

DRY FOREST DEFORESTATION DYNAMICS IN BRAZIL'S PONTAL BASIN¹

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ABSTRACT - Reliable information on vegetation cover and its dynamics over time is essential for managing life, resources, and supporting policies. Although many related initiatives have been undertaken in Brazil since the 1980s, knowledge about its dry forests is still limited. In this study, we address the drivers of deforestation and their threat to the Brazilian dry forest called Caatinga. We evaluated the land cover dynamics and landscape metrics in the watershed of the Pontal River, as it has become one of the most socially and environmentally important areas in Brazil. The overall process consists of a systematic sampling grid of hydrological samples, where Landsat images (1975 to 2013) combined with the FRAGSTATS package were used to evaluate landscape metrics indices for the Caatinga. Data showed that the relative area (*RA*) decreased from 90.25% to 60.98% over the 38-year period, while fragmentation (*PD*) presented an increasing bias. In addition, the spatial distribution of both indices became more heterogeneous and clustered in the north. We suggest that appropriateness of land for farming was the leading cause of deforestation; rainfall is 112% more intense in the north of the watershed than in the south. Therefore, the northern fauna and flora have been significantly altered and reduced. The relationship between deforestation and time shows an increasing threat. Further studies evaluating these causes are needed to improve our understanding of the vegetation dynamics in this region.

Keywords: Caatinga. Fragmentation. Landscape. Semiarid. Remote Sensing.

DINÂMICA DO DESMATAMENTO DE FLORESTA SECA NA BACIA DO PONTAL NO BRASIL

RESUMO - Informações confiáveis sobre a cobertura vegetal e sua dinâmica ao longo do tempo são essenciais para a gestão de vidas, recursos, e apoio a políticas. Embora muitas iniciativas tenham sido realizadas no Brasil desde a década de 1980, o conhecimento sobre suas florestas secas ainda é limitado. Neste estudo, abordamos os moduladores do desmatamento e sua ameaça à floresta seca brasileira chamada Caatinga. Avaliamos a dinâmica da cobertura da terra e métricas de paisagem na bacia do rio Pontal, a qual se tornou uma das áreas mais socialmente e ambientalmente importantes do Brasil. O processo em geral consiste em uma amostragem sistemática baseada em características hidrológicas, onde imagens Landsat (1975 a 2013) combinadas com o software FRAGSTATS foram utilizadas para avaliar índices de métricas de paisagem para a Caatinga. Os dados mostraram que a área relativa (*RA*) diminuiu de 90,25% para 60,98% ao longo do período de 38 anos, enquanto que a fragmentação (*PD*) apresentou uma tendência crescente. Além disso, a distribuição espacial de ambos os índices se tornou mais heterogênea e agrupada ao norte. Sugerimos que a aptidão da terra para a agricultura foi a principal causa do desmatamento. A chuva é 112% mais intensa no norte da bacia do que no sul. Portanto a fauna e flora ao norte foram significativamente alteradas e reduzidas. A relação entre desmatamento e tempo mostrou uma ameaça crescente. Outros estudos que avaliem essas causas são necessários para melhorar a compreensão da dinâmica da vegetação nesta região.

Palavras-chave: Caatinga. Fragmentação. Paisagem. Semiárido. Sensoriamento Remoto.

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INTRODUCTION

Reliable information on vegetation cover and its dynamics over time is essential for managing life and resources, and devising supporting policies at various levels. However, such information is not homogeneously distributed across the biomes of the planet. Rainforests have been widely studied while dry tropical forests (DTFs) receive less attention (PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010); therefore, data on these ecosystems is often scarce, inconsistent, and limited even though 42% of all forests in tropical regions are classified as seasonally dry (BULLOCK; MOONEY; MEDINA, 1995).

Northeast Brazil makes up 18% of the country, and 75% of its land surface is covered by semiarid regions (LIMA; BARBOSA; BARBOSA, 2009). The predominant ecosystem in these regions is a dry forest called Caatinga. With an area of 735,000 km², it is recognized as the "Earth's last wild place" and is considered as one of the 37 "Wilderness Areas of the World" (ALBUQUERQUE et al., 2012). It contains around 187 species of bees, 240 species of fish, 167 species of reptiles and amphibians, 516 species of birds, and 148 mammal species, with endemism levels varying from 9% in birds to 57% in fishes (LEAL; TABARELLI; SILVA, 2003). Moreover, it contains over 1,000 vascular plant species distributed as a mosaic of seasonally dry tropical forests (SDTFs) and shrub vegetation. However, such biodiversity contrasts with high levels of degradation, placing the Caatinga among the most endangered ecosystems on Earth, given its high rates of land conversion. Currently, the converted area in the region exceeds 60% of its original area (MENEZES et al., 2012).

