aggravated by exploration methods used in the Amazon, which increases fauna and flora prejudices and causes a considerable soil productivity loss (Machado and Aguiar, 2001).

Regarding the current deforestation processes, most

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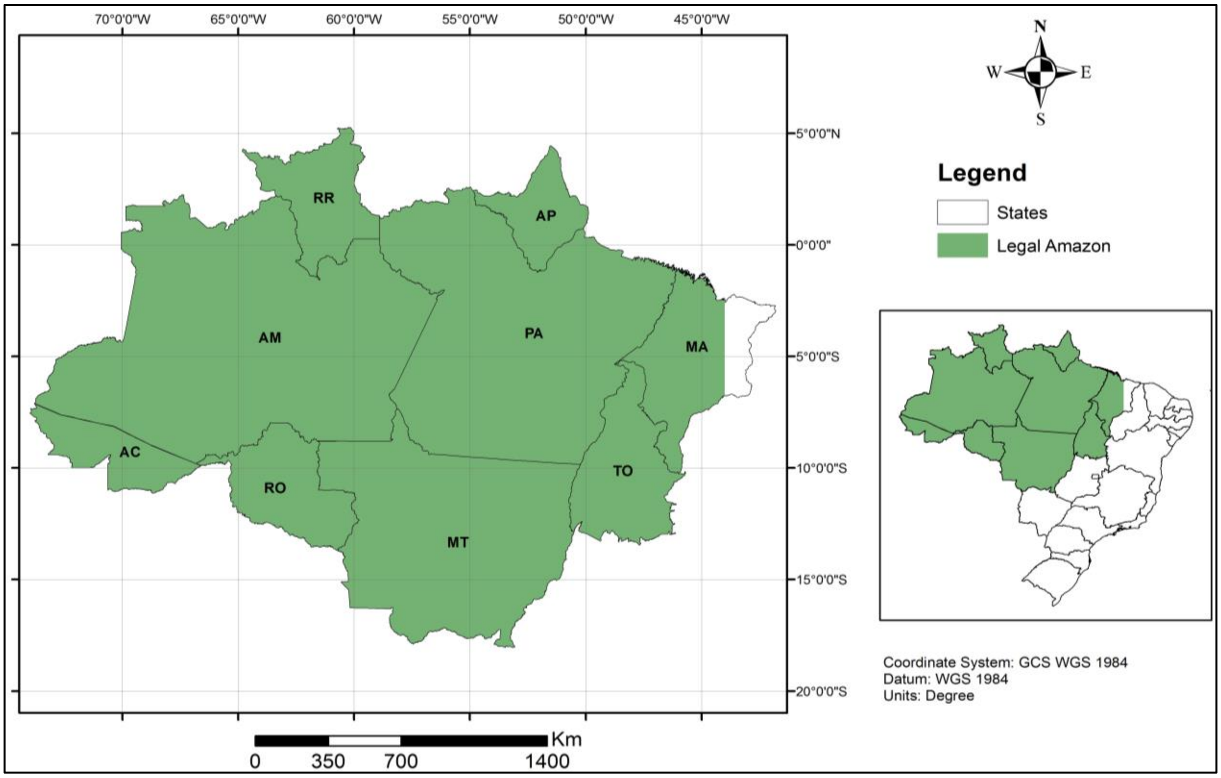

Figure 1. Study area.

researches stated that agricultural activities expansion occurs according to private economic logic (Margulis, 2003). Silva (2006) affirms that most of the Amazon deforestation, until 1997, occurred on lands that presented greater agricultural potential, which was supported by Chomitz and Thomas (2001), who verified that land exploration for agricultural proposes decreases if said area rainfall levels increases, therefore, humid areas are not interesting under an economic perspective, and are least vulnerable to deforestation (Oliveira, 2011). In other researches, major political-economic causes for deforestation in the Amazon are cattle raising (Miragaya, 2008); agriculture of grains (Cattaneo, 2005); logging (Matricardi et al., 2010); and distance to highways (Godar et al., 2012).