Since the 1980s, monitoring these changes has been given priority, with many initiatives such as the programs PRODES (Monitoring Brazilian Amazon Forest by Satellite), DETER (Detecting Deforestation in Real Time), PROBIO (Projeto de Conservação e Utilização Sustentável da Diversidade Biológica), and more recently, PMDBBS (Projeto Monitoramento do Desmatamento dos Biomas Brasileiros por Satélite). However, the present perception of land cover changes in the Caatinga is still limited because most studies have assessed such changes using medium-resolution satellite imagery (~1 km) alone. Only a few have used Landsat imagery (~30 m), which lacks precise vegetation information data prior to 2002. Moreover, most

studies have analyzed the entire Caatinga, losing geographic details on the changes induced by projects that enhance local economic productivity by promoting agricultural and livestock practices. These practices often end up increasing natural forest fragmentation over time. Therefore, in this study, we evaluated the land cover dynamics and landscape metrics in the watershed of the Pontal River. In recent years, this area has become one of the most important sub-basins in northeast Brazil, playing a significant social, environmental, and commercial role in the state of Pernambuco, especially in terms of agricultural production. We conclude that the rapid and aggressive land cover conversion is creating hotspots of degradation and will negatively affect local ecology and geography.

MATERIAL AND METHODS

Study area

The Pontal River watershed is located in western Pernambuco, Brazil, between the coordinates 08° 19' 00" S, 40° 11' 42" W and 09° 13' 24" S, 41° 20' 39" W. It occupies an area of 6,057 km², 6.12% of the state (Figure 1). The drainage area includes four municipalities, but only the municipality of Afrânio is fully enclosed in the watershed. Its water spring is also located in Pernambuco, between the borders of Piauí and Bahia. The climate in the area is semiarid, with a mean annual temperature of 27°C; rainfall is irregular and concentrated within 2-3 months of the year, with the possibility of heavy rainfall (120-130 mm) over a period of 24 h. The predominant vegetation is the Caatinga, but a rapid expansion in irrigated agriculture of grape, mango, and guava has been observed, which is seriously threatening many native forest areas.

Surface properties and sampling design

In order to spatially characterize the Pontal watershed, elevation data from Aster GDEM raster (30 × 30 m) were downloaded at <http://earthexplorer.usgs.gov/>; soil classification data were acquired from the public database Zoneamento Agroecológico do Estado de Pernambuco (ZAPE; www.uep.cnps.embrapa.br/zape/); and historic annual rainfall data from gauges were downloaded at <http://hidroweb.ana.gov.br/> and interpolated using a spline technique. All data are presented in map form.

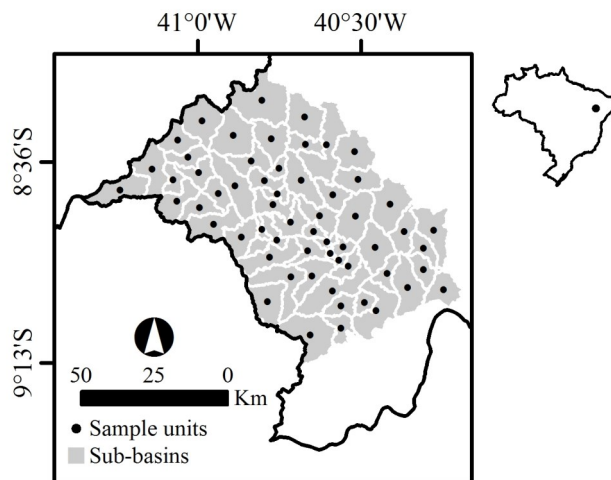


Figure 1. Location of the study area, the Pontal watershed in Brazil. The sample sites and sub-basins are also noted.

The overall process was developed as part of the System of Hydrologic Response Units for the Pernambuco (SUPer) Project implemented by University Federal of Pernambuco (UFPE) in association with Texas A&M University (TAMU). The project consists of a systematic sampling grid for samples in every watershed in Pernambuco, covering the entire state. Each sample unit has an area of approximately 10^8 m^2 (Figure 1) defined using soil classifications; the delineation of each sample unit reflects the spatial distribution of soil in the watershed. The sample units were made using the ArcSWAT extension for the ArcGIS package (ESRI, 2011). For each sample unit, we produced 8 land

cover maps from 42 cloud-free images from all sensors of the Landsat series. Each map is from a different period (Table 1) and is composed by a set of scenes with a maximum average distance to each target period of 12 months. All images were selected from the Landsat archives of the United States Geological Survey (USGS) and Brazilian National Space Research Institute (INPE) based on radiometric quality and absence of cloud cover ($< 10\%$). Each image underwent extensive pre-processing, including verification of image geolocation, conversion to at-surface reflectance, and merging.

Table 1. Selected images from all sensors of the Landsat series used in the analysis. The left column includes images from path/row 217/66, and the right, from 218/66.

Sensor/Satellite	Date of image	Sensor/Satellite	Date of image
MSS/Landsat 1	07/28/1975	MSS/Landsat 1	08/16/1975
MSS/Landsat 1	11/13/1975	TM/Landsat 5	10/18/1992
TM/Landsat 5	08/24/1992	TM/Landsat 5	05/14/1993
TM/Landsat 5	08/11/1993	TM/Landsat 5	09/09/1993
TM/Landsat 5	12/17/1993	ETM/Landsat 7	08/27/1999
TM/Landsat 5	06/25/1999	TM/Landsat 5	09/04/1999
TM/Landsat 5	12/04/2000	TM/Landsat 5	09/22/2000
TM/Landsat 5	10/04/2001	TM/Landsat 5	09/25/2001
ETM/Landsat 7	01/03/2003	ETM/Landsat 7	10/03/2001
TM/Landsat 5	07/06/2003	ETM/Landsat 7	07/18/2002
TM/Landsat 5	11/13/2004	ETM/Landsat 7	10/22/2002
TM/Landsat 5	10/12/2004	TM/Landsat 5	06/27/2003
TM/Landsat 5	10/15/2005	TM/Landsat 5	06/13/2004
TM/Landsat 5	07/30/2006	TM/Landsat 5	08/16/2004
TM/Landsat 5	01/22/2007	TM/Landsat 5	12/06/2004
TM/Landsat 5	09/24/2009	TM/Landsat 5	01/07/2005
OLI/Landsat 8	09/03/2013	TM/Landsat 5	07/18/2005
OLI/Landsat 8	05/10/2013	TM/Landsat 5	09/04/2005
		TM/Landsat 5	11/07/2005
		TM/Landsat 5	01/26/2006
		TM/Landsat 5	07/24/2007
		TM/Landsat 5	09/26/2007
		TM/Landsat 5	08/27/2008
		OLI/Landsat 8	09/26/2013

Image preprocessing and classification

For multi-temporal analysis, particularly when comparing images from different sensors (such as in the present study; Table 1), not only a good geometric match between images is essential, but also the use of high-quality at-surface reflectance products, instead of at-sensor spectral radiances, is necessary. This is because at-surface reflectance products have no negative effects from different solar zenith angles or variation in the Earth–Sun distance due to the time difference between acquisition dates. In addition, they are normalized for the exoatmospheric solar irradiance arising from each spectral band, and all atmospheric effects (CHANDER; MARKHAM; HELDER, 2009). This is important because these variations may spatially and temporally degrade the data quality.

In this context, the registration and orthorectification of all the images had to be enhanced. We used the well-established Automated Registration and Orthorectification Package (MASEK, 2009) distributed by the USGS to orthorectify TM Landsat images from the Global Land Survey (GLS) archives that provide the best radiometric, geometric quality, and cloud cover (GUTMAN et al., 2013). The images were georeferenced to the Universal Transverse Mercator projection system and the World Geodetic System (WGS84; RMSE < 0.25 pixels). Moreover, the variability in scene-to-scene was drastically reduced by converting the calibrated digital numbers (Q_{cal}) from level 1 images to at-surface reflectance (ρ_p), following the methods used by Chander, Markham and Helder (2009), and using the Geospatial Data Abstraction Library (GDAL). All required rescaling factors were found in the metadata for each image. To correct for atmospheric effects on all images, we used the module *i.atcorr* in the software GRASS to

perform the 6S algorithm (Second Simulation of the Satellite Signal in the Solar Spectrum) (NETELER et al., 2012), which is a radiative transfer model that works in a manner similar to corrections in the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. Finally, to create high-quality mosaic data, pixel-by-pixel compositions were created using the weighted average of each pixel; the weights were based on the distances from the center of each image.