Even considering its relevance, between 1990 and 2015, around 358 000 km² of vegetal coverage were destroyed at the Amazon biome. However, in the last few years, deforestation rates decreased, when compared to data collected on early 2000's. In 2004, annual deforestation estimates reached 27.772 km², and from 2005 onwards, a strong decline on the deforestation occurred, reaching 4571 km² in 2015. Nevertheless, even with deforestation reduction in the last few years, the rates are still expressive and can increase again.

Therefore, considering that the Amazon rainforest is indispensable, detailed researches to analyze and comprehend deforestation are necessary in order to support governmental and non-governmental actions to control and reduce deforestation areas.

This research aims to evaluate social-economic variables that influence the Brazilian Amazon deforestation, using as a source, a series of temporal data that covers a period from 1990 to 2015.

MATERIALS AND METHODS

Studied area

The research covers the Legal Amazon area (Figure 1), whose concept originates from Brazilian law number 1.806, January 6th, 1953. With a 5.1 million km² extension, the Legal Amazon included in its domain the seven states of Brazils north region plus the Mato Grosso state and part of Maranhão state (west of the 44º west meridian).

Such official geographic clipping was established considering regional promotion and economic development goals, especially on agricultural frontier areas, influencing the transformation processes of land use.

Studied variables

Variables were chosen based on existing literature focused on studying deforestation that indicated them as causes of forest degradation. Table 1 contains all variables considered in the research and its respective unity of measurement.

Table 1. Variables in the analysis.

Variables	Measures
Deforestation	km²
Cattle	Unities
Logging	m³
Population	Unities
Rural Credit	US$
Road Network	Km
Gross National Product	US$
Crop Area	Ha
Log Price	US$/m³

Database

The database comprehend a period between 1990 and 2015, was collected for every state that constitutes the Legal Amazon, and then the results were organized in a panel; it presented a sampling space whose "n" was equal to 207. Since eight explicative variables was used plus the deforestation as a dependent variable, created a matrix (9 x 207), summing 1863 elements.

Such material was collected using literature focused on that specific matter and pertinent governmental and non-governmental institutes, as well.

The currency used in this study is the dollar (US$), and all monetary values were deflated in order to avoid results distortion caused by inflation.

Statistical analysis

The data set was submitted to statistical analysis, using the multivariate data analysis method, specifically, the discriminant analysis. To perform the statistical analysis the used software were "STATISTICA 8.0" and "SPSS 22".

Discriminant analysis

The discriminant analysis is a statistic technique that enables to identify which variables differentiate the studied groups, and which ones are necessary to improve individuals' classification results in a certain population (Corrar, 2009). Such techniques aim to find a variable that combines others linearly (independents) and that is able to explain, in the best way possible, groups differences. This linear combination is also known as discriminant function:

$$Z_{jk} = a + W_1X_{1k} + W_2X_{2k} + \cdots + W_nX_{nk} \quad (1)$$

In which Z_{jk}= Z discriminant score of the discriminant function j for the k object; W_i = discriminant coefficient for the independent variable i; X_{ik} = independent variable I for the k object.

The (Z) score provides a direct manner for comparing observations in each function. The discriminant function can be expressed by standardized and non-standardized weights and values, considering the standardized version more useful for interpretation purposes (Hair, 2009).

In this research context, the dependent variable was the deforestation, categorized in tree groups (high, medium and low). This categorization was based on states' annual deforestation values quartiles, where lower values regarding the first quartile (lower quartile) were categorized as low, values between the first and third quartile (upper quartile) were characterized as medium and deforestation values whose were above the upper quartile were qualified as high.

The independent variables were chosen according to the literature and data availableness, which was important for discriminant function construction. In other words, while using the discriminant analysis is essential to determine among the sampling elements, variables able to describe population (groups), because otherwise discriminant adjusting quality is compromised (Johnson and Wichern, 2007).