Reference data for classifier training and accuracy assessment were collected through human interpretation of high-resolution imagery in Google Earth (<http://earth.google.com>) using interpretation criteria. Three thousand sample points were created using the function `arcpy.CreateRandomPoints_management()` available in ArcGIS, and all samples without QuickBird imagery (resolution = 2.4 to 2.8 m²) were removed (Table 2). Next, using these points, we created spectral signatures for each image and classified all images, which resulted in three classes: irrigated areas, Caatinga, and rainfed pastures or agriculture (Table 3). We could not acquire any valid sample points for 1975; thus, an average spectral signature was created using all applicable bands from other years. All the maps were converted to shapefile format and completely topo-error corrected using the *v.clean* tool installed in the software GRASS GIS (NETELER et al., 2012). To avoid “pepper and salt” polygons, all areas less than 100,000 m² were merged with the nearest polygon of equal class.

Owing to the lack of field data for our study, we opted for a consistency assessment based on the assumption that using over 15,000 assessments covering the 9 periods would be enough to guarantee the consistency for all maps. The advantages of this methodology have been fully explained by Redo, Aide and Clark (2013).

Table 2. The number of valid samples used for classifier training and accuracy assessment in the Pontal watershed, Pernambuco, Brazil. IRA = Irrigated agriculture, RFP = Rainfed pastures or agriculture, and CAT = Caatinga.

Year	IRA	CAT	RFP	Total
1975	0	0	0	0
1993	0	33	4	37
2001	8	2,015	654	2,677
2003	14	1,970	697	2,682
2005	14	1,924	754	2,692
2007	11	1,864	816	2,690
2009	14	1,935	754	2,703
2013	15	1,726	965	2,706

Landscape and statistical analysis

For studying Caatinga, calculations of the following landscape metrics/indexes were performed using the FRAGSTATS package (MCGARIGAL; MARKS, 1995):

$$RA = \frac{A_c}{A_t} \tag{Eq. 1}$$

$$PD = \left(\frac{N_c}{A_c} \right) \times 10^6 \tag{Eq. 2}$$

where *RA*, *PD*, and *A_c* are the relative area, patch density, or fragmentation, and area of each class, respectively; *A_t* is the total area of all classes; and *N_c* is the number of fragments per class. More information on the statistical functions in FRAGSTATS can be found in Zaragozí et al. (2012).

Table 3. Description of each land use class evaluated in the Pontal watershed.

Class name	Description
Irrigated agriculture (IRA)	Includes areas with forest and herbaceous vegetation that have been cleared for irrigated crops, such as grapes, mango, and some tropical fruits.
Rainfed pastures or agriculture (RFP)	Includes areas with forest and herbaceous vegetation that have been cleared for extensive grazing beef cattle, goats, sheep, and horses, and for rainfed production of corn, pineapple, lemon, and beans.
Caatinga (CAT)	Corresponds to areas with dry forest and shrubland. Areas with forest are densely populated by trees with an average height of 5 m, that have irregular trunks and lose most of their leaves during the dry season. Areas with shrubs are sparse with herbaceous vegetation and bare soil, and are often associated with shallow and rocky soils.

To identify patterns between *RA* and time, we used the non-linear regression model tool in the package R (FOX, 2005). To evaluate the intensity at which *RA* and *PD* changed over an interval of two years, we used Eq. 3 (see below). However, some intervals were greater than two years; for these, we used Eq. 4 to estimate the changes per year.

$$C_P = V_p - V_{p-1} \quad (\text{Eq. 3})$$

$$C_P = \left[\left(\left(\frac{V_p}{V_{p-1}} \right)^{\frac{1}{N_y}} \right) - 1 \right] \times 100 \quad (\text{Eq. 4})$$

where C_P , V_p , and V_{p-1} , respectively, are the absolute change in a given parameter P , the value P from a given period p , and the value P from the previous period p ; and N_y is the number of years in a period interval. To statistically test the spatial distribution of *RA* and *PD* over the area, we used the `arcpy.SpatialAutocorrelation_stats()` tool available in the ArcGIS suite. It basically evaluates the spatial pattern expressed from a given parameter as clustered, dispersed, or random. The results from all analyses were considered significant when $p \leq 0.05$.

RESULTS AND DISCUSSION

We established 59 sample units covering the entire Pontal watershed. These sampling units, extracted using ArcSWAT, allow us to recognize spatial arrangements of soils, which may favor the identification of homogeneous areas, and offer support to make inferences about the size of sample units. Tropical dry forests are among the most threatened ecosystems in the world as a consequence of intensive anthropogenic disturbance (FOLEY et al., 2005; SANTOS et al., 2011). Through the period 1975-2013, the Caatinga's *RA* in the Pontal watershed showed substantial depletion (from 90.25% to 60.98% in a polynomial pattern;

Figure 2). Conversions of natural forests progressed first as rainfed pastures or agriculture, followed by irrigated agriculture. The same process occurred in many other areas in Pernambuco. In the municipality of Belém de São Francisco, rainfed areas were increasingly promoted through government rural development programs; this was the main reason for the deforestation of the Caatinga in the area (ASSIS et al., 2014). In the municipality of Santa Maria da Boa Vista, the main drive for land transformation was the aggressive expansion of urban areas (TAURA et al., 2010). In total, the gross loss of Caatinga between 1990 and 2010 was 25,335 km² with an annual rate of change of -0.44% yr⁻¹ (BEUCHLE et al., 2015). Most of these areas were converted into agriculture and livestock areas (COELHO et al., 2014). Using Landsat Thematic Mapper TM data from the years 1999, 2000, and 2001 (162 satellite images), Vieira et al. (2013) showed that farming areas occupied 55% of Pernambuco.

The pressure for converting natural areas is strong but varies according to environmental conditions (MAYAUX et al., 2005). The pressure in favor of land use conversion does not always increase; sometimes it will slow down or even stop. For certain periods, the weather or economic characteristics might not be favorable for rural practices, leading to changes in all the land use dynamics in a given area. These mechanisms are not new; Beuchle et al. (2015) pointed out the importance of estimating and discussing them as they are significant in most regions but are nevertheless hard to evaluate. In addition, Mayaux et al. (2005) showed that during these periods, secondary forests can be established through re-growth on abandoned land and forest plantations, with different ecological, biophysical, and economic characteristics compared with primary forests. The Caatinga's deforestation rate in the Pontal watershed has slowed down only in recent years (2009-2013). We hypothesize that this could be related to weather variations; 2012 and 2013 were atypically dry years, and the dominantly rainfed agriculture or pastures are precipitation dependent.

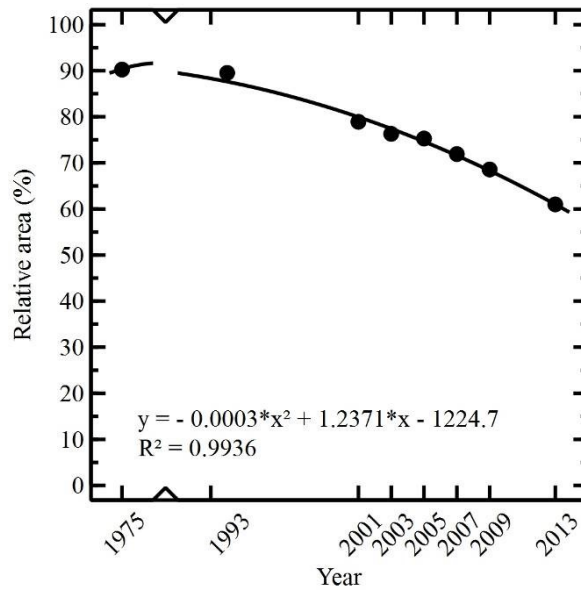


Figure 2. Relationship between time and relative area of Caatinga over 48 years in the Pontal watershed.