There are automatic selection methods to choose independent variables that might help searching for the most important answer-variables for the discrimination process. Among those methods, the stepwise is one of the most recommendable, being the one chosen for this study.

The step-wise discriminant analysis along the Wilks' Λ method was used to identify which studied variables allow discriminating the tree deforestation intensity groups (high, medium, low). According to this criteria, the variables are included or removed whether its inclusion decreases, or not, the Λ value (Maroco, 2007).

The F value for Λ alteration for when a variable enters or leaves the model is:

$$F = \left(\frac{n-g-p}{g-1}\right)\left(\frac{1-\frac{\Lambda_{p+1}}{\Lambda_p}}{\frac{\Lambda_{p+1}}{\Lambda_p}}\right) \quad (2)$$

In which n is sample global dimension, g is the group number, p corresponds to independents variables number. Λ_p is Wilks' lambda value before adding/removing a new variable and Λ_{p+1} is Wilks' lambda value after adding/removing a new variable. This statistic has an F-snedecor distribution with (g-1) and (n-g-p) liberty rates, and the associated significance probability measures new variable addition/removal significance.

According to Hair (2009), some conditions are necessary to apply the discriminant analysis, such as independent variables multivariate normality, linearity, and variance and covariance matrixes homogeneity and multi-collinearity absence.

In addition, according to Corrar (2009) the two last presumptions are the most relevant, since they affect the discriminant analysis results the most, especially if the analysis goal is identify the characteristics (variables) that most affect the observed groups. To verify the variant and covariant matrixes equality, the Box's M Test is used.

RESULTS AND DISCUSSION

Discriminant analysis

Using the group means equality it was possible to perform a preliminary evaluation aiming to identify which variables are better discriminators for the studied groups. Table 2 shows the results.

According to the Wilks' Lambda the lower the statistic variable, the better its group discrimination capacity, therefore, as seen on Table 2, the variable Cattle is the most capable to define the deforestation groups, since its Wilks Lambda statistics was lower.

On the said table the F-ANOVA test is shown, as well which assists previous test interpretation and evaluation. In this test, the variable Cattle is confirmed as a good option and the variable Log Price is discarded as a

Table 2. Tests of equality of group means.

Variables	Wilks' Lambda	Z	df1	df2	Sig.
Crop Area	0.842	19.092	2	204	0.000
Logging	0.764	31.566	2	204	0.000
Population	0.716	40.447	2	204	0.000
Cattle	0.630	59.816	2	204	0.000
Rural Credit	0.858	16.840	2	204	0.000
Log Price	0.984	1.694	2	204	0.186
PIB	0.684	47.158	2	204	0.000
Road Network	0.699	43.854	2	204	0.000

Table 3. Inserted variables [a,b,c].

Step	Inserted variables	Wilks' Lambda				Exact F			
		Statistics	df1	df2	df3	Statistics	df1	df2	Sig.
1	Cattle	0.630	1	2	204	59.816	2	204	0.00
2	Logging	0.482	2	2	204	44.726	4	406	0.00
3	Population	0.423	3	2	204	36.189	6	404	0.00
4	Crop Area	0.398	4	2	204	29.403	8	402	0.00
5	Road Network	0.373	5	2	204	25.521	10	400	0.00

In each step, the variable that minimizes the Wilks' Lambda is inserted. [a] Steps maximum quantity is 16. [b] F maximum significance to be inserted is 0.05. [c] F minimum significance to be removed is 0.10.

Table 4. Eigenvalues.

Function	Eigenvalues	Variance %	Cumulative %	Canonic Correlation
1	1.325	89.6	89.6	0.755
2	0.154	10.4	100.0	0.365

possible candidate to be included in the discriminant function.

The result of the Box's M Test, the variant/covariant matrixes homogeneity presumption is invalid, based on the test, the null hypothesis was rejected, meaning homoscedasticity absence.