One of the principal consequences of deforestation is the creation of landscapes occupied by forest fragments that are remnants of the original continuous forest cover (PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010). These fragments are usually embedded in matrices of transformed habitats. Currently, the remains of the natural ecosystem in the Pontal are highly fragmented. Patch density or fragmentation (*PD*) indicated an increasing bias, with a peak in *PD* during the 2007-2009 period, which was also the beginning of a declining period for that variable (Table 4). Therefore, the fauna and flora have been significantly altered and reduced. Ecologically, the distributions of these fragments in space and time may affect their microclimates, spatial distribution, and composition of species, species interactions, community trophic structure, and movement of individuals between fragments. Thus, large fragments capture the majority of species and processes vital for maintaining ecosystem functions, while smaller fragments usually have less species diversity, especially when the fragments are old, because resources have become scarce and difficult

to find over time. In fact, these fragments have a high probability of being converted to other land cover (PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010). In the Pontal watershed, the mean area of the fragments varied over time, from $21.13 \times 10^6 \text{ m}^2$ in 1975 to $0.98 \times 10^6 \text{ m}^2$ in 2013. There is a general negative bias, with the exception of the 2007-2009 period when values increased around 50% from 2005 (Figure 3). This suggests that some very small patches were converted, increasing the mean area of fragments. From the social point of view, the Caatinga has consistently received the lowest social investment. Political leaders and governments have not yet focused on the potential relation between biodiversity and poverty. As the Caatinga gets degraded, the air and surface temperature, evapotranspiration, and geochemical cycle change; stored water and nutrients in the soil get depleted, making it harder to plant anything near the Caatinga. These contributions from biodiversity to livelihoods through maintenance of productive land and ecosystems have also been described by Roe et al. (2014).

Table 4. Periodic mean variations and ratios, in percentage, of relative area and patch density in Caatinga for all samples from the Pontal watershed.

Period	N_y^*	N_l^*	Relative area (<i>RA</i>)	Patch density (<i>PD</i>)	Ratio <i>RA:PD</i>
1975-1993	18	9	-0.54 (-0.03 per yr)	16.83 (0.87 per yr)	0.03
1993-2001	8	11	-11.64 (-1.53 per yr)	106.24 (9.47 per yr)	0.16
2001-2003	2	10	-1.06	5.42	0.20
2003-2005	2	16	-0.79	6.39	0.12
2005-2007	2	16	-2.36	6.32	0.37
2007-2009	2	7	-2.43	10.46	0.23
2009-2013	4	5	-10.68 (-2.79 per yr)	22.29 (5.16 per yr)	0.54

* N_y = number of years, N_l = number of images used in computation.

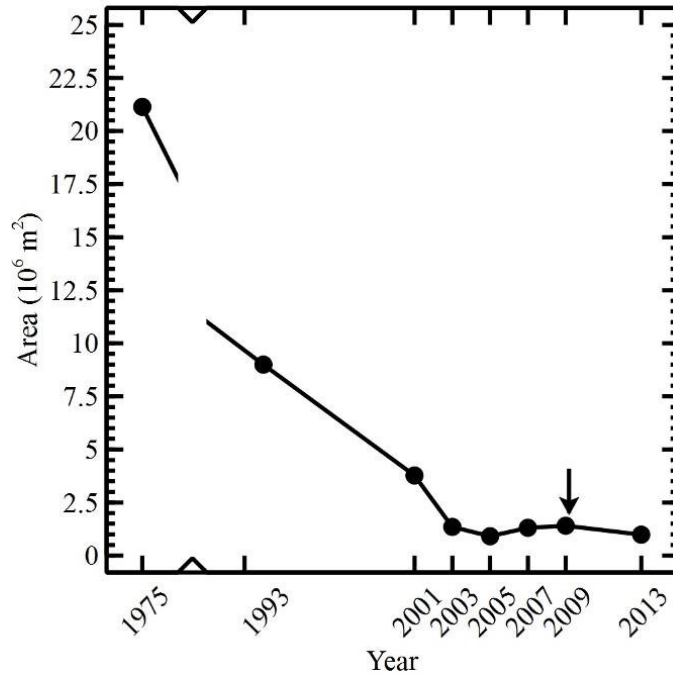


Figure 3. Mean area of fragments in Caatinga over 48 years in the Pontal watershed, west Pernambuco, Brazil; the arrow marks the beginning of a period of increasing values.

Historically, it is difficult to evaluate the distribution of natural ecosystems and fauna loss in Brazil over the last 500 years. The deforestation process has been active in the region since the 1500s, and historical records are few and far between (COIMBRA-FILHO; CÂMARA, 1996). In our study, the spatial distribution of both *RA* and *PD* became more heterogeneous and clustered in the north of the watershed (Figures 4 and 5). However, in 1975, both variables showed a random distribution (Table 5). We only observed clustered distributions after 1993 and 2001 for relatively small areas and high fragmentation spots, respectively, and only in 2007 did the south start to show increased degradation. We suggest that a possible leading cause is likely the appropriateness of land for agriculture, which can be attributed to an isolated distribution or a combination of optimal soil, terrain slope, and water availability in the north. The maps indicate that elevation (z) is higher in the north of the watershed than in the south (a difference of 414 m; Figure 6), but only a single slope class is dominant and well distributed in the watershed, showing no specific spatial pattern. The terrain is predominately undulating (82.37% of the watershed), but we also

identified flat (7.58%), very undulating (9.85%), and steep areas (0.2%). Acrisols are the dominant soil type, covering 82.42% of the watershed, and as expected, share the same spatial characteristics as the undulating slope class; this type of soil commonly forms undulating areas. Acrisols are characterized by high levels of clay, and are the second most abundant soil type in Brazil following Ferralsols. In the Pontal watershed, only the precipitation pattern correlated with the Caatinga's dynamics. The difference can reach 298 mm of rainfall, 112% more intense in the north of the watershed than in the south; which may enhance land quality for farming, making that region of the Caatinga more susceptible to agriculture conversion. The low rainfall in the southwest of the watershed is probably associated with instabilities caused by cold fronts moving from the Antarctic to the northeast region of Brazil, more precisely to the south of Bahia (ASSIS; SOUZA; SOBRAL, 2015). These fronts often generate instabilities from December to February. There are many weather systems in the north, but the intertropical convergence zone dominates. It often produces meteorological events between the months of March and April.

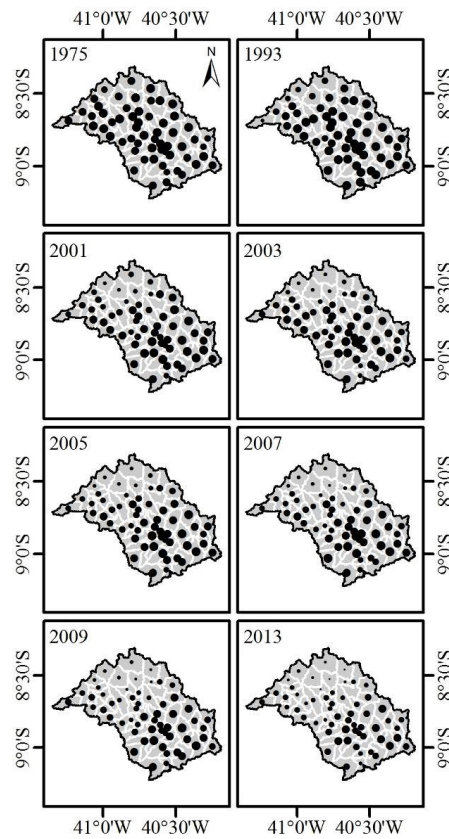


Figure 4. Spatial changes in relative area of the Caatinga over 48 years in the Pontal watershed, west Pernambuco, Brazil. 98% (●), 50% (◐), and 17% (◑) of the Caatinga at the scale 1:4,250 (1 cm = 42.5 km).

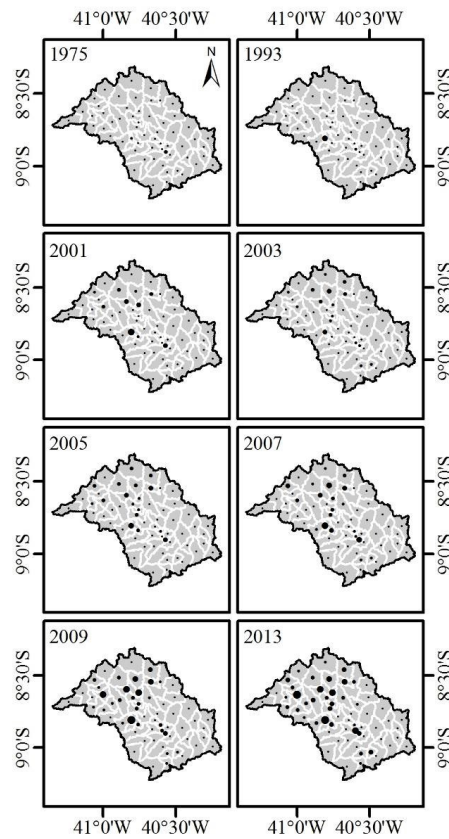


Figure 5. Spatial changes in patch density or fragmentation in the Caatinga over 48 years in the Pontal watershed, west Pernambuco, Brazil. 85% (●), 50% (◐), and 0.5% (◑) of fragmentation at the scale 1:4,250 (1 cm = 42.5 km).