In accordance with study's methodology, the stepwise process was used to select variables that best discriminate the population. The process result is on Table 3.

The stepwise procedure includes variables containing huge discriminant capacity and that were least related among each other (correlated). Therefore, the following variables were included, in this order: Cattle, Logging, Population, Crop Area, and Road Network.

Other variables were not selected (PIB, Rural Credit and Log Price), because, according to the stepwise method the said variables do not contribute to improve the discriminant functions.

Discrimination groups were generated by five explicative variables; they were statistically relevant during proceeding's five steps, according to the p-value. It can be concluded that the discriminant analysis signalized that those five variables are needed to differentiate the groups, with high, medium or low deforestation levels.

Table 4 contains the functions eigenvalues. This statistic indicates that the first function presents a superiority degree when compared to the second function. Each variable explanation capacity is given by the canonic correlation that, in this case, was 0.755 for the first function and 0.365 for the second. By squaring these values, an explanation measure of the variance is obtained: in the first function it is possible to explain 57% of the classification and 13.3% with the second, in other words, functions 1 and 2 are able to explain 70.3% of the total variance.

Analysis next step was to verify if groups' population averages were statistically different from each other, showing that the function is able to define the elements of

Table 5. Wilks' Lambda.

Function tests	Wilks' Lambda	Chi-square	df	Sig.
1 to 2	0.373	199.370	10	0.000
2	0.866	28.951	4	0.000

Table 6. Classification table.

Classification		Deforestation	Predicted Group Association			Total
			Low	Medium	High	
Original	Count	Low	16	36	0	52
		Medium	5	87	12	104
		High	0	7	44	51
	%	Low	30.8	69.2	0.0	100
		Medium	4.8	83.7	11.5	100
		High	0.0	13.7	86.3	100
Cross-validated	Count	Low	15	37	0	52
		Medium	9	82	13	104
		High	0	8	43	51
	%	Low	28.8	71.2	0.0	100
		Medium	8.7	78.8	12.5	100
		High	0.0	15.7	84.3	100

Table 7. Standardized discriminant functions coefficients.

Variables	Function	
	1	2
Crop Area	-0.820	0.864
Logging	0.638	-0.433
Population	-0.053	1.120
Cattle	1.050	-0.749
Road Network	0.577	-0.248

each groups. To testify the discriminant functions the Wilks' Lambda Test was used. The results are on Table 5. The Wilks' Lambda Test showed that is possible to reject the null hypothesis where the groups averages are equal, proving that function 1 and function 2 are significant and can define the groups well.

On Table 6, it is possible to observe the classification efficiency considering the created discriminant functions.

Considering the sample that originated the discriminant functions 1 and 2, it was stated that 30.8% of the samples considered as a low deforestation were classified correctly. As for medium deforestation cases, 83.7% were classified correctly and the high deforestation cases, 86.3% were classified correctly. In relation to the global index, 71% of the deforestation rates were classified correctly.

In the cross validation section each case is classified while leaving it out from the model calculations. The cross-validation global index rate was 67.7%.

By observing the results it is possible to state that the Linear Discriminant Functions presented a satisfactory performance, indicating that the discriminant model is valid and has appropriated statistic levels, because, the success proportion (global index) was higher than the maximum chance criteria, 62.8% and higher than the proportional chance criteria, 47.0%. It is necessary to emphasize that the high deforestation group sample classification, given its elevated accuracy.

In Table 7 it is possible to visualize variables standardized coefficients that are part of the discriminant functions developed with the chosen methodology.

Comparing Table 7 coefficients with Table 8 coefficients

Table 8. Rotated discriminant functions coefficients.

Variables	Functions	
	1	2
Cattle	1.192*	-0.493
Crop Area	-0.993*	0.658
Logging	0.718*	-0.278
Road Network	0.618*	-0.112
Population	-0.304	1.079*

* Higher absolute coefficient among the discriminant functions.

Table 9. Structure Matrix.