Table 5. Spatial autocorrelation (Moran's I) of relative area and patch density in the Caatinga in the Pontal watershed.

	Year	Moran's Index	z-score	p-value
Relative area	1975	0.061052	0.961642	0.336229
	1993	0.238799	3.336578	0.000848**
	2001	0.424582	5.424173	0.000001**
	2003	0.412357	5.253958	0.000001**
	2005	0.444226	5.624971	0.000001**
	2007	0.520138	6.535147	0.000001**
	2009	0.583219	7.311988	0.000001**
	2013	0.590187	7.395845	0.000001**
Fragmentation	1975	0.036148	0.767403	0.442842
	1993	0.012842	0.445187	0.656185
	2001	0.139494	1.971831	0.048629*
	2003	0.362335	4.611361	0.000004**
	2005	0.267797	3.474459	0.000512**
	2007	0.278079	3.601036	0.000317**
	2009	0.381022	4.857508	0.000001**
	2013	0.392939	4.980496	0.000001**

p-value statistically significant at 0.05 (*) and 0.01 (**).

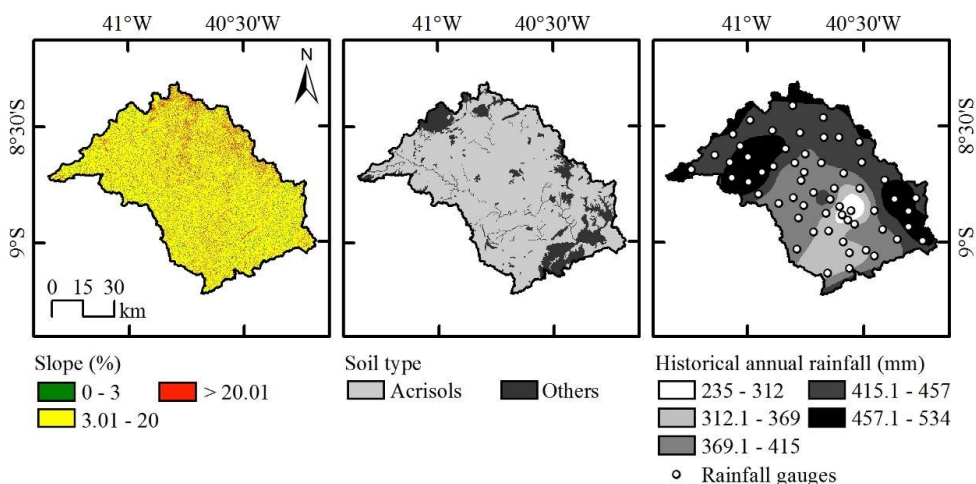


Figure 6. Spatial characterization of the Pontal watershed.

CONCLUSION

In summary, the relationship between deforestation and time shows an increasing threat of land use conversion against the Caatinga. The leading causes of this change in spatial pattern are still unclear, but we hypothesize that the rainfall pattern could be enhancing land quality for farming in the north, and also making the Caatinga more susceptible to land cover conversion. Perhaps those who tried and did not succeed in farming passed this knowledge down through generations: the northern areas were more suitable for farming. Further studies are needed to evaluate the causes for land conversion and the vegetation dynamics in the Caatinga. Deforestation is very aggressive, showing a loss of 30% of vegetation cover over the 38-year period, as well as occupation in the area through the conversion of natural forests, primarily into rainfed

pastures or agriculture, followed by irrigated agriculture. The same process has occurred in many other semiarid regions in Pernambuco, Brazil. The relationship between deforestation and time shows an increasing threat to the natural environment.

The results of this work provide an important contribution to planning the water resource management policy in the Pontal basin, an especially vital resource in this semiarid region of Brazil.

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