Variables	Function	
	1	2
Cattle	0.665*	0.096
Road Network	0.559*	0.322
Logging	0.482*	-0.111
Crop Area	0.369*	0.210
Population	0.469	0.824*

*Higher absolute correlation between each variable and any discriminant function.

Table 10. Potency index.

Variables	Potency Index
Cattle	0.397
Road Network	0.291
Population	0.268
Logging	0.209
Crop Area	0.127

it is possible to observe that after functions rotation, in this case the “Varimax” rotation, a load distribution improvement occurred, which enables a better coefficients evaluation.

It is possible to analyze the structural coefficient matrixes in Table 9, which enabled to correlate the independent variables with the discriminant functions 1 and 2.

The structural coefficients, or discriminant loads, provided functions variables importance. The higher the structural variable coefficient value, the higher its discriminant capacity. Therefore, first function describing variables are Cattle, Road Network and Crop Area. The variable Population is the describing variable of the second function.

Using the obtained values on Table 10, it is possible to affirm that according to the potency Index, the variables that most differentiate whether the deforestation level is high, medium or low were the following: Cattle, Road Network, Population, Logging and Crop Area, respectively.

Thus, the variable “Cattle” that represents the cattle amount existing in Legal Amazon states held an important position in this deforestation phenomenon analysis, showing that the cattle raising during the study period was the major influence over Brazilian Amazon Deforestation.

Several other studies also stated that cattle (Miragaya, 2008), road network (Pfaff et al. 2007), population (Alves, 2010), logging (Asner et al., 2005) and crop areas (Cattaneo, 2005) are determinants for the Brazilian Amazon Deforestation. However, this research is different because identifies determinants’ order of importance and magnitude, in other words, the variables that better discriminate whether the deforestation levels were high, medium, low considering its relevance.

Due the impact caused by the deforestation determinants highlighted in this research, it is recommended take priority on using these factors to elaborate strategies designed to handle deforestation in the Amazon.

It is possible to affirm that according to the results, there are three major forces: agriculture expansion, demographic expansion and logging, these forces are interconnected and cause the mass deforestation. Regarding the population expansion, such phenomenon is accompanied by the infrastructure increasing, mostly the roads, which was highlighted in this research, as well.

Figure 2 demonstrated territorial map and the graphic representation of each group discriminant functions centroids. On the map, it is possible to visualize that function 1 is able to determine the high groups of medium and low deforestation levels, while function 2 separates low and medium groups but it can be observed a substantial overlap among these groups, which affects low deforestation group classification.

In general, the results indicate that an enormous concern regarding forest areas zoning and managed public forests conservation areas should exist. Financing and cost-cutting mechanisms should be established in order to encourage sustainable practices, developing instruments that restrict and raise deforestation costs are some of the public policy strategies that must be implemented.

Angelo (2008) defends adopting economic incentives as and strategy to decrease deforestation rates and encourage sustainable management. The lack of such strategies turns Amazon’s soil exploration more economically interesting for other practices.

Conclusions

The presented research evaluates the deforestation matter in the Brazilian Amazon, using the discriminant analysis and the statistical results obtained from it.

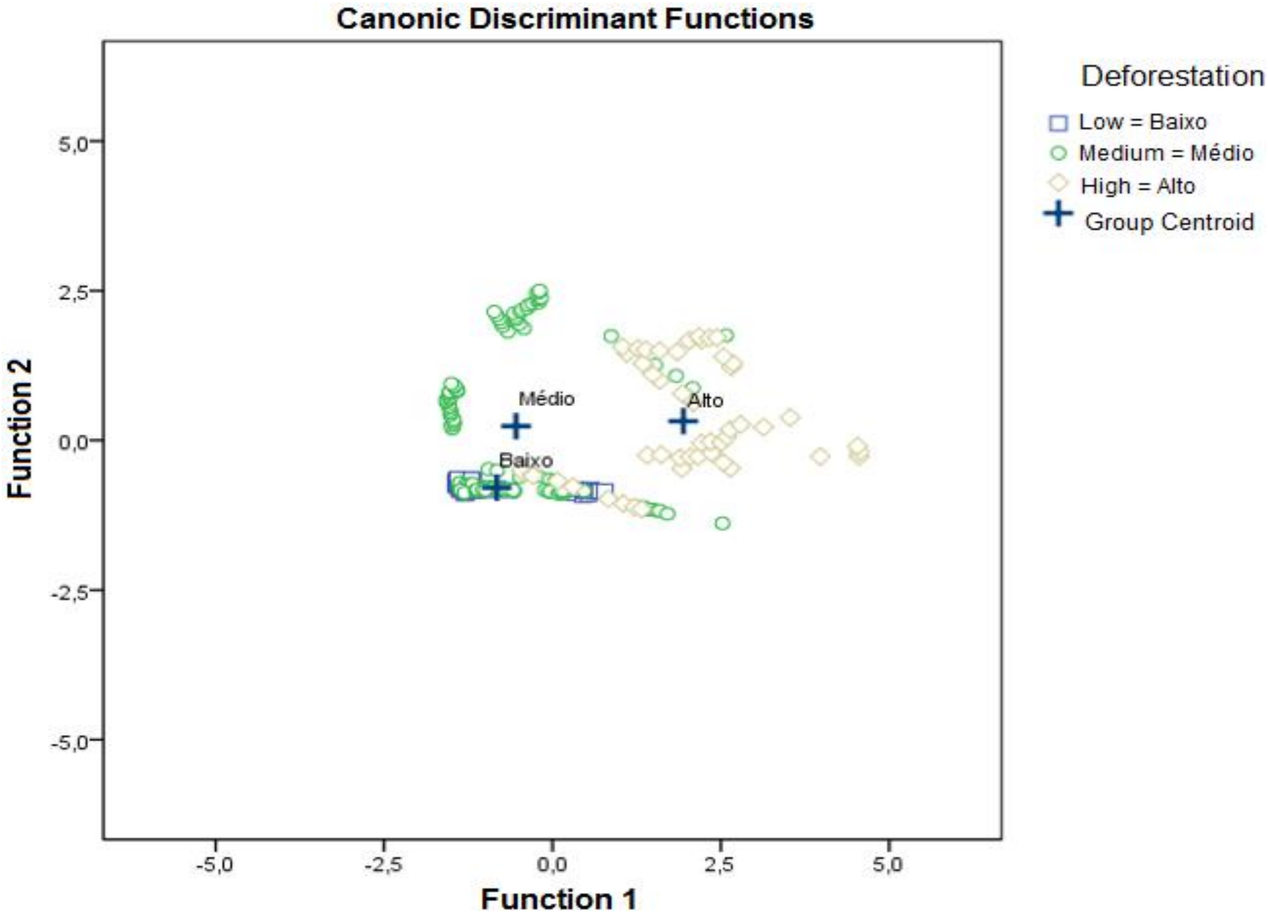

Figure 2. Territorial map.

Therefore, the Linear Discriminant Functions 1 and 2 presented on the results had a classification performance with 71% of success (global index) indicating that the discriminant model is valid and has appropriated statistic levels.

Based on this discriminant model, the deforestation variables were ranked by the potency index that represent the discriminant capacity of the variables. In decreasing order of discriminant power: cattle, road network, population, logging and crop areas. These highlighted variables were defined in this order as the major factors that contribute for the deforestation process and since the deforestation is a complex phenomenon, the research contribution is the statistical support that despite the population and agriculture contribution to the deforestation the major force was the cattle expansion.

In order to reduce the deforestation, this type of information is important to support public policy and strategies aiming to preserve the Amazon biome.

Although, it is imperative to implement public policy mechanisms, that not only fight against the environment aggressions, but also encourage the biome's conservation and sustainable use.

Conflict of Interests

The authors have not declared any conflict of interests.

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